NATIONAL INVENTORY REPORT 1990–2019: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

CANADA'S SUBMISSION TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

PART 1

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Cat. No.: En81-4E-PDF
ISSN: 1910-7064
EC8369

The Executive Summary of this report is available at: canada.ca/ghg-inventory

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Environment and Climate Change Canada's **50th anniversary**
50e anniversaire d'Environnement et Changement climatique Canada

Meteorological Service of Canada's **150th anniversary**
150e anniversaire du Service météorologique du Canada

FOREWORD

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC or Convention) on December 4, 1992. Under Decisions 3/CP.1, 9/CP.2 and 24/CP.19 of the UNFCCC, national inventories of sources and sinks of greenhouse gases (GHGs) must be submitted to the UNFCCC by April 15 of each year. This report is part of Canada's annual inventory submission under the Convention.

Canada's 2021 National GHG Inventory complies with the requirements of the Revised UNFCCC Reporting Guidelines for national GHG inventories (see Decision 24/CP.19). The Reporting Guidelines require Annex I Parties to develop their national inventories using the *2006 Guidelines for National GHG Inventories by the Intergovernmental Panel on Climate Change* (IPCC). The Reporting Guidelines also require inventory reports to provide detailed and complete information on estimate development, including the formal arrangements supporting their preparation and any significant changes to inventory preparation and submission procedures. The Reporting Guidelines also commit Parties to improve the quality of emission and removal estimates on an ongoing basis.

In addition to the description and explanation of inventory development and national arrangements, the present National Inventory Report analyzes trends in emissions and removals. The report also describes the several improvements incorporated in this edition of the inventory, along with the subsequent recalculations.

This report represents the efforts of many years of team work and builds on the results of previous reports, published in 1992, 1994, and yearly from 1996 to 2020. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

April 2021

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ACKNOWLEDGEMENTS

The Pollutant Inventories and Reporting Division (PIRD) of Environment and Climate Change Canada wishes to acknowledge the many individuals and organizations that contributed to the National Inventory Report (NIR) and Common Reporting Format (CRF) Tables. Although the list of all researchers, government employees and consultants who provided technical support is too long to include here, the Division would like to highlight the contributions of the following authors and reviewers of Canada's *National Inventory Report 1990–2019: Greenhouse Gas Sources and Sinks in Canada*, whose work helped to improve this year's report.

Executive Summary

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Chapter 6: Land Use, Land-Use Change and Forestry (CRF Sector 4)

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Chapter 7: Waste (CRF Sector 5)

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Chapter 8: Recalculations and Improvements

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Annexes

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Overall coordination of Canada's National Inventory Report was led by Raphaëlle Pelland St-Pierre and Anne-Marie St-Laurent Thibault, with support from Vanessa Gagnon-Chantereau and Bénédicte Hurlet. Centralized data compilation and the generation of comprehensive emission tables was led by Catherine Robert. Compilation of uncertainty estimates as well as key category analyses were led by Catherine Robert. Compilation and layout of the National Inventory Report for publication were led by Marida Waters. Editing and translation services were provided by the Translation Bureau of Public Services and Procurement Canada (PSPC). Special thanks to David Maher for the development of webpages related to this publication. The compilation and coordination of the CRF tables (companion to this document in Canada's United Nations Framework Convention on Climate Change submission) was managed by Catherine Robert. Policy context was drafted by Geneviève Rolland.

We would like to acknowledge the efforts of our colleagues from the Environment and Energy Statistics Division at Statistics Canada, especially Corben Bristow, Sheri Fritzsche, Norman Fyfe, Evona Jamroz, Russ Kowaluk, Jiahua Li, Kristin Loiselle-Lapointe, Flo Magmanlac, Maya Murphy, Jake Purdy, Rowan Spence, Donna Stephens, Michael Warbanski, Lloyd Widdis, Paul Allen and Dores Zuccarini for their help in compiling, analyzing and interpreting Canada's energy supply and demand data, as well as Amélie Angers, Manon Dupuis and Sean Fagan from the Centre for Special Business Projects for their data confidentiality assessment and data sharing dissemination services. We wish to thank the Environment and Energy Statistics Division Director, Carolyn Cahill and Assistant Directors, René Beaudoin and Jeff Fritzsche for their support.

We are also grateful to our federal colleagues that contributed activity data and estimates for the reporting of the Land Use, Land-Use Change and Forestry (LULUCF), Agriculture, and Industrial Process sectors. In particular, we would like to thank Andrew Dyk, Mark Hafer, Ben Hudson, Werner Kurz, Michael Magnan, Georgina Magnus, Juha Metsaranta, Eric Neilson, Stephanie Ortlepp, Sally Tinis, Sheng Xie and Mihai Voicu of the Canadian Forest Service and France Séguin and Julie Simon of the Minerals and Metals Statistics Division of Natural Resources Canada; Wenjun Chen of the Canadian Centre for Mapping and Earth Observation Division of Natural resources Canada; Darrel Cerkowniak, Ray Desjardins, Jiangui Liu, Dan MacDonald, Tim Martin and Devon Worth of Agriculture and Agri-Food Canada.

Of the many people and organizations that provided support and information, we are especially indebted to the individuals in various industries, industry associations, engineering consulting firms, provincial ministries and universities who provided technical and scientific support. In particular, we would like to thank Brad Griffin, Executive Director of the Canadian Energy and Emissions Data Centre at Simon Fraser University, for providing critical analyses and industrial survey data compiled by the Centre.

Readers' Comments

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC	criteria air contaminant
CANSIM	Statistics Canada's key socioeconomic database
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
ECCC	Environment and Climate Change Canada
EF	emission factor
GDP	gross domestic product
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
HFC	hydrofluorocarbon
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Proccesses and Product Use
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
MSW	municipal solid waste
N/A	not available
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
NPRI	National Pollutant Release Inventory
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
POP	persistent organic pollutant
QA	quality assurance
QC	quality control
RESD	*Report on Energy Supply and Demand in Canada*
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Chemical Formulas

Al	aluminium
Al_2O_3	alumina
CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3 \cdot MgCO_3$)
CaO	lime; quicklime; calcined limestone
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene
C_6H_6	benzene
$CHCl_3$	chloroform
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HF	hydrogen fluoride
HNO_3	nitric acid
K_2CO_3	potassium carbonate
Mg	magnesium
$MgCO_3$	magnesite; magnesium carbonate
MgO	magnesia; dolomitic lime

N .... nitrogen

N_2 .... nitrogen gas

Na_2CO_3 .... sodium carbonate; soda ash

Na_3AlF_6 .... cryolite

NF_3 .... nitrogen trifluoride

NH_3 .... ammonia

NH_4+ .... ammonium

NH_4NO_3 .... ammonium nitrate

N_2O .... nitrous oxide

N_2O-N .... nitrous oxide emissions represented in terms of nitrogen

NO .... nitric oxide

NO_2 .... nitrogen dioxide

NO_3- .... nitrate

NO_x .... nitrogen oxides

O_2 .... oxygen

SF_6 .... sulphur hexafluoride

SiC .... silicon carbide

SO_2 .... sulphur dioxide

SO_x .... sulphur oxides

Notation Keys

IE .... included elsewhere

NA .... not applicable

NE .... not estimated

NO .... not occurring

Units

g .... gram

Gg .... gigagram

Gt .... gigatonne

ha .... hectare

kg .... kilogram

kha .... kilohectare

km .... kilometre

kt .... kilotonne

kWh .... kilowatt-hour

m .... metre

Mg .... megagram

Mha .... million hectares

mm .... millimetre

ML .... megalitre

Mt .... megatonne

MW .... megawatt

PJ .... petajoule

t .... tonne

TWh .... terrawatt-hour

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EXECUTIVE SUMMARY

ES.1. Key Points

- After fluctuations in recent years, in 2019 (the most recent dataset in this report) Canada's greenhouse gas (GHG) emissions were 730 megatonnes of carbon dioxide equivalent (Mt CO_2 eq), about a 1 Mt or 0.2% increase from 2018 emissions and a net decrease of 9 Mt or 1.1% from 2005 emissions.
- Emission trends since 2005 have remained consistent with previous editions of the inventory; emission increases in the Oil and Gas and Transport sectors being offset by decreases in other sectors, notably Electricity and Heavy Industry.
- During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per Gross Domestic Product [GDP]) has declined by 37% since 1990 and by 23% since 2005.
- Continuous improvement is a key principle upon which Canada's annual greenhouse gas inventory is developed. Important method improvements are being implemented in this edition of the NIR (methane emissions from landfills) and will be implemented in its 2022 edition (fugitive methane emissions from upstream oil and gas). The enhanced methods use Canadian-specific studies and knowledge, facilitate the adoption of new scientific data, and better capture the impact of improvements in technologies and industry practices on emissions.
- The government's strengthened climate plan, *A Healthy Environment and a Healthy Economy*, builds on the Pan-Canadian Framework on Clean Growth and Climate Change, which has resulted in emissions in 2030 being projected to be 227 million tonnes lower than before it was adopted. Before the Pan-Canadian Framework, absolute emissions in 2019 were forecasted to be 764 Mt (Second Biennial Report, 2015), which is 34 Mt higher than this year's 2019 data. Once fully implemented, the strengthened climate plan is expected to reduce Canada's emissions by at least an additional 85 million tonnes, enabling Canada to exceed its current 2030 target. In partnership with provinces and territories, and working with the private sector and others, Canada can strive for a range of 32-40% below 2005 levels and the Government of Canada is committed to bringing forward an updated Nationally Determined Contribution (NDC) before the 26th Conference of the Parties (COP26). Looking beyond 2030, Canada is also committed to reaching net-zero emissions by 2050, and the *Canadian Net-Zero Emissions Accountability Act* will establish a legally binding process of interim targets, plans and reports toward this objective.

ES.2. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty established in 1992 to cooperatively address climate change issues. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. Canada ratified the UNFCCC in December 1992, and the Convention came into force in March 1994.

To achieve its objective and implement its provisions, the UNFCCC sets out several guiding principles and commitments. Specifically, Articles 4 and 12 commit all Parties to develop, periodically update, publish and make available to the Conference of the Parties their national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol.[1]

Canada's National Greenhouse Gas Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year in accordance with the revised *Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on annual inventories* (UNFCCC Reporting Guidelines), adopted through Decision 24/CP.19 in 2013. The annual inventory submission consists of the National Inventory Report (NIR) and the Common Reporting Format (CRF) tables.

The GHG inventory includes emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)

1 The Montreal Protocol on Substances that Deplete the Ozone Layer is an international environmental agreement designed to reduce the global production and consumption of ozone depleting substances. The United Nations Environment Programme (UNEP) is assisting the Parties in the achievement of the Montreal Protocol objectives. (UNEP, n.d.)

in the following five sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture; Waste; and Land Use, Land-Use Change and Forestry (LULUCF). The GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the Intergovernmental Panel on Climate Change's (IPCC) *2006 Guidelines for National Greenhouse Gas Inventories*. In line with the principle of continuous improvement, the underlying data and methodology for estimating emissions are revised over time; hence, total emissions in all years are subject to change as both data and methods are improved.

Significant improvements to NIR estimates are anticipated in the 2022 edition of this report, following the implementation of a new fugitive emission model to estimate CO_2 and CH_4 emissions from pneumatic devices, compressor seals and equipment leaks in the upstream oil and gas industry. The new model will use Canadian-specific studies and knowledge, will facilitate the adoption of new scientific data, and better capture the impact of improvements in technologies and industry practices on emissions.

In May 2015, Canada indicated its intent to reduce GHG emissions by 30% below 2005 levels by 2030. Canada later confirmed this target in its NDC to the Paris Agreement. Since 2005 was adopted as a base year for Canada's targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the UNFCCC Reporting Guidelines.

The Pan-Canadian Framework on Clean Growth and Climate Change

The Pan-Canadian Framework on Clean Growth and Climate Change (PCF) was adopted on December 9, 2016, as Canada's plan to take ambitious action to fight climate change, build resilience to a changing climate, and drive clean economic growth. It is the first climate change plan in Canada's history to include joint and individual commitments by federal, provincial and territorial levels of government and to have been developed with input from Indigenous Peoples, businesses, non-governmental organizations, and Canadians from across the country. The PCF is built on four pillars: pricing carbon pollution, complementary actions to reduce emissions across the economy, adaptation and climate resilience, and clean technology, innovation, and jobs. It includes more than 50 concrete actions that cover all sectors of the Canadian economy.

Actions under the PCF, supported by historic federal investments, are well advanced as governments enter the fifth year of implementation. Notably, Canada now has a price on carbon pollution across the country. Under the *Greenhouse Gas Pollution Pricing Act* passed in 2018, carbon pollution pricing systems were put in place in all provinces and territories across Canada (either provincial/territorial systems or the federal system). Other key mitigation measures include phasing out traditional coal-fired electricity by 2030 and a commitment to reduce emissions of methane in the oil and gas sector by 40-45% below 2012 levels by 2025. Between 2015 and 2019, the Government of Canada invested $60 billion to drive down GHG emissions, generate clean technologies, help Canadians and communities adapt to a changing climate, and protect the environment.

The 2016 Pan-Canadian Framework has been effective in limiting emissions in recent years while Canada's economy continued to grow. Before the Pan-Canadian Framework, absolute emissions in 2019 were forecasted to be 764 Mt (Second Biennial Report, 2015), which is 34 Mt higher than this year's 2019 data. Emissions projections included as part of the Pan-Canadian Framework in late 2016 forecasted that in 2019 Canada's emissions would be 733 Mt, which is very close to the 730 Mt reported in the 2021 NIR. In the absence of national minimum carbon pollution pricing from April – December of 2019, Canada's GHG emissions were forecasted to be higher than this year's 2019 data. In addition, early modelling for 2020 shows that as a result of the policies under the Pan-Canadian Framework and the Strengthened Climate Plan, absolute emissions in Canada are projected to decrease annually starting in 2020, reaching 503 Mt by 2030.

Canada's Strengthened Climate Plan: A Healthy Environment and a Healthy Economy

Recognizing that additional action is needed, in December 2020, the Government of Canada released *A Healthy Environment and a Healthy Economy*, Canada's plan to build a better future with a healthier economy and environment. This plan builds on the work done to date and efforts that are already underway under the PCF, and will enable us to exceed our current 2030 emissions reduction target under the Paris Agreement.

This includes federal policies, programs and $15 billion in investments, in addition to the Canada Infrastructure Bank's $6 billion for clean infrastructure announced this past fall, to accelerate the fight again against climate change, create new jobs, make life more affordable for households, and build a better future, including steps to:

- make the places Canadians live and gather more affordable by cutting energy waste;
- make clean, affordable transportation and power available in every Canadian community;
- continue to ensure pollution isn't free and households get more money back;
- build Canada's clean industrial advantage; and,
- embrace the power of nature to support healthier families and more resilient communities.

Under these pillars, some specific measures include a continued commitment to pricing carbon pollution with a proposed price trajectory set to the year 2030, support for innovation, zero emission vehicles and energy efficiency retrofits for buildings, and measures to support the achievement of Canada's existing methane reduction commitment and pursue deeper reductions in methane by 2030.

Projected Emissions Reductions

Before the Paris Agreement and Canada's National Determined Contribution (2015), Canada's national GHG emissions were projected to increase 12% above 2005 levels by 2030 (815 Mt). Driven by mitigation measures in the Pan-Canadian Framework, Canada's December 2019 GHG emissions projections estimated that Canada's GHG emissions in 2030 would be 227 million tonnes lower than projected prior to the PCF, or 19% below 2005 levels. Canada's 2020 Emissions Projections Report confirms the new commitments from Canada's Strengthened Climate Plan put Canada on a path to exceed its 2030 target of 30% below 2005 levels, projecting a 31% reduction in 2030, due to at least 85 million tonnes beyond the reductions in the PCF. In partnership with provinces and territories, and working with the private sector and others, Canada can strive for a range of 32–40% below 2005 levels. The Government of Canada is committed to bringing forward an updated NDC before COP26.

Canadian Net-Zero Emissions Accountability Act

Looking beyond 2030, the Government of Canada recently tabled legislation to help ensure Canada achieves net-zero emissions by 2050. Bill C-12, the proposed *Canadian Net-Zero Emissions Accountability Act* (CNZEAA), would codify the Government's commitment for Canada to achieve net-zero emissions by 2050 and require the government to set national emissions reduction targets at five-year intervals for 2030, 2035, 2040 and 2045. Once the bill becomes law, the government will be required to develop an emission reduction plan for each target and explain how that plan will contribute to reaching net-zero in 2050. The Act would also require interim progress reports on implementation and effectiveness, as well as final assessment reports on the achievement of on each target. For missed targets, the government would be required to address the relevant assessment report, including an explanation of the reasons why the target was missed, and a description of any planned corrective actions that will be taken to address the failure.

The Bill also requires that Canada's Commissioner of the Environment and Sustainable Development examine and report on implementation of the measures intended to achieve the target, at least once every five years. It also requires that provinces and territories, Indigenous peoples, stakeholders, and experts be given the opportunity to provide input into this process, and establishes an independent expert Advisory Body to advise the Government on the best pathways to growing the economy while reducing emissions.

Net-Zero Advisory Body

In February 2021, the Minister of Environment and Climate Change launched the Net-Zero Advisory Body. The advisory body will report regularly to the Minister of Environment and Climate Change and to the public on the most likely pathways for Canada to achieve net-zero emissions by 2050. It will provide ongoing, evergreen advice that is forward-looking but grounded in the current realities of socio-economic circumstances, available technologies, and global trends. The initial members bring together a diverse range of expertise and experience, including in science, business and finance, labour, clean-technology, policy-making, rural economic development, and Indigenous governance. The advisory body will draw on existing and emerging research, analysis, and technical expertise and will establish a robust and inclusive engagement process. As part of its initial mandate, the advisory body will provide advice on actions Canada can take now to ensure a strong economic recovery while laying the foundation for net-zero emissions by 2050.

Conclusion

Canada's National Inventory Report, along with other reports such as Canada's National Communications and Biennial Reports, the greenhouse gas and air pollutant emissions projections (also submitted to the UNFCCC), annual synthesis reports on the status of implementation of the PCF, and future legislated reports, all support Canada's assessment of its progress in reducing emissions and combatting climate change.

Section ES.3 of this Executive Summary provides the latest information on Canada's net anthropogenic (i.e. human-induced) GHG emissions over the 2005–2019 period and links this information to relevant indicators of the Canadian economy. Section ES.4 outlines the major trends in emissions.

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which they originate. Section ES.5 presents Canada's emissions by the following economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others.[2] Throughout this report, the word "sector" generally refers to activity sectors as defined by the IPCC for national GHG inventories; exceptions occur when the expression "economic sectors" is used in reference to the Canadian context.

Section ES.6 details GHG emissions for Canada's 13 sub-national jurisdictions. Finally, section ES.7 provides some detail on the components of this submission and outlines key elements of its preparation.

2 Others includes Coal Production, Light Manufacturing, Construction and Forest Resources.

ES.3. Overview, National GHG Emissions

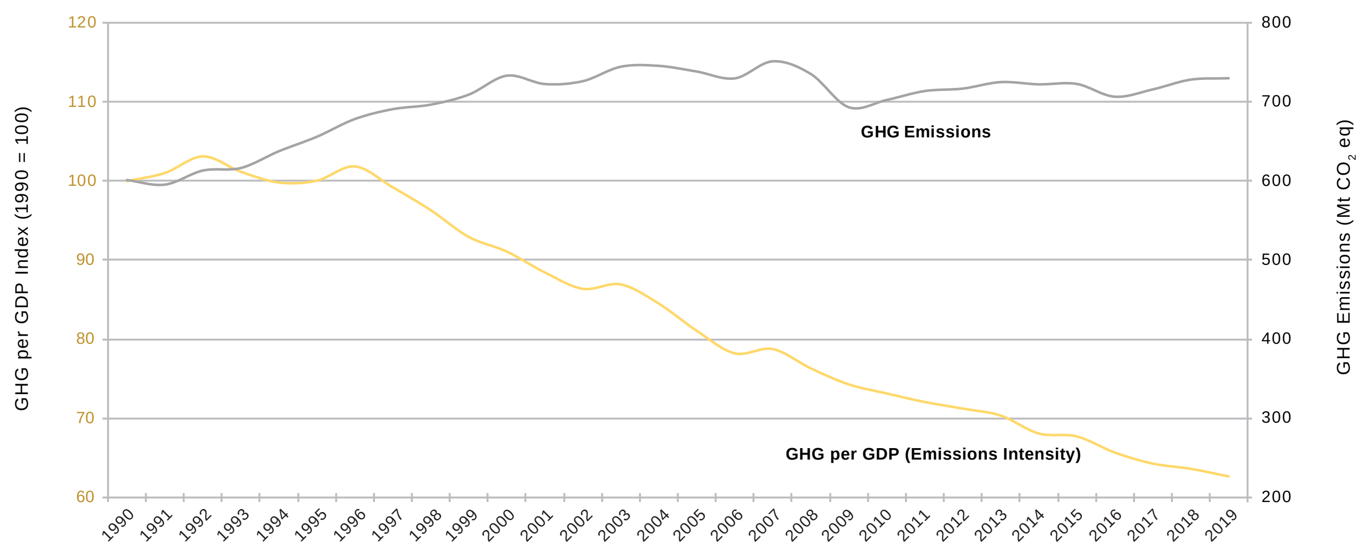
After fluctuations in recent years, in 2019 (the most recent dataset in this report) Canada's GHG emissions were 730 Mt CO_2 eq,[3] a net decrease of 9 Mt or 1.1% from 2005 emissions (Figure ES–1).[4] Emission trends since 2005 have remained consistent with previous editions of the NIR, with emission increases in the Oil and Gas and Transport sectors being offset by decreases in other sectors, notably Electricity and Heavy Industry.

In general, year-to-year fluctuations are superimposed over actual trends observed over a longer time period. During the period covered in this report, Canada's economy has grown more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per GDP) has declined by 37% since 1990 and by 23% since 2005 (Figure ES–1 and Table ES–1). The decline in emissions intensity can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

3 Unless explicitly stated otherwise, all emissions estimates given in Mt represent emissions of GHGs in Mt CO_2 eq.

4 Throughout this report, data are presented as rounded figures. However, all calculations (including the ones to obtain percentages) have been performed using unrounded data.

Figure ES–1 **Canadian GHG Emissions and Indexed Trend Emission Intensity (excluding Land Use, Land-Use Change and Forestry)**



Notes:

Emissions do not yet reflect the impact of the most recent mitigation policies. Total emissions fall within a 2% uncertainty range.

GDP data source – StatCan (n.d.[a])

The emissions trends and their drivers are summarized in the remainder of this Executive Summary and described in greater detail in Chapter 2 of this report.

In 2019, the Energy sector (consisting of Stationary Combustion, Transport and Fugitive Sources) emitted 589 Mt, or 81% of Canada's total GHG emissions (Figure ES–2). The remaining emissions were largely generated by the Agriculture and IPPU sectors (8% and 7%, respectively), with contributions from the Waste sector (4%). In 2019, the LULUCF sector emitted 9.9 Mt to the atmosphere.

Canada's emissions profile is similar to that of most industrialized countries, in that CO_2 is the largest contributor to total emissions, accounting for 80% of total emissions in 2019 (Figure ES–3). The majority of CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2019 amounted to 98 Mt or 13% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems, agriculture, and landfills. N_2O emissions mostly arise from agricultural soil management and transport and accounted for 37 Mt or 5.0% of Canada's emissions in 2019. Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) accounted for slightly less than 2% of national emissions.

Canada accounted for approximately 1.5% of global GHG emissions in 2017 (Climate Watch, 2020), although it is one of the highest per capita emitters. Canada's per capita emissions have declined since 2005 from 22.9 t CO_2 eq/capita to a new low of 19.4 t CO_2 eq/capita in 2019 (Figure ES–4).

Table ES–1 **Trends in GHG Emissions and Economic Indicators, Selected Years**

Year	2005	2014	2015	2016	2017	2018	2019
Total GHG (Mt)	**739**	**723**	**723**	**707**	**716**	**728**	**730**
Change since 2005 (%)	NA	-2.2%	-2.1%	-4.3%	-3.1%	-1.4%	-1.1%
GDP[a] (Billion 2012$)	**1 654**	**1 926**	**1 938**	**1 953**	**2 022**	**2 078**	**2 115**
Change since 2005 (%)	NA	16%	17%	18%	22%	26%	28%
GHG Intensity (Mt/$B GDP)	**0.45**	**0.38**	**0.37**	**0.36**	**0.35**	**0.35**	**0.35**
Change since 2005 (%)	NA	-16%	-16%	-19%	-21%	-22%	-23%

Notes:

NA = Not applicable

a. Data source – StatCan (n.d.[a])

Figure ES–2 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2019)**

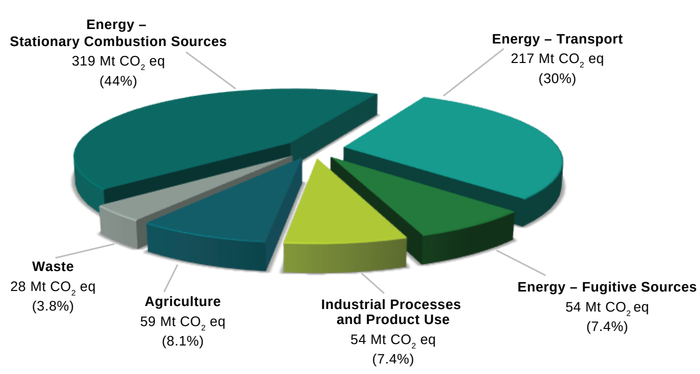
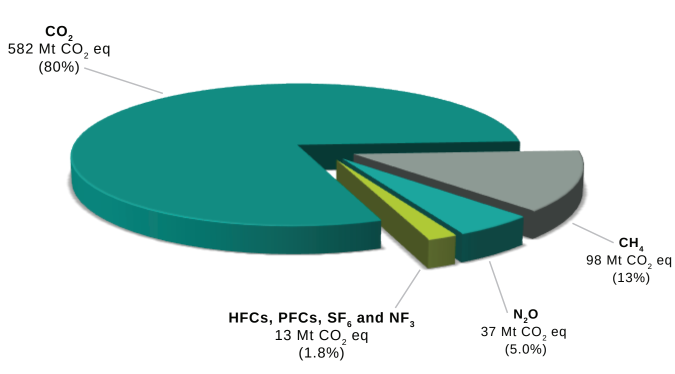


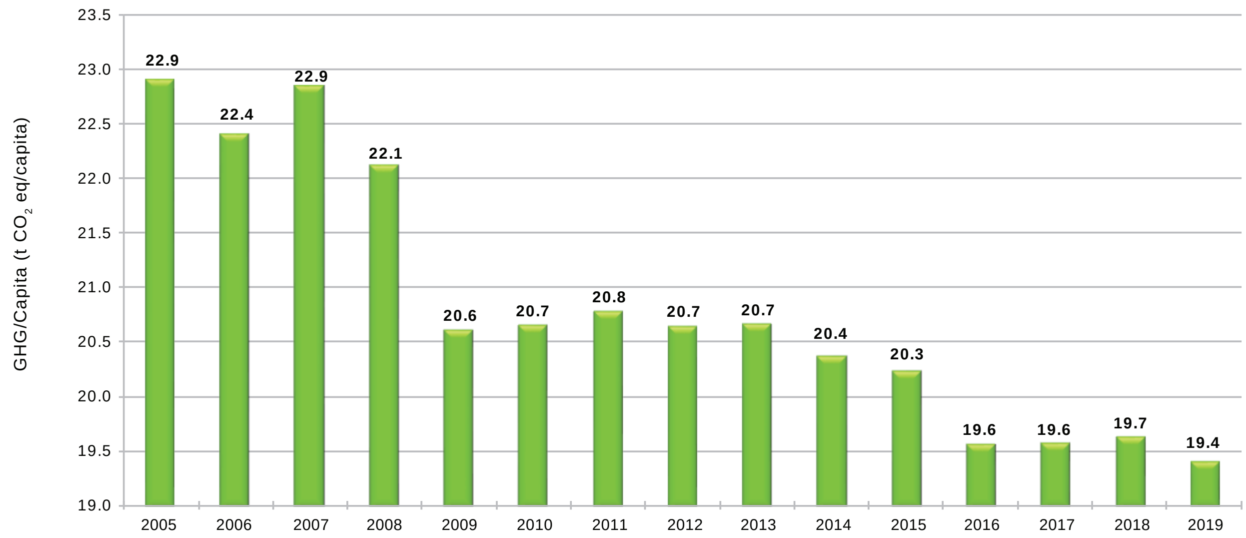
Figure ES–3 **Breakdown of Canada's Emissions by GHG (2019)**



Total: 730 Mt CO_2 eq

Note: Totals may not add up to due to rounding.

Figure ES–4 **Canadian per Capita GHG Emissions (2005–2019)**



Note: Population data source – StatCan (n.d.[b])

ES.4. GHG Emissions and Trends by Intergovernmental Panel on Climate Change Sector

Trends in Emissions

Over the 2005–2019 period, total emissions have decreased by 9 Mt or 1.1 % (Figure ES–5). Two sources of the Energy sector dominated this trend, with emission decreases of 22 Mt (6.4%) in Stationary Combustion Sources and 7.1 Mt (12%) in Fugitive Sources (Table ES–2). Over the same period, emissions have decreased by 3.4 Mt (11%) in the Waste sector and 2.3 Mt (4.1%) in the IPPU sector. However, emissions from Transport (also in the Energy sector) have increased by 27 Mt (14%), partially offsetting the decreases from the other categories (Figure ES–6).

Emission increases since 2009, when emissions were at their lowest in the latest decade, have been driven by growth in Oil and Gas Extraction (27 Mt), in the number of light-duty gasoline trucks (13 Mt) and heavy-duty diesel vehicles in operation (12 Mt), in the production and consumption of halocarbons, SF_6 and NF_3 (5.5 Mt), and in the application of inorganic nitrogen fertilizers (3.5 Mt). During the same period, there was a 32 Mt decrease in emissions from electricity generation, which partly offset the growth in emissions.

Chapter 2 provides more information on trends in GHG emissions from both 1990 and 2005 and their drivers.[5] Further breakdowns of emissions and a complete time series can be found at open.canada.ca.

The following describes the emissions and trends of each IPCC sector since 2005 in further detail.

Energy – 2019 GHG Emissions (589 Mt)

In 2019, GHG emissions from the IPCC Energy sector (589 Mt) were 0.3% lower than in 2005 (591 Mt). Within the Energy sector, a 42-Mt increase in combustion emissions from Oil and Gas Extraction and a 24-Mt growth in Road Transportation emissions were largely offset by a 56-Mt decrease in emissions from Public Electricity and Heat Production and a 5.6-Mt drop in emissions from Manufacturing.

Stationary Combustion (319 Mt)

Decreasing electricity generation from coal and oil (decreases of 53% and 78%, respectively) was a large driver of the 56-Mt decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2019. The permanent closure of all coal generating stations in Ontario by 2014[6] contributed 48% of the decreased coal consumption, and reduced coal consumption in Alberta contributed an additional 44%. Reduced coal

5 The complete NIR can be accessed here: http://www.publications.gc.ca/site/eng/9.506002/publication.html

6 Ontario Power Generation News. 2014. April 15. [accessed 2018 Jan]. Available online at: http://www.opg.com/news-and-media/news-releases/Pages/news-releases.aspx?year=2014.

Figure ES–5 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2019)**

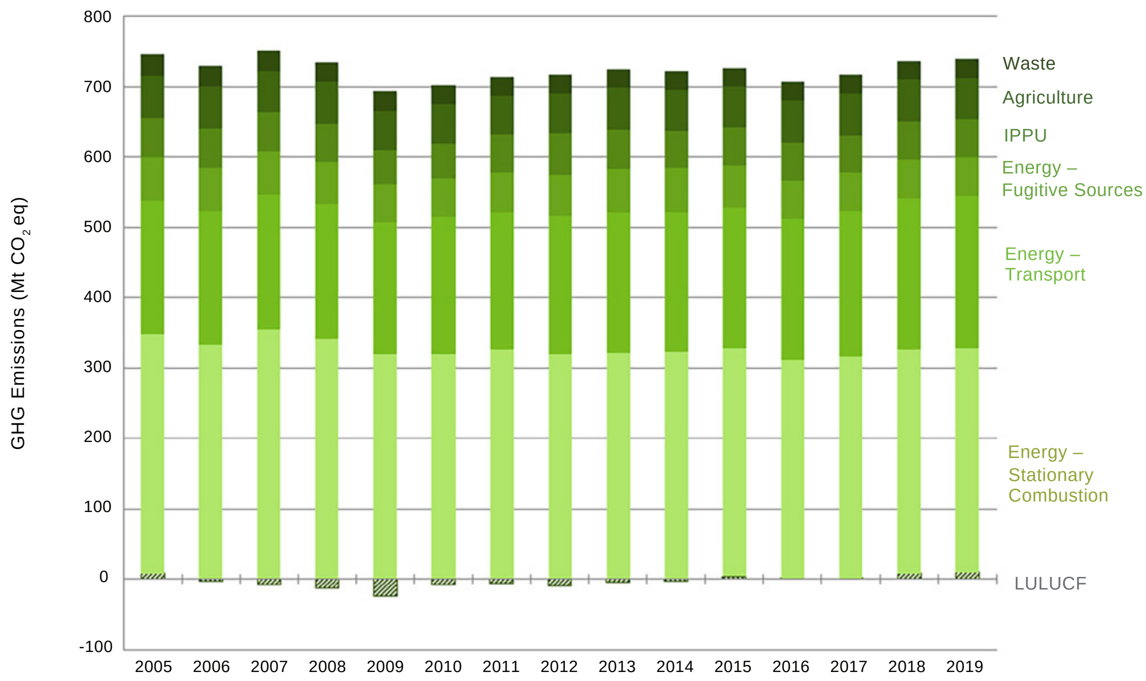


Figure ES–6 **Changes in GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2019)**

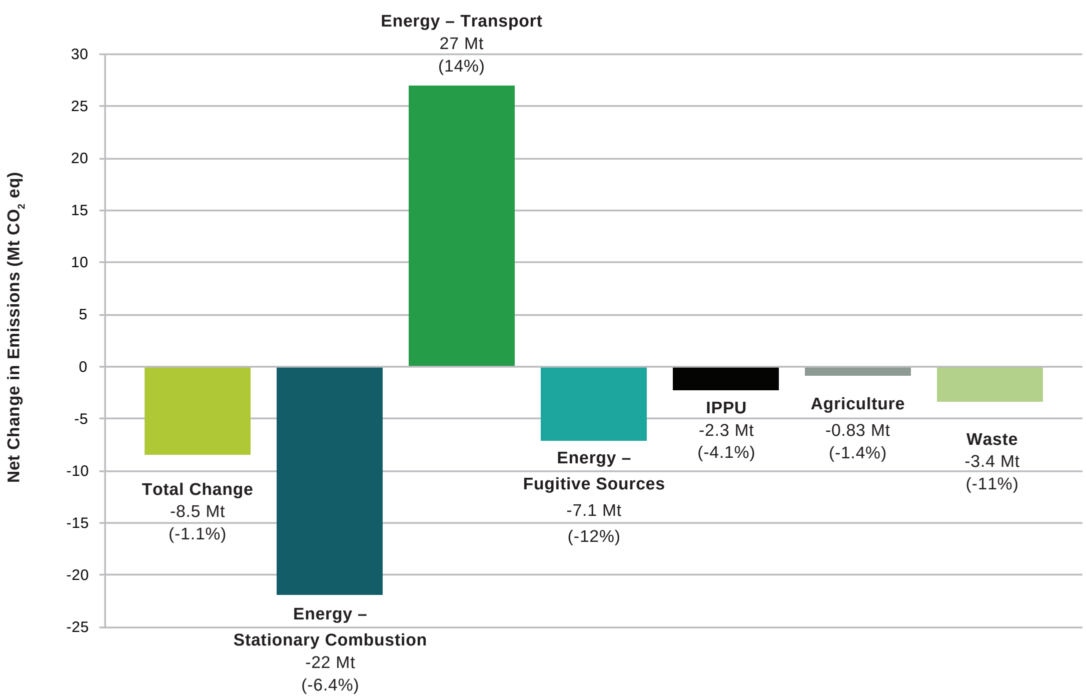


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Table ES–2 **Canada's GHG Emissions by Intergovernmental Panel on Climate Change Sector, Selected Years**

Greenhouse Gas Categories		2005	2014	2015	2016	2017	2018	2019
		Mt CO_2 Equivalent						
TOTAL[a, b]		**739**	**723**	**723**	**707**	**716**	**728**	**730**
ENERGY		**591**	**584**	**585**	**566**	**578**	**588**	**589**
a.	Stationary Combustion Sources	341	323	324	311	316	318	319
	Public Electricity and Heat Production	125	84	87	81	78	70	69
	Petroleum Refining Industries	20	16	16	16	14	15	15
	Oil and Gas Extraction	63	95	97	94	97	104	105
	Mining	4.3	5.1	4.6	4.3	4.9	6.3	6.4
	Manufacturing Industries	48	45	43	42	42	42	42
	Construction	1.5	1.3	1.3	1.3	1.3	1.4	1.4
	Commercial and Institutional	33	31	30	30	32	33	34
	Residential	44	41	40	39	41	42	42
	Agriculture and Forestry	2.2	3.8	3.6	3.8	3.7	3.8	3.7
b.	Transport	190	199	201	201	207	215	217
	Aviation	7.7	7.6	7.6	7.5	7.9	8.7	8.5
	Road Transportation	130	142	143	145	148	152	153
	Railways	6.6	7.5	7.1	6.5	7.5	7.6	7.7
	Marine	4.0	3.5	3.4	3.5	3.6	3.8	4.4
	Other Transportation	42	39	40	39	40	43	43
c.	Fugitive Sources	61	63	59	54	55	55	54
	Coal Mining	1.4	1.3	1.1	1.3	1.2	1.3	1.4
	Oil and Natural Gas	60	61	58	53	54	53	52
d.	CO_2 Transport and Storage	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**54**	**53**	**54**	**53**	**54**	**54**
a.	Mineral Products	10	7.8	8.0	7.9	8.6	8.7	8.8
b.	Chemical Industry	10	6.4	6.7	7.0	6.4	6.8	6.8
c.	Metal Production	20	15	14	15	15	15	14
d.	Production and Consumption of Halocarbons, SF_6 and NF_3	5.1	11	11	11	12	13	12
e.	Non-Energy Products from Fuels and Solvent Use	10	13	13	12	11	11	12
f.	Other Product Manufacture and Use	0.54	0.48	0.57	0.62	0.66	0.73	0.75
AGRICULTURE		**60**	**58**	**58**	**59**	**58**	**59**	**59**
a.	Enteric Fermentation	31	24	24	24	24	24	24
b.	Manure Management	8.8	7.7	7.8	7.9	7.9	7.9	7.9
c.	Agricultural Soils	19	23	24	25	24	25	24
d.	Field Burning of Agricultural Residues	<0.05	0.05	0.06	0.05	0.05	0.05	0.05
e.	Liming, Urea Application and Other Carbon-Containing Fertilizers	1.4	2.5	2.6	2.5	2.4	2.6	2.6
WASTE		**31**	**27**	**27**	**27**	**27**	**27**	**28**
a.	Solid Waste Disposal (Landfills)	25	22	22	22	22	23	23
b.	Biological Treatment of Solid Waste	0.24	0.31	0.31	0.31	0.32	0.37	0.38
c.	Wastewater Treatment and Discharge	0.94	1.0	1.0	1.0	1.0	1.0	1.0
d.	Incineration and Open Burning of Waste	0.34	0.17	0.20	0.20	0.19	0.18	0.19
e.	Industrial Wood Waste Landfills	4.4	3.5	3.4	3.3	3.2	3.1	3.0
LAND USE, LAND-USE CHANGE AND FORESTRY		**8.2**	**-3.5**	**4.0**	**0.10**	**0.70**	**8.4**	**9.9**
a.	Forest Land	-134	-141	-134	-136	-136	-133	-133
b.	Cropland	-10	-8.1	-7.0	-6.3	-5.7	-4.8	-4.2
c.	Grassland	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
d.	Wetlands	3.1	3.1	2.9	2.9	3.0	2.7	2.6
e.	Settlements	1.7	2.3	2.6	2.4	2.2	2.4	2.2
f.	Harvested Wood Products	148	140	139	137	137	141	143

Notes:

Totals may not add up due to rounding.

a. National totals calculated in this table do not include removals reported in LULUCF.

b. This summary data is presented in more detail at open.canada.ca.

consumption also occurred in Nova Scotia (16%), New Brunswick (36%), Manitoba (100%) and Saskatchewan (12%). Decreased oil consumption for electricity generation in New Brunswick (94%) and Nova Scotia (95%), offset by increased consumption in Newfoundland and Labrador (40%) accounts for 99% of the reduced oil consumption. Emission fluctuations over the period reflect variations in the mix of electricity generation sources; over the time period, the amount of low-emitting generation in the mix has increased.[7]

The 42-Mt increase in emissions from stationary fuel consumption in Oil and Gas Extraction is consistent with a 200% rise in the extraction of bitumen and synthetic crude oil from Canada's oil sands operations since 2005.

GHG emissions from Manufacturing Industries have decreased by 5.6 Mt between 2005 and 2019, consistent with both a 12% decrease in energy use and an observed decline in output in these industries (StatCan, n.d.[c]).

Transport (217 Mt)

The majority of transport emissions in Canada are related to Road Transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy-duty vehicles. The growth in road transport emissions is largely due to more driving, exemplified by increases in the supply of diesel, in gasoline retail pump sales as well as in the number of on-road vehicles. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet has increased by 42% since 2005, most notably for trucks (both light- and heavy-duty), leading to more kilometres driven overall.

Fugitive Sources (54 Mt)

Since 2005, fugitive GHG emissions from fossil fuel production (coal, oil and natural gas) have decreased by 7.1 Mt, largely the result of provincial regulations to increase conservation of natural gas, which is mainly comprised of CH_4.

Industrial Processes and Product Use – 2019 GHG Emissions (54 Mt)

The IPPU sector covers non-energy GHG emissions that result from manufacturing processes and use of products, such as limestone calcination in cement production and the use of HFCs and PFCs as replacement refrigerants for ozone-depleting substances (ODSs). Emissions from the IPPU sector contributed 54 Mt (7.4%) to Canada's 2019 emissions.

Between 2005 and 2019, process emissions from most IPPU categories decreased. A notable exception is the 7.3 Mt (143%) increase in emissions from the use of HFCs to replace CFCs and HCFCs before the gradual phase out of HFCs mandated under the Kigali Amendment to the Montreal Protocol, which came into force in 2019.

The aluminium industry has decreased its process emissions by 3.4 Mt (-39%) since 2005, largely due to the implementation of technological improvements to mitigate PFC emissions and the shutdown of older smelters using Søderberg technology, the last of which was closed in 2015. Closure of primary magnesium plants in 2007 and 2008 also contributed to 1.0 Mt of the overall process emission drop (-6.4 Mt or -32%) seen in Metal Production between 2005 and 2019.

The overall decrease of 3.6 Mt (35%) of GHG emissions from chemical industries since 2005 is primarily the result of the 2009 closure of the sole Canadian adipic acid plant located in Ontario. N_2O emissions abatement installations at a nitric acid production facility are responsible for a smaller proportion (0.9 Mt) of the decrease. Variations throughout the time series in petrochemical industry-related emissions can be attributed to facility closures and changes in production capacities at existing facilities, such as the closure of two methanol facilities in 2005 and 2006, and the noted increase in ethylene production in 2016.

Agriculture – 2019 GHG Emissions (59 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. Emissions from Agriculture accounted for 59 Mt, or 8.1% of total GHG emissions for Canada in 2019.

In 2019, Agriculture accounted for 29% of national CH_4 emissions and 78% of national N_2O emissions.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and the application of inorganic nitrogen fertilizers to agricultural soils in the Prairie provinces. Since 2005, fertilizer use has increased by 71%, while major livestock populations peaked in 2005, then decreased sharply until 2011. In 2019, emissions from livestock digestion (enteric fermentation) accounted for 41% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 23% of total agricultural emissions.

Waste – 2019 GHG Emissions (28 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 28 Mt (3.8%) to Canada's total emissions in 2019 and 31 Mt (4.2%) in 2005.

The primary sources of emissions in 2019 for the Waste sector are municipal solid waste (MSW) disposal in landfills (23 Mt) and Industrial Wood Waste Landfills (3.0 Mt). In 2019, these landfills combined accounted for 94% of Waste emissions, while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste together contributed the remaining 6%.

In 2019, CH_4 emissions from MSW landfills made up 83% of all waste emissions; these emissions decreased by 8.4% between 2005 and 2019. Of the 37 Mt CO_2 eq of CH_4 generated by MSW landfills in 2019, only 23 Mt CO_2 eq (62%) were actually emitted to the atmosphere,

7 The mix of electricity generation sources is characterized by the amount of fossil fuel versus hydro, other renewable sources and nuclear sources. In general, only fossil fuel sources generate net GHG emissions.

with a large portion (31% or 12 Mt CO_2 eq) being captured by landfill gas collection facilities and flared or used for energy, as compared to 21% in 2005.

Land Use, Land-Use Change and Forestry – 2019 (Net GHG Emissions of 9.9 Mt)

The LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, including those associated with land-use change and emissions from Harvested Wood Products (HWP), which are closely linked to Forest Land.

In this sector, the net flux is calculated as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere. In 2019, this net flux amounted to net emissions of 9.9 Mt that, when included with emissions from other sectors, increases Canada's total GHG emissions by 1.4%.

Net emissions/removals from the LULUCF sector have fluctuated over recent years, switching from a net source of 8.2 Mt in 2005 to a net sink of 24 Mt in 2009 and subsequently back to a net source of 9.9 Mt in 2019. Fluctuations are driven mainly by variations in emissions from HWP and removals from Forest Land that are closely tied to harvest rates.

The Forest Land estimates are split between emissions and removals resulting from significant natural disturbances on managed forests (wildfires and insects) and anthropogenic emissions and removals associated with forest management activities. Net anthropogenic removals in Forest Land have fluctuated between 130 Mt and 140 Mt over the period between 2005 and 2019, as forests recover from peak harvest rates in the early 2000s and continue to be impacted by low-level insect disturbances. Over this same period, emissions from HWP originating from domestic harvest declined from 150 Mt in 2005 to 140 Mt in 2019.

Approximately 30% of HWP emissions result from long-lived wood products reaching the end of their economic life decades after the wood was harvested. Emission and removal patterns in both HWP and Forest Land have therefore been influenced by recent forest management trends and by the long-term impact of forest management practices in past decades.

After peaking in the years 2006 to 2011, current net removals from Cropland are 4.2 Mt, 6.2 Mt lower than in 2005, mainly as a result of increased conversion of perennial to annual crops on the Prairies and the declining effect of the adoption of conservation tillage on cropland that mainly occurred in the 1980s and 90s.

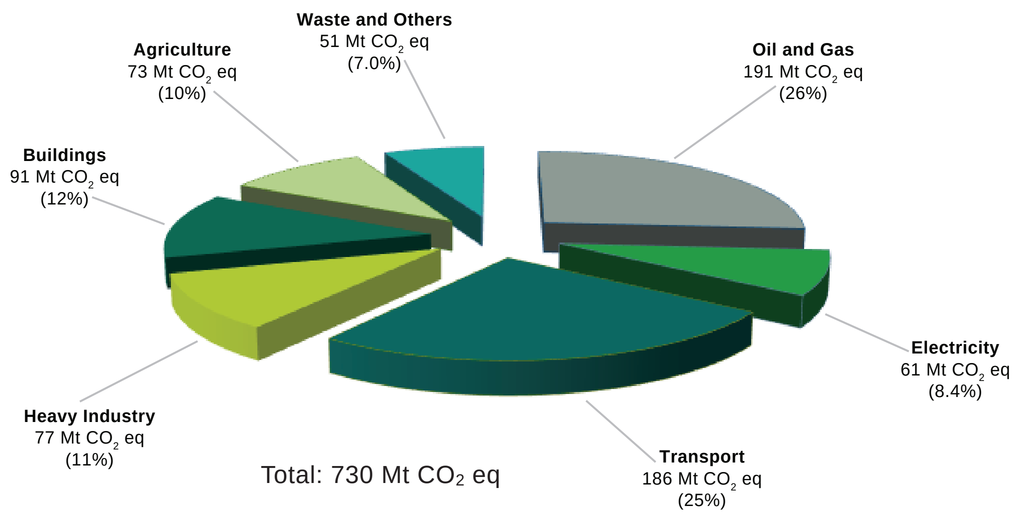
The conversion of forests[8] to other land uses is still a prevalent practice in Canada and is mainly due to resource extraction and cropland expansion. Emissions due to forest conversion in the years 2005 to 2019 have fluctuated around 16 Mt.

ES.5. Canadian Economic Sectors

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which the emissions originate. In general, a comprehensive emission profile for a specific economic sector is developed by reallocating the relevant proportion of emissions from various IPCC subcategories. This reallocation simply recategorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

8 Forest conversion emissions are incorporated within sums of emissions of other LULUCF categories; therefore, the values reported here are included in the sums associated with the other category totals.

Figure ES–7 **Breakdown of Canada's GHG Emissions by Economic Sector (2019)**



Note: Totals may not add up due to rounding.

Table ES–3 **Canada's GHG Emissions by Economic Sector, Selected Years**

	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 equivalent						
NATIONAL GHG TOTAL	**739**	**723**	**723**	**707**	**716**	**728**	**730**
Oil and Gas	160	190	190	181	183	191	191
Electricity	118	76	79	74	72	62	61
Transport	160	171	172	174	179	184	186
Heavy Industry[a]	87	79	77	76	75	77	77
Buildings	84	85	83	81	86	90	91
Agriculture[b]	72	71	71	72	71	73	73
Waste and Others[c]	57	50	50	50	50	51	51

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continuous improvement. Historical emissions may be changed in future publications as new data becomes available and methods and models are refined and improved.

a. Heavy Industry represents emissions arising from non-coal, -oil and -gas mining activities, smelting and refining, and the production and processing of industrial goods such as fertilizer, paper or cement.

b. Emissions assoicated with the production of fertilizer are reported in the Heavy Industry sector.

c. "Others" includes Coal Production, Light Manufacturing, Construction and Forest Resources.

GHG emissions trends in Canada's economic sectors are consistent with those described for IPCC sectors, with the Oil and Gas and Transport economic sectors showing emission increases of 20% and 16% respectively since 2005 (Figure ES–7 and Table ES–3). These increases have been more than offset by emission decreases in Electricity (48%), Heavy Industry (12%), and Waste and others (10%).

Further information on economic sector trends can be found in Chapter 2. Additional information on the IPCC and economic sector definitions, as well as a detailed crosswalk table between IPCC and economic sector categories, can be found in Part 3 of this report.

ES.6. Provincial and Territorial GHG Emissions

Emissions vary significantly by province and territory as a result of factors such as population, energy sources and economic structure. All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for electricity generation emit relatively more GHG than those that rely more on hydroelectricity.

Historically, Alberta and Ontario have been the highest emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 40 Mt (17%) since 2005, primarily as a result of the expansion of oil and gas operations (Figure ES–8 and Table ES–4). In contrast, Ontario's emissions have decreased by 42 Mt (21%) since 2005, owing primarily to the closure of coal-fired electricity generation plants.

Saskatchewan's emissions have increased by 7.0 Mt (10%) between 2005 and 2019 and those in British Columbia have also increased by 2.7 Mt (4.3%) over the same time period. Emissions in Manitoba and Newfoundland and Labrador have also increased since 2005, but to a lesser extent (2.0 Mt or 9.8% and 0.6 Mt or 5.4%, respectively). Provinces that have seen significant decreases in emissions include New Brunswick (7.6 Mt or a 38% reduction), Nova Scotia (6.9 Mt or a 30% reduction), Quebec (3.9 Mt or a 4.4% reduction) and Prince Edward Island (0.3 Mt or a 14% reduction).

ES.7. National Inventory Arrangements

Environment and Climate Change Canada is the single national entity with responsibility for preparing and submitting the national GHG inventory to the UNFCCC and for managing the supporting processes and procedures.

The institutional arrangements for the preparation of the inventory include: formal agreements on data collection and estimate development; a quality management plan, including an improvement plan; the ability to identify key categories and generate quantitative uncertainty analysis; a process for performing recalculations due to improvements; procedures for official approval; and a working archive system to facilitate third-party review.

Submission of information regarding the national inventory arrangements, including details on institutional arrangements for inventory preparation, is also an annual requirement under the UNFCCC Reporting Guidelines (see Chapter 1, section 1.2).

Figure ES–8 **GHG Emissions by Province and Territory in 2005, 2010 and 2019**

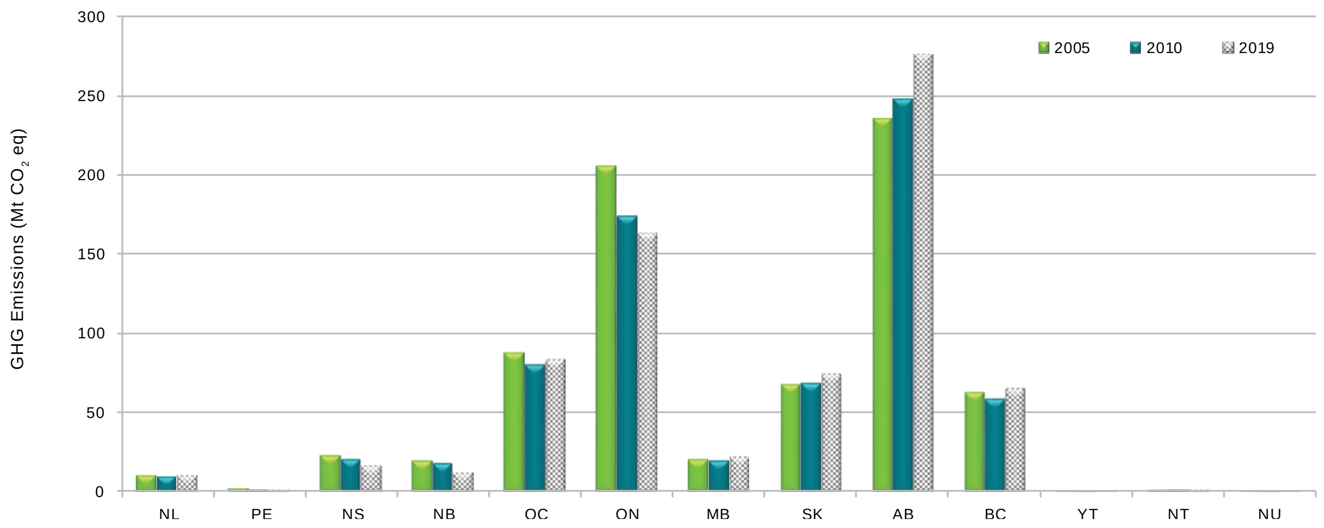


Table ES–4 **GHG Emissions by Province and Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)							Change (%)
Year	2005	2014	2015	2016	2017	2018	2019	2005–2019
GHG Total (Canada)	**739**	**723**	**723**	**707**	**716**	**728**	**730**	**-1.1%**
NL	11	11	11	11	11	11	11	5.4%
PE	2.0	1.7	1.7	1.7	1.7	1.7	1.8	-14%
NS	23	17	17	16	16	17	16	-30%
NB	20	13	14	14	13	13	12	-38%
QC	88	79	79	79	81	83	84	-4.4%
ON	206	164	163	161	158	163	163	-21%
MB	21	21	21	21	22	23	23	10%
SK	68	74	76	74	76	76	75	10%
AB	235	278	278	264	271	272	276	17%
BC	63	60	59	62	63	66	66	4.3%
YT	0.57	0.50	0.53	0.53	0.56	0.64	0.69	22%
NT	1.6	1.5	1.7	1.6	1.3	1.4	1.4	-16%
NU	0.58	0.70	0.64	0.74	0.75	0.75	0.73	25%

Note: Totals may not add up due to rounding.

Structure of Submission

The UNFCCC requirements include the annual compilation and submission of both the NIR and the CRF tables. The CRF tables are a series of standardized data tables containing mainly numerical information that are submitted electronically. The NIR contains the information to support the CRF tables, including a comprehensive description of the methodologies used in compiling the inventory, the data sources, the institutional structures, and the quality assurance and quality control procedures.

Part 1 of the NIR includes Chapters 1 to 8. Chapter 1 (Introduction) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory (i.e., the national inventory arrangements), quality assurance and quality control procedures, and a description of Canada's facility emission-reporting system. Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting structure and a breakdown of emission trends by Canadian economic sectors. Chapters 3 to 7 provide descriptions and additional analysis for each sector, according to UNFCCC reporting requirements. Chapter 8 presents a summary of recalculations and planned improvements.

Part 2 of the NIR consists of Annexes 1 to 7, which provide a key category analysis, an inventory uncertainty assessment, detailed explanations of estimation methodologies, Canada's energy balance, completeness assessments, emission factors and information on ozone and aerosol precursors.

Part 3 comprises Annexes 8 to 13, which present rounding procedures, summary tables of GHG emissions at the national level and for each provincial and territorial jurisdiction, sector and gas, as well as additional details on the GHG intensity of electricity generation. Detailed GHG data is also available on the Government of Canada's Open Data website at open.canada.ca.

Executive Summary References

[Climate Watch] Climate Watch Historical GHG Emissions. 2020. Washington (DC): World Resources Institute. Available online at: https://www.climatewatchdata.org/ghg-emissions.

[StatCan] Statistics Canada. No date (a). Table 36-10-0369-01 (formerly CANSIM 380-0106): Gross domestic product, expenditure-based, at 2012 constant prices, annual (x 1,000,000) [accessed 2021 Feb 9]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610036901.

[StatCan] Statistics Canada. No date (b). Table 17-10-0005-01 (formerly CANSIM 051-0001): Population estimates on July 1st, by age and sex [accessed 2021 Feb 9]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501.

[StatCan] Statistics Canada. No date (c). Table 25-10-0025-01 (formerly CANSIM 128-0006): Manufacturing industries, total annual energy fuel consumption in gigajoules, 31-33 [accessed 2021 Feb 9]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002501.

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CHAPTER 1

INTRODUCTION

1.1. Greenhouse Gas Inventories and Climate Change

Climate change is one of the most important environmental issues of our time. There is a very strong body of evidence, based on a wide range of indicators, that the climate is changing and the climate system is warming. Although climate change can be caused by both natural processes and human activities, human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases (GHGs) are the highest in history (IPCC, 2014).

Climate change refers to a long-term shift in weather conditions. In order to understand climate change, it is important to differentiate between weather and climate. Weather is the state of the atmosphere at a given time and place. The term "weather" is used mostly when reporting these conditions over short periods of time. Climate, on the other hand, is the average pattern of weather, usually taken over a 30-year period, for a particular region.

It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times across the globe. Since 1750, the concentration of atmospheric carbon dioxide (CO_2) has increased by 148%, methane (CH_4) by 260% and nitrous oxide (N_2O) by 123%. There are numerous anthropogenic activities and economic sectors involved. Important CO_2 increases are caused primarily by the use of fossil fuels as a source of energy and cement production. Main CH_4 outpouring are agriculture, fossil fuel exploitation and biomass burning. Finally, N_2O emissions are released predominantly by biomass burning, fertilizer use, and various industrial processes. (WMO, 2020)

Recent climate changes have had widespread impacts on human and natural systems (IPCC, 2014). In Canada, the impact of climate change may be felt in extreme weather events, the reduction of fresh water resources, increased risk and severity of forest fires and pest infestations, a reduction in Arctic ice, and an acceleration of glacial melting. Canada's national average temperature for 2019 was 1°C above normal (see Figure 1–1). The averaged annual temperatures have remained above the baseline average since 1996, with a warming trend of 1.7°C over the past 72 years (ECCC, 2020).

1.1.1. Canada's National Greenhouse Gas Inventory

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1992, and the Convention came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. To facilitate the achievement of its objective and implementation of its provisions, the UNFCCC sets out a number of guiding principles and commitments. It requires governments to gather and share information on GHG emissions, national policies and best practices; to launch national strategies for reducing GHG emissions and adapting to expected impacts of climate change; and to cooperate in adapting to those impacts. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to develop, periodically update,[1] publish and make available to the COP national inventories of anthropogenic[2] emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol[3] that use comparable methodologies.

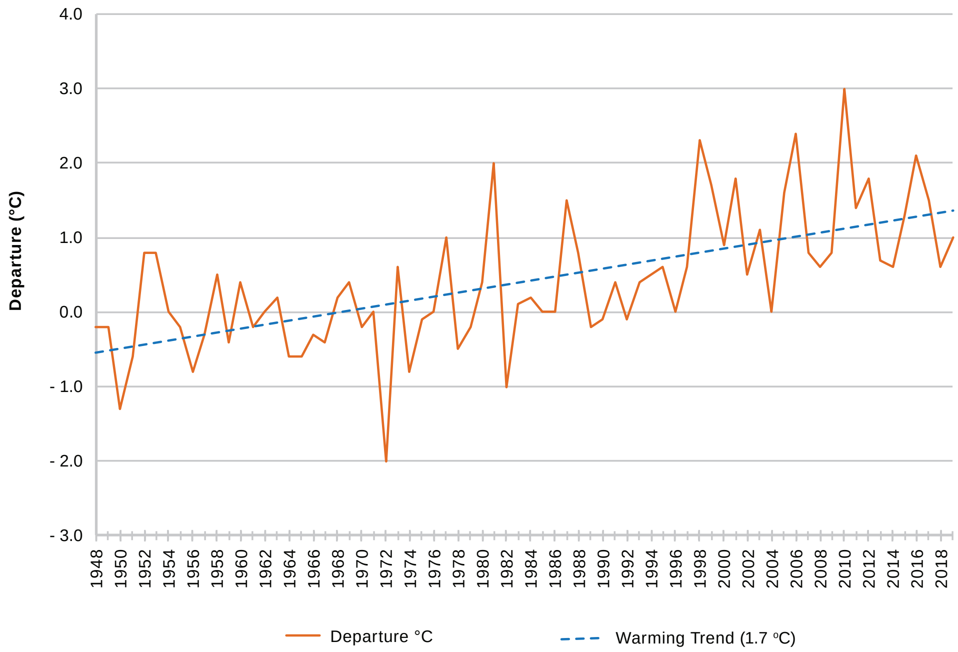
This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the period 1990−2018. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2020 submission to the UNFCCC. The NIR

1 Annex I Parties (or developed countries) are required to submit a national inventory annually by April 15.

2 Anthropogenic refers to human-induced emissions and removals that occur on managed lands.

3 Under the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement designed to reduce the global consumption and production of ozone-depleting substances.

Figure 1–1 **Annual Canadian Temperature Departures and Long-Term Trend, 1948–2019**



Note: Data source – ECCC (2019)

and CRF tables have been prepared in accordance with the revised Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: *UNFCCC reporting guidelines on annual greenhouse gas inventories* (UNFCCC Reporting Guidelines), adopted by the Conference of the Parties at its nineteenth session in 2013.

1.1.2. Greenhouse Gases

This report documents estimates of Canada's emissions and removals of the following GHGs: CO_2, CH_4, N_2O, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). In addition, and in keeping with the UNFCCC Reporting Guidelines, Annex 7 provides the online location to information on ozone and aerosol precursors: carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x).

Carbon Dioxide

CO_2 is a naturally occurring, colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. The global carbon cycle is made up of large carbon flows and reservoirs. Through these, CO_2 is constantly being removed from the air by its direct absorption into water and by plants through photosynthesis and, in turn, is naturally released into the air by plant and animal respiration, decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of CO_2 are also injected directly into the atmosphere by volcanic emissions and through slow geological processes such as the weathering of rock (Hengeveld et al., 2005). Although human-caused releases of CO_2 are relatively small (1/20) compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (Hengeveld et al., 2005), human influences now appear to be significantly affecting this natural balance. This is evident in the measurement of the steady increase of atmospheric CO_2 concentrations since pre-industrial times across the globe (Hengeveld et al., 2005). Anthropogenic sources of CO_2 emissions include the combustion of fossil fuels and biomass to produce energy, building heating and cooling, transportation, land-use changes including deforestation, the manufacture of cement, and other industrial processes.

Methane

CH_4 is a colourless, odourless, flammable gas and is the simplest hydrocarbon. CH_4 is present in the Earth's atmosphere at low concentrations and acts as a GHG. CH_4 usually in the form of natural gas, is used as feedstock in the chemical industry (e.g., hydrogen and methanol production), and as fuel for various purposes (e.g., heating homes and operating vehicles). CH_4 is produced naturally during the decomposition of plant or organic matter in the absence of oxygen and is released from wetlands (including rice paddies) and through the digestive processes of certain insects and animals, such as termites, sheep and cattle. CH_4 is also released from industrial processes, fossil fuel extraction, coal mines, incomplete fossil fuel combustion, and garbage decomposition in landfills.

Nitrous Oxide

N_2O is a colourless, non-flammable, sweet-smelling gas that is heavier than air. Used as an anaesthetic in dentistry and surgery, as well as a propellant in aerosol cans, N_2O is most commonly produced via the heating of ammonium nitrate (NH_4NO_3). It is also released naturally from oceans, by bacteria in soils, and from animal wastes. Other sources of N_2O emissions include the industrial production of nylon and nitric acid, combustion of fossil fuels and biomass, soil cultivation practices, and the use of commercial and organic fertilizers.

Perfluorocarbons

PFCs are a group of human-made chemicals composed of carbon and fluorine only. These powerful GHGs were introduced as alternatives to ozone-depleting substances (ODSs), such as chlorofluorocarbons (CFCs) in manufacturing semiconductors. PFCs are also used as solvents in the electronics industry and as refrigerants in some specialized refrigeration systems. In addition to being released during consumption, they are emitted as a by-product during aluminium production.

Hydrofluorocarbons

HFCs are a class of human-made chemical compounds that contain only fluorine, carbon and hydrogen, and are powerful GHGs. As HFCs do not deplete the ozone layer, they are commonly used as replacements for ODSs such as CFCs, hydrochlorofluorocarbons (HCFCs) and halons in various applications including refrigeration, fire-extinguishing, semiconductor manufacturing and foam blowing.

Sulphur hexafluoride

SF_6 is a synthetic gas that is colourless, odourless, and non-toxic, except when exposed to extreme temperatures. It acts as a GHG due to its very high heat-trapping capacity. SF_6 is primarily used in the electricity industry as insulating gas for high-voltage equipment. It is also used as a cover gas in the magnesium industry to prevent oxidation (combustion) of molten magnesium. In lesser amounts, SF_6 is used in the electronics industry in the manufacturing of semiconductors and as a tracer gas for gas dispersion studies in industrial and laboratory settings.

Nitrogen Trifluoride

NF_3 is a colourless, non-flammable gas that is used in the electronics industry as a replacement for PFCs and SF_6. It has a higher percentage of conversion to fluorine—the active agent in the industrial process—than PFCs and SF_6 for the same amount of electronics production. It is used in the manufacture of semi-conductors, liquid crystal display (LCD) panels and photovoltaics. NF_3 is broken down into nitrogen and fluorine gases in situ, and the resulting fluorine radicals are the active cleaning agents that attack the poly-silicon. NF_3 is further used in hydrogen fluoride and deuterium fluoride lasers, which are types of chemical lasers (UNFCCC, 2010).

1.1.3. Global Warming Potentials

Each GHG has a unique atmospheric lifetime and heat-trapping potential. The radiative forcing[4] effect of a gas within the atmosphere is a quantification of its ability to cause atmospheric warming. Direct effects occur when the gas itself is a GHG, whereas indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are GHGs or when a gas influences the atmospheric lifetimes of other gases.

By definition, a global warming potential (GWP) is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the substance expressed relative to the radiative forcing from the release of 1 kg of CO_2. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas; it is a relative measure of the warming effect that the emission of a radiative gas (i.e., a GHG) might have on the surface atmosphere.

The concept of a GWP has been developed to allow some comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2. It also allows characterization of GHG emissions in terms of how much CO_2 would be required to produce a similar warming effect over a given time period. This is called the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO_2 eq enables the quantification of “total national emissions” expressed as CO_2 eq.

The Intergovernmental Panel on Climate Change (IPCC) develops and updates the GWPs for all GHGs. As GWP values are based on background conditions of GHG concentrations and climate, they need to be adjusted on a regular basis to capture the increase of gases already existing in the atmosphere and changing atmospheric conditions. Consistent with Decision 24/CP19, the 100-year GWP values provided by the IPCC in its Fourth Assessment Report (Table 1–1) are used in this report. For example, the 100-year GWP for CH_4 used in this inventory is 25; as such, an emission of 100 kilotonnes (kt) of CH_4 is equivalent to 25 x 100 kt = 2500 kt CO_2 eq.

4 The term “radiative forcing” refers to the amount of heat-trapping potential for any given GHG. It is measured in units of power (watts) per unit of area (metres squared).

Table 1–1 **IPCC Global Warming Potentials (GWPs)**

GHG	Formula	100-Year GWP	Atmospheric Lifetime (years)
Carbon dioxide	CO_2	1	Variable
Methane [a]	CH_4	25	12 ± 1.8
Nitrous oxide	N_2O	298	114
Sulphur hexafluoride	SF_6	22 800	3 200
Nitrogen trifluoride	NF_3	17 200	740
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	14 800	270
HFC-32	CH_2F_2	675	4.9
HFC-41	CH_3F	92	2.4
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640	15.9
HFC-125	CHF_2CF_3	3 500	29
HFC-134	CHF_2CHF_2	1 100	9.6
HFC-134a	CH_2FCF_3	1 430	14
HFC-143	CH_2FCHF_2	353	3.5
HFC-143a	CH_3CF_3	4 470	52
HFC-152	CH_2FCH_2F	53	0.60
HFC-152a	CH_3CHF_2	124	1.4
HFC-161	CH_3CH_2F	12	0.3
HFC-227ea	CF_3CHFCF_3	3 220	34.2
HFC-236cb	$CH_2FCF_2CF_3$	1 340	13.6
HFC-236ea	CHF_2CHFCF_3	1 370	10.7
HFC-236fa	$CF_3CH_2CF_3$	9 810	240
HFC-245ca	$CH_2FCF_2CHF_2$	693	6.2
HFC-245fa	$CHF_2CH_2CF_3$	1 030	7.6
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794	8.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	7 390	50 000
Perfluoroethane	C_2F_6	12 200	10 000
Perfluoropropane	C_3F_8	8 830	2 600
Perfluorobutane	C_4F_{10}	8 860	2 600
Perfluorocyclobutane	$c\text{-}C_4F_8$	10 300	3 200
Perfluoropentane	C_5F_{12}	9 160	4 100
Perfluorohexane	C_6F_{14}	9 300	3 200
Perfluorodecalin	$C_{10}F_{18}$	7 500	1 000
Perfluorocyclopropane	$c\text{-}C_3F_6$	17 340	1 000

Notes:

Data source: IPCC's Fourth Assessment Report – Errata (IPCC, 2012).

a. The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour.

1.2. Canada's National Inventory Arrangements

Canada's inventory arrangements for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol encompasses the institutional, legal and procedural arrangements necessary to ensure that Canada meets its reporting obligations. These arrangements, including formal agreements and descriptions of the roles and responsibilities of the various contributors to the preparation and submission of the national GHG inventory, are fully documented in Canada's inventory archives.

The national entity responsible for Canada's inventory arrangements is the Pollutant Inventories and Reporting Division of Environment and Climate Change Canada. The National Inventory Focal Point is:

Director
Pollutant Inventories and Reporting Division
Science and Risk Assessment Directorate
Science and Technology Branch
Environment and Climate Change Canada
351 Saint-Joseph Boulevard, 7th floor
Gatineau QC K1A 0H3
Email: ec.ges-ghg.ec@canada.ca
Telephone: 1-877-877-8375

A detailed description of the functions of the Pollutant Inventories and Reporting Division is provided in section 1.2.2 "Process for Inventory Preparation".

1.2.1. Institutional Arrangements

As the federal agency responsible for preparing and submitting the national inventory to the UNFCCC, Environment and Climate Change Canada (ECCC) has established all aspects of the arrangements supporting the GHG inventory and manages them.

Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. Leveraging the best available technical and scientific expertise and information, ECCC has defined roles and responsibilities for the preparation of the inventory, both internally and externally, and is involved in many agreements, formal and informal, with data providers and expert contributors. They include partnerships with other government departments, namely Statistics Canada, Natural Resources Canada (NRCan), Agriculture and Agri-Food Canada (AAFC); arrangements with industry associations, consultants and universities; and collaborative bilateral agreements with provincial and territorial governments.

Figure 1–2 identifies the various partners and contributors to the inventory agency and their contribution to the development of Canada's national inventory.

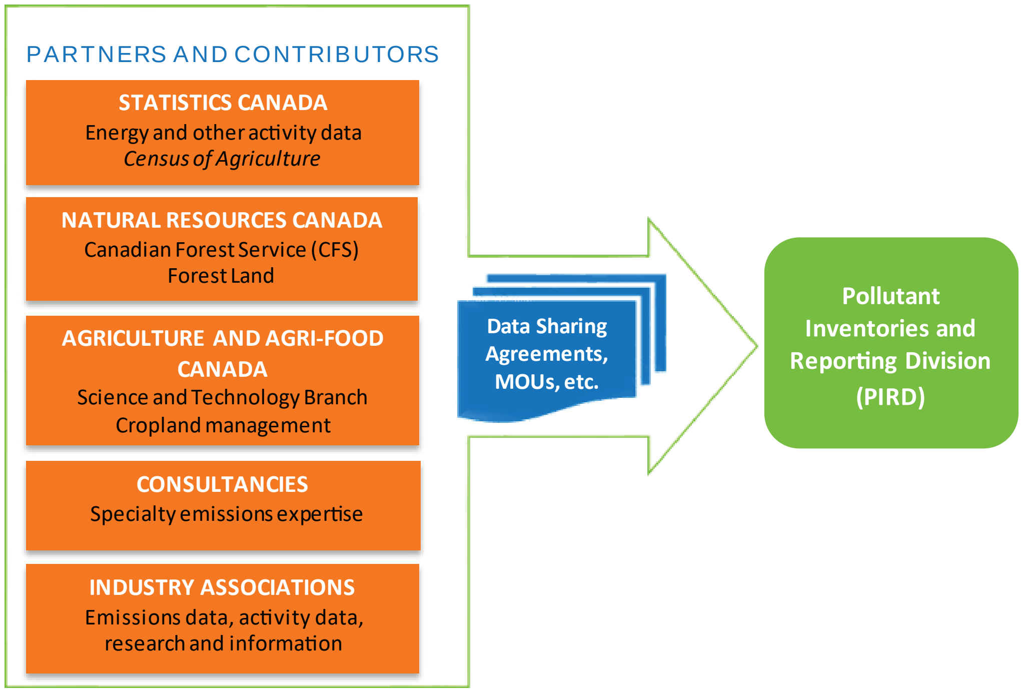
1.2.1.1. Statistics Canada

As Canada's national statistical agency, Statistics Canada provides ECCC with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes and Product Use (IPPU) sectors. Statistics Canada is responsible for the collection, compilation and dissemination of Canada's energy balance in its annual *Report on Energy Supply and Demand in Canada* (RESD). The energy balance is transmitted annually to ECCC according to the terms of a Letter of Agreement between the two departments. Statistics Canada also conducts an annual *Industrial Consumption of Energy* (ICE) survey, which is a comprehensive survey of industries whose results feed into the development of the energy balance.

Statistics Canada's quality management system for the energy balance includes an internal and external review process. Owing to the complexity of energy data, experts from Statistics Canada, ECCC, Natural Resources Canada (NRCan) and the Canadian Energy and Emissions Data Centre (CEEDC) of Simon Fraser University review quality and technical issues related to the RESD and ICE data and provide advice, direction and recommendations on improvements to the energy balance. Refer to Annexes 3 and 4 of this report for additional information on the use of the energy balance in the development of energy estimates.

Statistics Canada also collects other energy data, such as mining and electricity information, and other non-energy-related industrial information, including urea and ammonia production information, as well as activity data on petrochemicals. In addition, it collects agricultural activity data (related to crops, crop production and management practices) through the *Census of Agriculture* and provides animal population data.

Figure 1–2 **Partners and Contributors to National Inventory Arrangements**



1.2.1.2. NRCan and AAFC: Canada's Monitoring System for Land Use, Land-Use Change and Forestry

ECCC has officially designated responsibilities to AAFC and the Canadian Forest Service of NRCan (NRCan/CFS) for the development of key components of the Land Use, Land-Use Change and Forestry (LULUCF) sector. This has been formalized through memoranda of understanding (MOUs).

NRCan/CFS annually develops and delivers estimates of GHG emissions/removals from forest land and harvested wood products, land conversion to forest land (afforestation) and forest land converted to other land (deforestation). The Deforestation Monitoring Group provides estimates of forest conversion activity.

AAFC delivers estimates of GHG emissions/removals from cropland for the LULUCF sector that include the effect of management practices on agricultural soils and the residual impact of land conversion to cropland soils. In addition, AAFC provides scientific support to the Agriculture sector of the inventory.

ECCC manages and coordinates the annual inventory development process, develops all other LULUCF estimates, undertakes cross-cutting quality control and quality assurance, and ensures the consistency of land-based estimates through an integrated land representation system.

1.2.1.3. Other Agreements

In addition to its support to Canada's LULUCF estimates (see section 1.2.1.2), NRCan provides energy expertise and analysis, serves as expert reviewer for the Energy sector data, and collects and provides activity data on mineral production, ethanol consumption and wood residues. Road vehicle data, such as fuel efficiency and driving rates, are provided by both Transport Canada and NRCan.

ECCC annually collects GHG emissions data from facilities that emit large amounts of GHGs under its GHG Reporting Program (GHGRP). The facility-level GHG data are used directly in the national inventory estimates in a few specific sectors. In addition, the facility data acts as an important component of the overall inventory development process in comparing and verifying certain inventory estimates in the NIR. For more information on the facility data reported under the GHGRP, refer to section 1.3.4.1.

A bilateral agreement with the Aluminium Association of Canada (AAC) has been signed, under which process-related emission estimates for CO_2, PFCs and SF_6 are to be provided annually to ECCC. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF_6 emissions and supplementary data relating to power transmission systems.

When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on developing or updating country-specific emission factors (EFs).

1.2.2. Process for Inventory Preparation

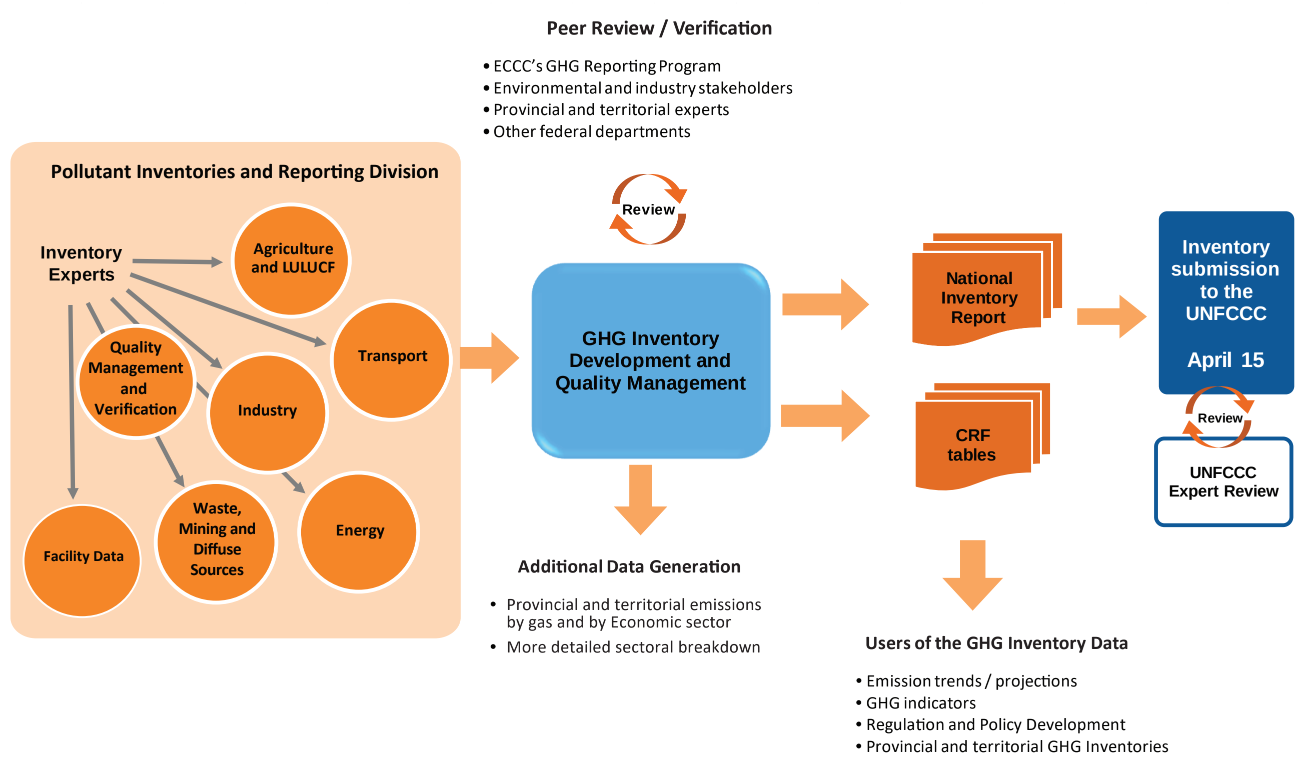
Canada's inventory is developed, compiled and reported annually by ECCC's Pollutant Inventories and Reporting Division, with input from numerous experts and scientists across Canada. Figure 1–3 identifies the various stages of the inventory preparation process.

The inventory builds from a continuous process of methodological improvements, refinements and review, in accordance with quality management and improvement plans. The Quality Management and Verification Section is responsible for preparing the inventory development schedule, which may be adjusted each year based on the results of the lessons-learned review of the previous inventory cycle, quality assurance/quality control (QA/QC) follow-up, the UNFCCC review report, and collaboration with provincial and territorial governments. Methodologies and EFs are reviewed, developed and/or refined on the basis of the outcomes. QA reviews of methodologies and EFs are typically undertaken for categories for which a change in methodology or emission factor is proposed and for categories that are scheduled for a QA review of methodology or emission factor.

During the early stages of the inventory cycle (May to October), collection of the required data begins while the inventory publication schedule and roles and responsibilities are finalized. Methodologies are finalized by the end of September and the data collection process is completed by the end of October. The data used to compile the national inventory are generally taken from published sources. Data are collected either electronically or manually (hard copies) from the source agencies, controlled for quality and entered into emission quantification tools: spreadsheets, databases and other forms of models. In November and December, draft estimates are developed by designated inventory experts and internally reviewed. NIR text and CRF tables are then prepared according to UNFCCC guidelines. QC checks and estimates are performed before the report and emission estimates are published. The inventory process also involves key category assessment, completeness assessment, recalculations, uncertainty calculation and documentation preparation.

Between January and March, the compiled inventory is first reviewed internally and components of it are reviewed externally by experts, government agencies and provincial and territorial governments, after which the NIR is finalized. Comments from the reviews are documented and, where appropriate, incorporated in the NIR and

Figure 1–3 **Inventory Preparation Process**



CRF, which are normally submitted to the UNFCCC electronically prior to April 15 of each year. Once finalized, the NIR is then translated and made available in French.

All documents relevant to the development and publication of Canada's GHG inventory are archived in a manner consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) and Canada's *Policy on Information Management* (Treasury Board of Canada, 2012). Canada maintains an electronic archive and reference library for these documents.

1.2.3. Procedures for the Official Consideration and Approval of the Inventory

In the process of considering the national inventory and the results, senior officials are briefed on several occasions prior to the report being sent to the Minister. Once reviewed and/or approved, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRF tables, which are then sent electronically.

1.2.4. Treatment of Confidentiality Issues

Confidential information is defined as information that could directly or indirectly identify an individual person, business or organization. During the development of the inventory, procedures are in place to ensure confidentiality of source data, when required. For instance, some emissions are aggregated to a level such that confidentiality is no longer an issue. For example, in certain cases, emissions from Croplands are aggregated with neighbouring reporting zones to protect confidential data. These procedures are documented, and confidential source data are protected and archived accordingly.

For data received from Statistics Canada used to estimate GHG emissions in the Energy and IPPU sectors, confidentiality protocols are applied to the GHG estimates prior to submission to the UNFCCC. This is to ensure that the statistical aggregates which are released or published do not directly or indirectly identify a person, business or organization, in accordance with the data sharing agreement between Statistics Canada and ECCC. In addition, for facility-reported data collected directly by ECCC through the GHGRP and used to develop certain inventory estimates, aggregation is applied where necessary to ensure non-disclosure of facility-specific information considered confidential by individual facilities.

1.2.5. Changes in the National Inventory Arrangements Since Previous Annual GHG Inventory Submission

There have been no changes to the national inventory arrangements since the previous annual GHG inventory submission.

1.3. Quality Assurance, Quality Control and Verification

QA/QC and verification procedures are an integral part of the inventory development and submission process. These procedures ensure that Canada is able to meet the UNFCCC reporting requirements of transparency, consistency, comparability, completeness and accuracy and, at the same time, continuously improve data and methods to ensure that a credible and defensible inventory is developed.

1.3.1. Overview of Canada's Quality Management System

The development of Canada's GHG inventory is based on a continuous process of data collection, methodological refinement and review. QA/QC procedures take place at all stages of the inventory development cycle.

In order to ensure that an inventory of high quality is produced each and every year, a national inventory quality management system has been developed and implemented for the annual compilation and publication of the national GHG inventory. The quality management system includes a QA/QC plan, an inventory improvement plan, processes for creation, documentation and archiving of information, a standardized process for implementing methodological change, identification of key roles and responsibilities, as well as a timeline for completing the various NIR related tasks and activities.

1.3.2. Canada's Quality Assurance / Quality Control Plan

Canada's QA/QC plan uses an integrated approach to managing the inventory quality and works towards achieving continuously improved emission and removal estimates. It is designed so that QA/QC and verification procedures are implemented throughout the entire inventory development process, from initial data collection through development of emission and removal estimates to publication of the National Inventory Report in English and French.

Documentation of QA/QC procedures is at the core of the plan. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each stage of the annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year.

1.3.2.1. Quality Control Procedures

Quality control (QC) procedures consist of routine technical checks to measure and control the quality of the inventory, ensure data consistency, integrity, correctness and completeness, and identify and address errors and omissions. The QC procedures used during the inventory development cycle cover a wide range of inventory processes, from data acquisition and handling to application of approved procedures and methods to calculation of estimates and documentation.

A series of systematic Tier 1 QC checks in line with the 2006 IPCC Guidelines (IPCC, 2006), Volume 1, Section 6.6, are performed annually by inventory experts on the key categories and across sectors. Prior to submission, cross-cutting QC checks are conducted on the final NIR documents (English and French). Also prior to submission, quality checks are performed on the data entered into the Common Reporting Format (CRF) online tool by the national inventory compiler and reviewer, and the tables are reviewed by the sector experts, for the entire time series of CRF tables.Category-specific Tier 1 QC procedures complement general inventory QC procedures, and are directed at specific types of data used. These procedures require knowledge of the specific category, including the methodology, the types of data available and the parameters associated with emissions or removals.

To facilitate these Tier 1 checks, QC checklists have been developed to standardize and document QC procedures that are performed. The QC checklists include a record of any corrective action taken and refer to supporting documentation. Minor updates to the QC checklist were made in 2015 (Environment Canada, 2015).

A Tier 2 QC assessment is an opportunity to critically review a specific category or categories. There is a need for a comprehensive assessment to ensure that the category will remain current and relevant for a number of years beyond the year of analysis. The investigation is typically broad and uses a variety of sector specific approaches, including performing assessments of continued applicability of methods, EFs, activity data, uncertainty, etc., and laying the foundation for future activities, including developing and prioritizing recommendations for improvement and making preparations for subsequent QA. Documentation of the Tier 2 QC checks may be done through a standard checklist or with an in-depth study to complete a comprehensive assessment.

1

1.3.2.2. Quality Assurance Procedures

As per the 2006 IPCC Guidelines (IPCC, 2006), QA activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process, and is performed in parallel with QC procedures. QA helps to ensure that the inventory represents the best possible estimates of emissions and removals given the current state of scientific knowledge and data availability, and it supports the effectiveness of the QC program. As with QC, QA is undertaken every year on components of the inventory. Selected underlying data and methods are independently assessed each year by various groups and individual experts in industry, provincial governments, academia and other federal government departments. QA is undertaken for the assessment of the activity data, methodology and emission factor utilized for developing estimates, and is preferably carried out prior to making a decision on implementing a methodological change.

1.3.3. Planning and Prioritization of Improvements

Inventory improvements can come from a variety of external and internal sources. For example, at the end of the annual in-depth review of Canada's GHG inventory, expert review teams (ERTs) provide feedback and recommendations on any methodological or procedural issues encountered. These recommendations usually refer to instances where the adherence of Canada's inventory to the guiding principles of transparency, consistency, comparability, completeness and accuracy could be improved. In addition to the improvements identified by the ERTs, the GHG inventory team is also encouraged to use their knowledge and experience in developing inventory estimates to identify areas for improvement in future inventories based on evolving science, new and innovative modelling approaches and new sources of activity data.

As many improvements will stretch over multiple years, Canada has developed an *Inventory Improvement Plan*, which identifies and tracks planned improvements to both the emission estimates (including the underlying activity data, EFs and methodologies) and components of the national inventory arrangements (including the QA/QC plan, data infrastructure and management, archiving processes, uncertainty analysis and key category assessment). The *Inventory Improvement Plan* contains all planned improvement activities that will further refine and enhance the transparency, completeness, accuracy, consistency and comparability of Canada's GHG inventory and is updated on an annual basis. Improvements are prioritized by each section based on the outcomes of the QA/QC and verification activities (as outlined in the QA/QC Plan), key category and uncertainty analysis, resource availability and assessment of potential impacts. Additional information on inventory improvements can be found in Chapter 8.

1.3.4. Verification

Verification activities typically include comparing inventory estimates to independent estimates to either confirm the reasonableness of the inventory estimates or identify major discrepancies. Appropriate comparisons depend on the availability of data (which may include data sets, EFs or activity data) that can be meaningfully compared to inventory estimates. For this reason, verification activities are often conducted on subsets of inventory categories. Consistency between the national inventory and independent estimates leads to an increase in the confidence level and reliability of the inventory estimates.

Details on verification activities are available in Chapters 3 to 7.

1.3.4.1. The GHG Reporting Program

In March 2004, the Government of Canada established the Greenhouse Gas Reporting Program (GHGRP) to collect GHG emissions information annually from facilities across the country. Under this mandatory reporting program, reporting requirements are described in the legal notice issued under section 46(1) of the *Canadian Environmental Protection Act, 1999* and published annually in the *Canada Gazette*.[5] The GHGRP has provided a way for the Government of Canada to continuously track GHG emissions from individual facilities to inform the public, the national GHG inventory and regulatory initiatives.

In December 2016, the Government of Canada published a Notice of Intent to inform stakeholders of its intention to expand the GHGRP using a phased approach. It is pursuing this expansion in order to: enable the direct use of the reported data in the national GHG inventory; increase the consistency and comparability of GHG data across jurisdictions; and obtain a more comprehensive picture of Canadian facility emissions. In 2017, the Government of Canada implemented Phase 1 of the expansion by lowering the reporting threshold from 50 kt to 10 kt for all facilities. Phase 1 also required manufacturers of lime, cement, aluminum, iron and steel as well as facilities involved in CO_2 capture, transport, injection and geological storage activities to use prescribed methods to quantify their emissions and to provide additional information on their calculations. Under Phase 2 of the expansion (2018 data), facilities in nine additional industry sectors were required to report additional information and use prescribed quantification methods. These sectors are manufacturers of ethanol, ammonia, nitric acid and hydrogen, facilities involved in electricity and heat generation, mining operations, petroleum refineries, pulp and paper production as well as base metal production.

5 The notice that required the reporting of 2019 emissions information published in the Canada Gazette can be found at: https://canadagazette.gc.ca/rp-pr/p1/2020/2020-02-01/html/sup1-eng.html#S91.

Facilities not covered by the expansion can choose the quantification methodologies most appropriate for their particular industry or application. However, these reporting facilities must use methods for estimating emissions that are consistent with the guidelines developed by the IPCC and adopted by the UNFCCC for the preparation of national GHG inventories. Voluntary submissions from facilities with GHG emissions below the 10kt reporting threshold are accepted.

To date, facility-reported GHG information has been collected and published through Environment and Climate Change Canada's GHGRP for the period 2004 to 2019. In 2019, a total of 1700 facilities (mostly industrial) reported their GHG emissions to the program. Environment and Climate Change Canada's GHGRP website[6] provides public access to the reported GHG emission information (GHG totals by gas by facility).

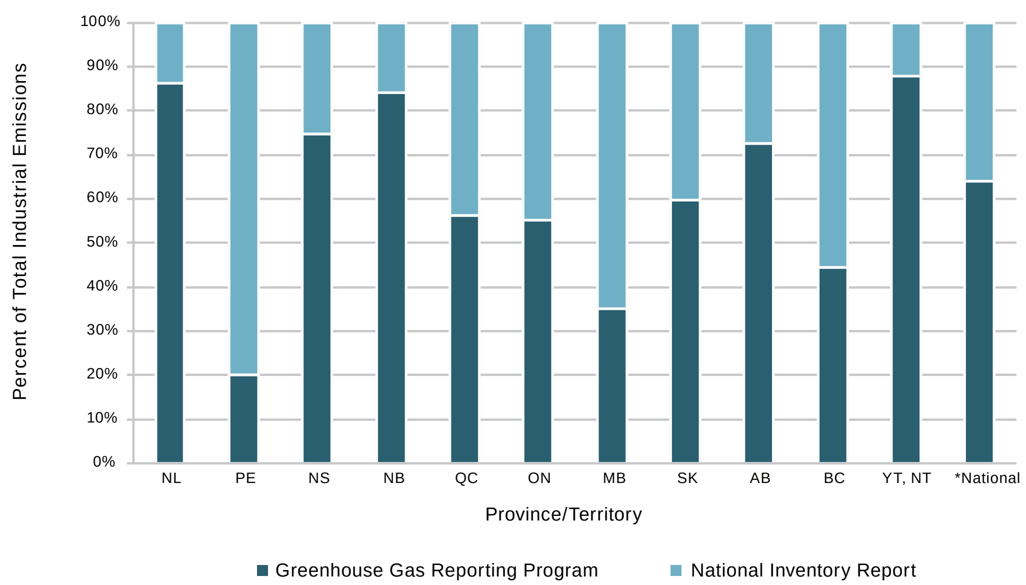
It is important to note that the GHGRP applies to specific emission sources that exist at facilities and does not cover all sources of GHG emissions (e.g., road transportation, combustion of fuels from residential sources, and agricultural sources), whereas the NIR is a complete accounting of all GHG sources and sinks in Canada. In 2019, the total facility-reported GHG emissions represents 40% of Canada's total GHG emissions (730 Mt) and 64% of Canada's industrial GHG emissions. The degree of coverage from the facility-reported data of industrial GHG emissions at the provincial level varies significantly from province to province, depending on the size and number of industrial facilities in each province that have emissions above the 10kt reporting threshold (Figure 1–4).

Facility-level GHG emission data are used, where appropriate, in the NIR, which is developed largely from national and provincial statistics and in accordance with UNFCCC reporting requirements. Information gathered from facilities is shared with provincial and territorial jurisdictions. The GHGRP provides Canadians with consistent information about the largest GHG-emitting facilities across Canada. The enhanced facility data collected to date as part of the expansion will continue to be reviewed, with the intent to further integrate more data over time into the NIR, to the extent possible. Additional information on how this data is used in emission estimates for various source categories can be found in chapters 3 to 7 of the NIR.

For more information on the facility data reported under Canada's GHGRP, including short- and long-term changes observed in facility emissions, refer to the publication *Facility Greenhouse Gas Reporting Program—Overview of 2019 Reported Emissions* (ECCC, 2021).

6 The Greenhouse Gas Reporting Program website can be found at: https://www.canada.ca/ghg-reporting.

Figure 1–4 **2019 Facility-Reported Emissions as a Percentage of Industrial GHG Emissions by Province/Territory**



Notes:

For this figure, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report, Greenhouse Gas Sources and Sinks in Canada 1990–2019*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

* Nunavut is not included due to the lack of data

1.4. Annual Inventory Review

Since 2003, except for 2018, Canada's national GHG inventory has been reviewed annually by independent ERTs following the *UNFCCC Review Guidelines for Annual Inventories for Annex I Parties*. The review process plays a key role in ensuring that inventory quality is improved over time, and that Parties to the Convention comply with agreed-upon reporting requirements. The completeness, accuracy, transparency, comparability and consistency of inventory estimates can also be attributed to the well-established review process. Canada's inventory has been subjected to both centralized and in-country reviews, with the last in-country review taking place in 2014.[7] Review reports are posted on-line by the UNFCCC Secretariat once finalized.[8]

1.5. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the UNFCCC and is divided into the following five main sectors: Energy, IPPU, Agriculture, LULUCF, and Waste. Each of these sectors is further subdivided in subsectors or categories. The methods described have been grouped, as closely as possible, by UNFCCC sector and subsector.

The methodologies contained in the 2006 IPCC Guidelines (IPCC, 2006) are followed to estimate emissions and removals of each of the following direct GHGs: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3.

While not mandatory, the UNFCCC Reporting Guidelines encourage Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs (see Annex 7: Ozone and Aerosol Precursors). For all sectors except LULUCF, these gases are inventoried and reported separately to the United Nations Economic Commission for Europe.[9]

In general, an inventory of emissions and removals can be defined as a comprehensive account of anthropogenic emissions by sources and removals by sinks where and when they occur, in the specified year and country area. It can be prepared "top-down," "bottom-up," or using a combination of approaches. Canada's national inventory is prepared using a "top-down" approach, providing estimates at a sectoral and provincial/territorial level, without attribution to individual emitters.

Emissions and removals are usually calculated or estimated using mass balance, stoichiometry or emission factor relationships under average conditions. In many cases, activity data are combined with average EFs to produce a "top-down" national inventory. Large-scale regional estimates, based on average conditions, have been compiled for spatially diffuse sources, such as transportation. Emissions from landfills are determined using a simulation model to account for the long-term slow generation and release of these emissions.

Manipulated biological systems, such as agricultural lands, forestry and land converted to other uses, are sources or sinks diffused over very large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals requires a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

The methodologies (Annex 3) and EFs (Annex 6) described in this document are considered to be the best available to date, given the available activity data. Limitations to the use of more accurate methods or EFs often arise due to the lack of activity data. Over time, numerous methods have undergone revision and improvement and some new sources have been added to the inventory.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis. It should be noted that planned improvements are often implemented over the course of several years. These methodology and data improvement activities are carried out with a view to further refining and increasing the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from 1990 to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 8.

1.6. Key Categories

The 2006 IPCC Guidelines (IPCC, 2006) defines procedures (in the form of decision trees) to select estimation methods. The decision trees formalize the choice of estimation method most suited to national circumstances, while considering the available knowledge and resources (both financial and human). Generally, the precision and accuracy of inventory estimates can be improved by using the most rigorous

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7 More information on the UNFCCC's review process and guidelines is available online at http://unfccc.int/national_reports/annex_i_ghg_inventories/review_process/items/2762.php.

8 Annual Inventory Review Reports are available online at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports/inventory-review-reports-2019.

9 Information on Canada's ozone and aerosol precursors, including CO, NOx, NMVOC and SOx can be found in Canada's Air Pollutant Emission Inventory, which is available online at www.canada.ca/APEI.

(highest-tier) methods; however, owing to practical limitations, the exhaustive development of all emissions categories is not possible. Therefore, it is good practice to identify and prioritize key categories in order to make the most efficient use of available resources.

In this context, a key category is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHG emissions in terms of the absolute level of emissions (level assessment), the trend in emissions from the base year to the current year (trend assessment), or both. Wherever feasible, key categories should be estimated with more refined country-specific methods and be subjected to enhanced QA/QC.

For the 1990–2019 GHG inventory, level and trend key category assessments were performed according to the recommended IPCC approach found in Volume 1, Section 4.3.1, of the 2006 IPCC Guidelines. The emission and removal categories used for the key category assessment generally follow those in the CRF and the LULUCF CRF. However, they have been aggregated in some cases and are specific to the Canadian inventory.

The categories that have the strongest influence on the national trend (excluding LULUCF) are:

1. Fuel Combustion – Road Transportation
2. Stationary Fuel Combustion – Manufacturing Industries and Construction
3. Fuel Combustion – Other Transportation (Off-Road)
4. Stationary Fuel Combustion – Energy Industries
5. IPPU – Adipic Acid Production

The categories that have the strongest influence on the national trend (including LULUCF) are:

1. Fuel Combustion – Road Transportation
2. LULUCF – Forest Land Remaining Forest Land
3. Stationary Fuel Combustion – Manufacturing Industries and Construction
4. Stationary Fuel Combustion – Energy Industries
5. LULUCF – Harvested Wood Products

Details and results of the key category assessments are presented in Annex 1.

1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently carry some uncertainty. Uncertainties[10] in the inventory estimates may be caused by systematic and/or random uncertainties present within the input parameters or estimation models. Quantifying and reducing uncertainty may require in-depth reviews of the estimation models, improvements to the activity data regimes and evaluation of EFs and other model parameters. In a limited number of cases, uncertainty may be reduced through a validation exercise using an independent data set, such as the total emissions reported by individual facilities in a given industry sector. The IPCC 2006 Guidelines (IPCC, 2006) specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

Annex 2 presents the uncertainty assessment for Canadian GHG emissions. While more complex methods (Approach 2) are in some cases applied to develop uncertainty estimates at the sectoral or category level, for the inventory as a whole these uncertainties were combined with the simple (Approach 1) error propagation method, using Table 3.3 in the IPCC 2006 Guidelines (IPCC, 2006). Separate analyses were conducted for the inventory as a whole with and without LULUCF. For further details on uncertainty related to specific sectors, see the uncertainty sections throughout Chapters 3 to 7.

Based on the error propagation method, the uncertainty for the national inventory, not including the LULUCF sector, is ±3%. The Energy sector had the lowest uncertainty, at ±2%, while the Waste sector had the highest uncertainty, at ±66%. The IPPU and Agriculture sectors had uncertainties of ±5% and ±47%, respectively.

The five emissions source categories that make the largest contribution to uncertainty at the national level when LULUCF is not included are:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Direct Agriculture Soils, N_2O
3. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills, CH_4
4. Agriculture – Enteric Fermentation, CH_4
5. Energy – Fuel Combustion – Manufaturing Industries and Construction, CO_2

10 Uncertainty is the lack of knowledge of the true value of a variable that can be described as a probability density function characterizing the range and likelihood of possible values (IPCC, 2006).

1

1

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±9%. The top five contributors influencing the national uncertainty when LULUCF is included were:

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. LULUCF – Harvested Wood Products, CO_2
3. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
4. Agriculture – Direct Agriculture Soils, N_2O
5. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills, CH_4

The calculation of trend uncertainty was performed with and without the LULUCF sector. The trend uncertainty, not including LULUCF, was found to be 1%. Therefore, the total increase in emissions since 1990 of 129 Mt CO_2 eq (+21%) falls within an uncertainty range of a minimum of +128 Mt CO_2 eq to a maximum of +129 Mt CO_2 eq. The trend uncertainty, including LULUCF, was found to be 1%.

1.8. Completeness Assessment

The national GHG inventory serves as a comprehensive assessment of anthropogenic GHG emissions and removals in Canada. Overall, this is a complete inventory of the seven GHGs required under the UNFCCC. However, emissions for some categories have not been estimated or have been included with other categories due to the following:

- Categories that are not occurring in Canada
- Data unavailability at the category level
- Methodological issues specific to national circumstances
- Emission estimates are considered insignificant[11]

As part of the NIR improvement plans, efforts are continuously being made to identify new or improved data sources or methodologies to provide estimates for those categories that are “not estimated”. Further details on the completeness of the inventory can be found in Annex 5 and in individual sector chapters (Chapters 3 to 7).

11 An emission should only be considered insignificant if the likely level of emissions is below 0.05% of the national total GHG emissions, and does not exceed 500 kt CO_2 eq. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1% of the national total GHG emissions (UNFCCC, 2014).

CHAPTER 2

GREENHOUSE GAS EMISSIONS TRENDS

2.1. Summary of Emissions Trends

After fluctuations in recent years, in 2019 (the most recent dataset in this report), Canada's greenhouse gas (GHG) emissions were 730 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[1] a net decrease of 8.5 Mt or 1.1% from 2005 emissions (Figure 2–1).[2] Dating back to 1990, annual emissions steadily increased for 10 years, fluctuated between 2000 and 2008, dropped in 2009 and gradually increased thereafter.

Emissions increases since 2009 have been driven by growth in Oil and Gas Extraction (27 Mt), in the number of light-duty gasoline trucks (13 Mt) and heavy-duty diesel vehicles in operation (12 Mt), in the production and consumption of halocarbons, sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) (5.5 Mt), and in the application of inorganic nitrogen fertilizers (3.5 Mt). During the same period, a 32 Mt decrease in emissions from electricity generation partly offset emissions growth. Section 2.3 provides more details on these and other key drivers of these trends.

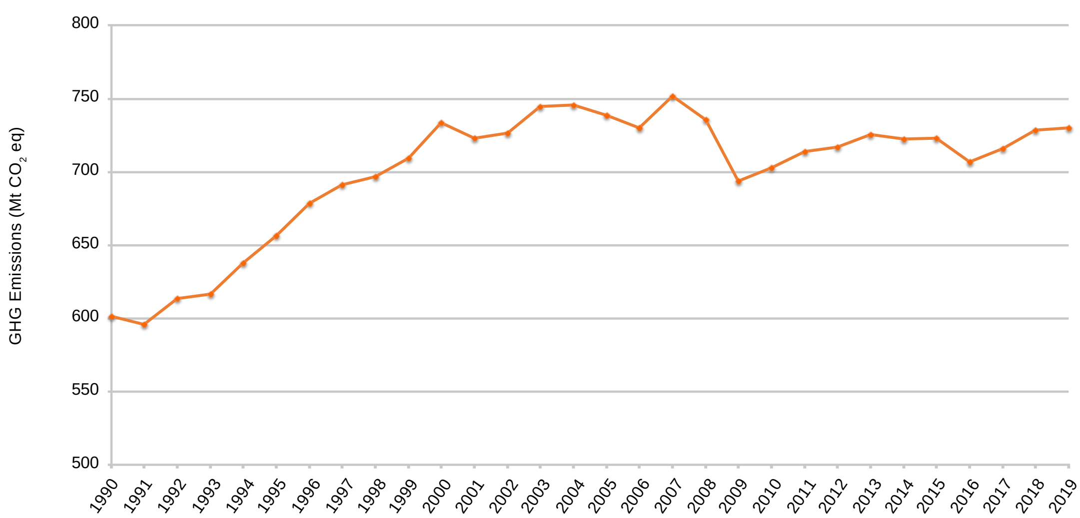
Over the long term, Canada's economy has grown more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (or GHGs per Gross Domestic Product [GDP]) has declined by 37% since 1990, and by 23% since 2005 (Table 2–1). The decline in emissions intensity since 1995 (Figure 2–2) can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Canada accounted for approximately 1.5% of global GHG emissions in 2017 (Climate Watch, 2020), although it is one of the highest per capita emitters. Canada's per capita emissions have declined since 2005 from 22.9 t CO_2 eq/capita to a new low of 19.4 t CO_2 eq/capita in 2019 (Figure 2–3).

1 Unless explicitly stated otherwise, all emissions estimates given in Mt represent emissions of GHGs in Mt CO_2 eq.

2 Throughout this report, data are presented in the form of rounded figures. However, all calculations (including the ones to obtain percentages) were performed using unrounded data.

Figure 2–1 **Canadian GHG Emission Trend (excluding Land Use, Land-Use Change and Forestry) (1990–2019)**



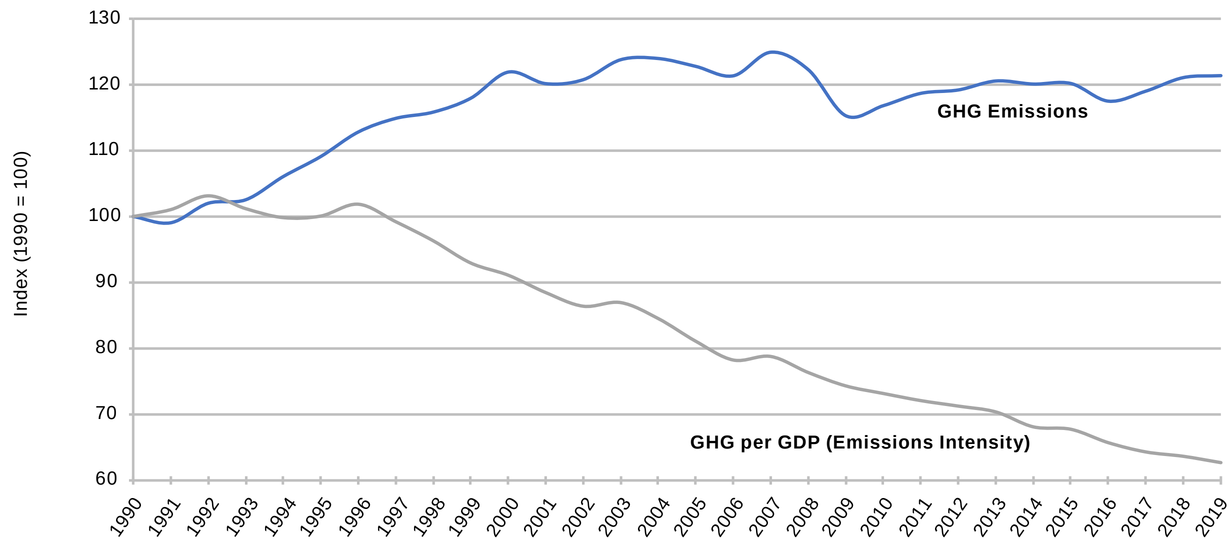
2.1.1. Provincial and Territorial GHG Emissions Trends

GHG emissions vary significantly by province and territory as a result of factors such as population, energy sources and economic structure. All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for electricity generation emit relatively more GHGs than those that rely more on low-emitting energy sources, such as nuclear power, hydroelectric generation, wind turbines, solar photovoltaic cells and tidal power (Figure 2–4).

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 40 Mt (17%) since 2005, primarily as a result of the expansion of oil and gas operations (Table 2–2). In contrast, Ontario's emissions have decreased by 42 Mt (21%) since 2005, owing primarily to the closure of coal-fired electricity generation plants.

Saskatchewan's emissions increased by 7.0 Mt (10%) between 2005 and 2019 as a result of expanding activities in the oil and gas industry, potash mining and transportation. Emissions in British Columbia have also increased by 2.7 Mt (4.3%) over the same time period. Emissions in Manitoba and Newfoundland and Labrador

Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2019)**



Note: GDP data source: StatCan (n.d.[a])

Table 2–1 **Trends in GHG Emissions and Economic Indicators, Selected Years**

Year	1990	2005	2014	2015	2016	2017	2018	2019
Total GHG (Mt)	**602**	**739**	**723**	**723**	**707**	**716**	**728**	**730**
Change since 2005 (%)	NA	NA	-2.2%	-2.1%	-4.3%	-3.1%	-1.4%	-1.1%
Change since 1990 (%)	NA	23%	20%	20%	18%	19%	21%	21%
GDPa (Billion 2012$)	**1 092**	**1 654**	**1 926**	**1 938**	**1 953**	**2 022**	**2 078**	**2 115**
Change since 2005 (%)	NA	NA	16%	17%	18%	22%	26%	28%
Change since 1990 (%)	NA	51%	76%	78%	79%	85%	90%	94%
GHG Intensity (Mt/$B GDP)	**0.55**	**0.45**	**0.38**	**0.37**	**0.36**	**0.35**	**0.35**	**0.35**
Change since 2005 (%)	NA	NA	-16%	-16%	-19%	-21%	-22%	-23%
Change since 1990 (%)	NA	-19%	-32%	-32%	-34%	-36%	-36%	-37%

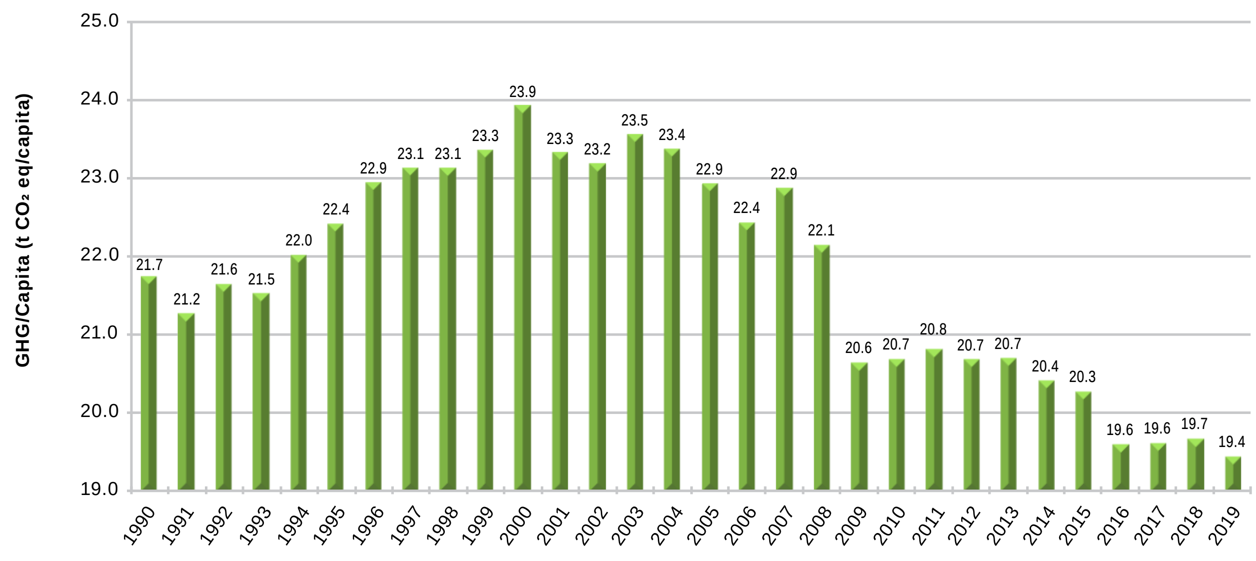
Notes:

a. Data source: StatCan (n.d.[a])

NA = Not applicable

have also increased since 2005, but to a lesser extent (2.0 Mt or 9.8% and 0.57 Mt or 5.4%, respectively). Provinces that have seen significant decreases in emissions include New Brunswick (7.6 Mt or a 38% reduction), Nova Scotia (6.9 Mt or a 30% reduction), Quebec (3.9 Mt or a 4.4% reduction) and Prince Edward Island (0.29 Mt or a 14% reduction). Furthermore, Northwest Territories emissions have also decreased (0.25 Mt or a 16% reduction), and Nunavut and Yukon have experienced an increase in emissions (0.15 Mt or 26% and 0.12 Mt or 22%, respectively).

Figure 2–3 **Canadian Per Capita GHG Emissions (1990–2019)**



Note: Population data source: StatCan (n.d.[b])

Figure 2–4 **GHG Emissions by Province and Territory in 2005, 2010 and 2019**

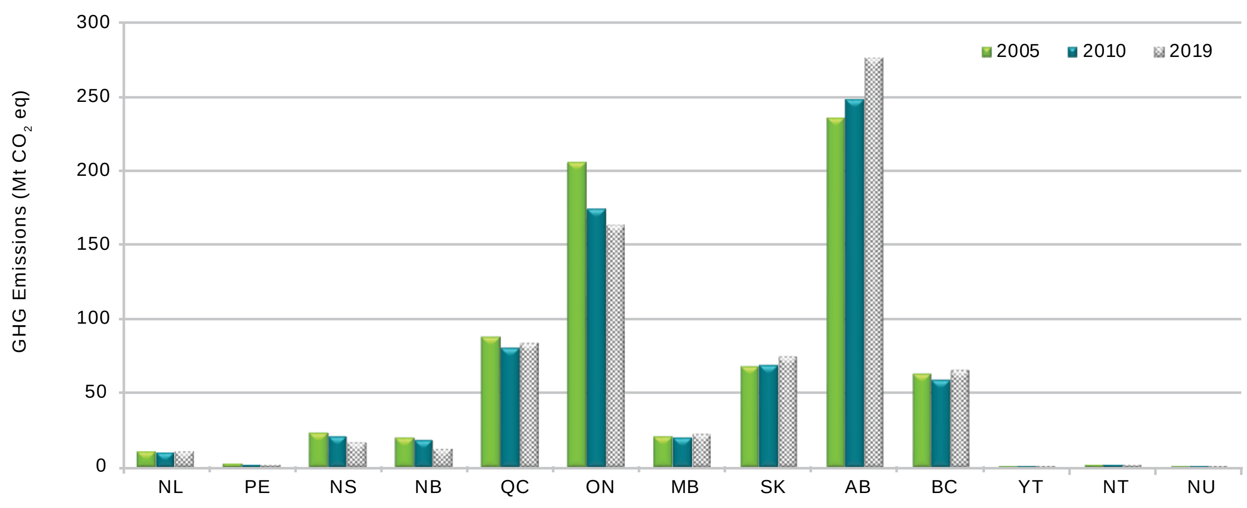


Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)
Year	1990	2005	2014	2015	2016	2017	2018	2019	2005–2019
GHG Total (Canada)	**602**	**739**	**723**	**723**	**707**	**716**	**728**	**730**	**-1.1%**
NL	9.5	11	11	11	11	11	11	11	5.4%
PE	1.9	2.0	1.7	1.7	1.7	1.7	1.7	1.8	-14%
NS	20	23	17	17	16	16	17	16	-30%
NB	16	20	13	14	14	13	13	12	-38%
QC	86	88	79	79	79	81	83	84	-4.4%
ON	180	206	164	163	161	158	163	163	-21%
MB	19	21	21	21	21	22	23	23	10%
SK	43	68	74	76	74	76	76	75	10%
AB	172	235	278	278	264	271	272	276	17%
BC	52	63	60	59	62	63	66	66	4.3%
YT	0.55	0.57	0.50	0.53	0.53	0.56	0.64	0.69	22%
NT	NA	1.6	1.5	1.7	1.6	1.3	1.4	1.4	-16%
NU	NA	0.58	0.70	0.64	0.74	0.75	0.75	0.73	25%

Notes:
Totals may not add up due to rounding.
NA = Not applicable

2.2. GHG Emissions Trends by Gas

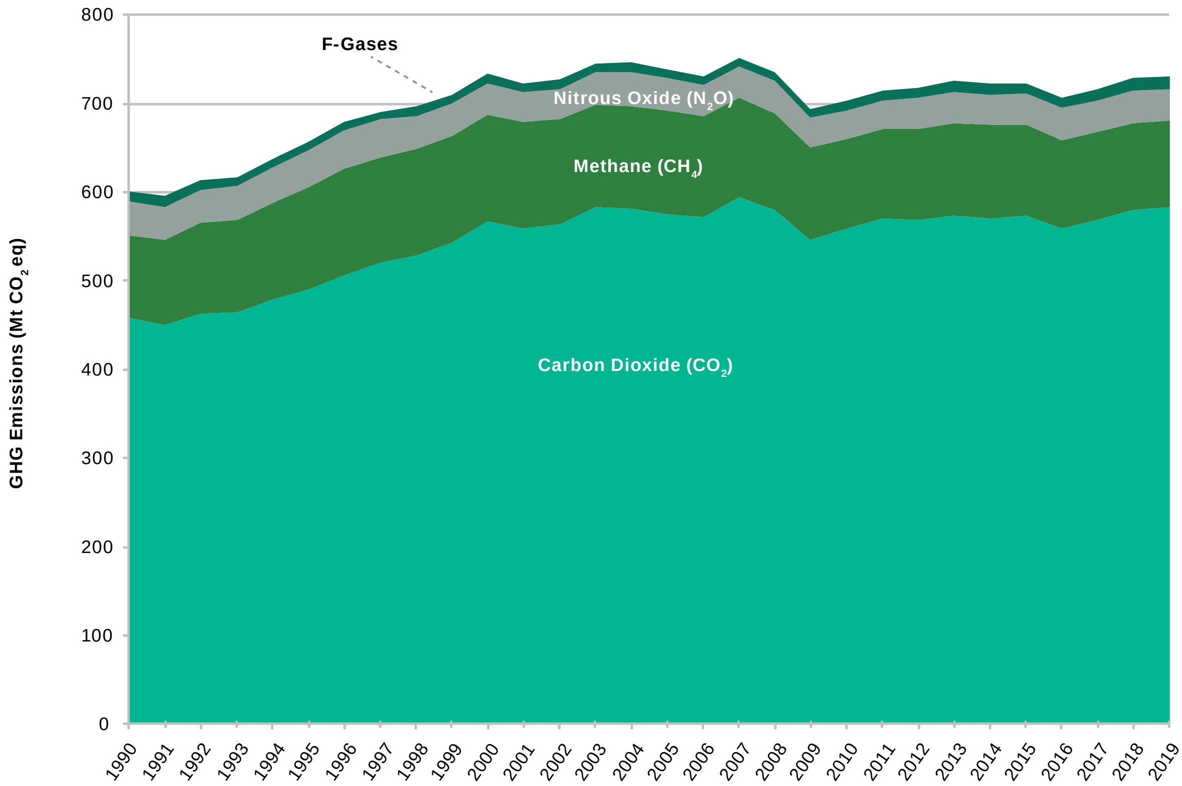
Canada's GHG emissions profile is similar to that of most industrialized countries in that carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions, accounting for 582 Mt (80% of total emissions) in 2019. As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions. The majority of the CO_2 emissions in Canada result from the combustion of fossil fuels (Figure 2–5).

Methane (CH_4) emissions in 2019 amounted to 98 Mt or 13% of Canada's total emissions. These emissions are largely from fugitive sources in oil and natural gas systems (37% of total CH_4 emissions), agriculture (29% of total CH_4 emissions) as well as solid waste disposal (municipal landfills) and industrial wood waste landfills (27% of total CH_4 emissions). Nationally, CH_4 emissions have increased by 4.5 Mt (4.8%) since 1990, largely due to the development of petroleum resources where there has been a 62% increase in natural gas production, 29% increase in conventional oil production and over 700% increase in oil sands production. Although, since 2005, CH_4 emissions have decreased by 18 Mt (15%). This decrease can be explained by a 27% decline in beef cattle populations, leading to a reduction in enteric fermentation emissions (-6.8 Mt), increased gas conservation in the oil and gas industry, leading to reductions in venting emissions (-5.1 Mt), and the combination of improved leak detection and repair (LDAR) programs and a 6% decrease in natural gas production, both of which have contributed to a decrease in fugitive leak emissions (-2.4 Mt).

Nitrous oxide (N_2O) emissions accounted for 37 Mt (5.0%) of Canada's emissions in 2019, down 1.9 Mt (4.9%) from 1990 levels and 0.34 Mt (0.9%) from 2005 levels. These emissions primarily arise from the application of nitrogen to agricultural soils. In 2019, the Agriculture sector accounted for 78% of national N_2O emissions, up from 37% in 1990 and 64% in 2005. Since 1990, a 10 Mt decrease in N_2O emissions has also occurred due to the cessation of adipic acid production in Canada.

Together, perfluorocarbons (PFCs), SF_6, hydrofluorocarbons (HFCs) and NF_3 accounted for 13 Mt or 1.8% of Canada's emissions in 2019. From 1990 to 2019, emissions of HFCs rose by 11 Mt (1179%), while emissions of PFCs and SF_6 decreased by 7.0 Mt (92%) and 2.7 Mt (85%), respectively. Similar to the 1990–2019 trends, since 2005, HFC emissions increased by 7.3 Mt (143%) and emissions of PFCs and SF_6 decreased by 3.2 Mt (84%) and 0.9 Mt (66%), respectively. The increase in HFC emissions can be explained by the replacement of ozone-depleting substances (ODSs), CFCs and HCFCs, by HFCs for refrigeration and air conditioning before the gradual phase out of HFCs mandated under the Kigali Amendment to the Montreal Protocol, which came into force in 2019. The decreases in emissions of PFCs are largely due to the Aluminium industry's efforts to modernize existing facilities and improve production efficiency. The decline of Magnesium Smelters and Casters have contributed to the decreased SF_6 emissions. Three primary magnesium production facilities had been in operation during the 1990 to 2008 time period, but the last facility closed in 2008. Additionally, of the 11 magnesium casting facilities that were in operation during the 1990 to 2004 period, only five were currently in operation in 2019.

Figure 2–5 **Trends in Canadian GHG Emissions by Gas (1990–2019)**



Note: F-gases consist of HFCs, PFCs, SF_6 and NF_3.

2.3. Emissions Trends by Intergovernmental Panel on Climate Change Category

In 2019, the Energy sector accounted for 589 Mt or 81% of Canada's total GHG emissions (Figure 2–6). The remaining emissions were largely generated by the Agriculture (8.1%) and Industrial Processes and Product Use (IPPU) sectors (7.4%), with contributions from the Waste sector (3.8%).

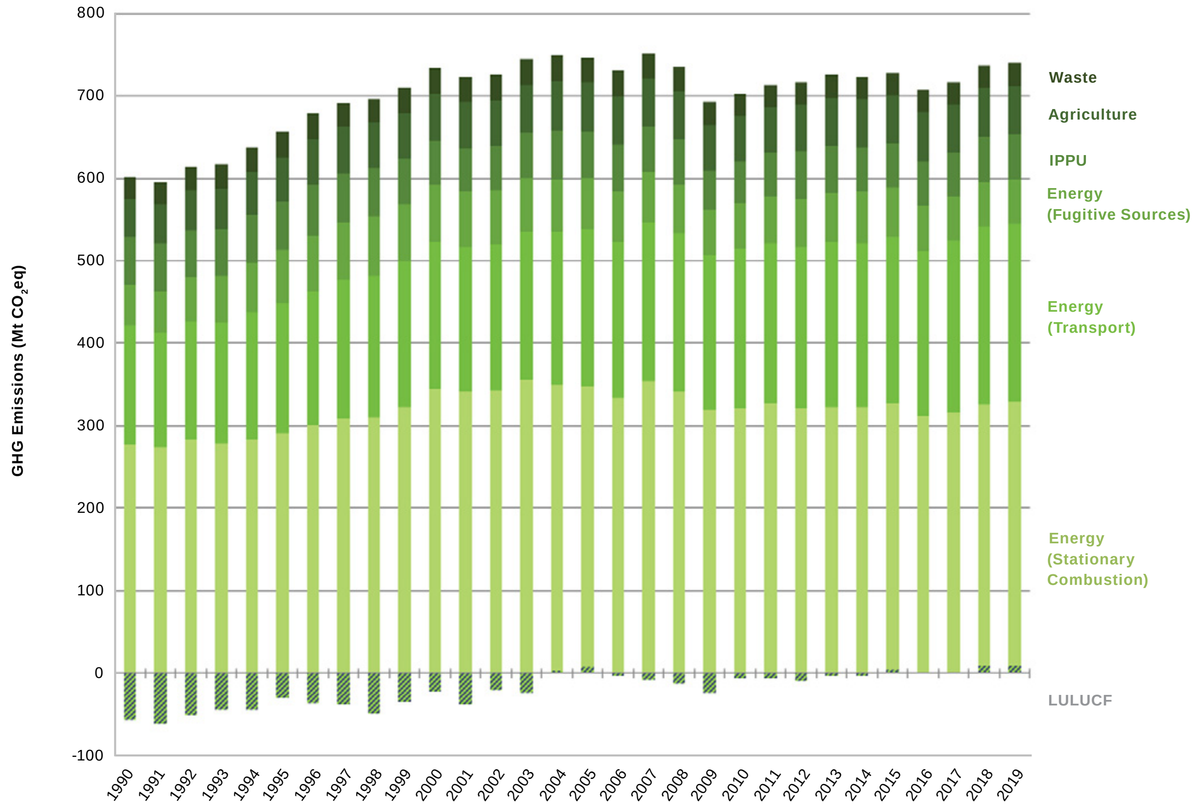
The Energy sector dominated the long-term trend over the 1990–2019 period, with increases of 72 Mt (50%) in Transport, 41 Mt (15%) in Stationary Combustion and 4.9 Mt (10%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 12 Mt (26%), while the IPPU sector saw a decrease of 2.7 Mt (4.7%). In 1990, net removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector were 57 Mt, but the net sink has declined since then and became a net source of emissions of 9.9 Mt in 2019. Over the time series the net change in LULUCF emissions and removals was 67 Mt (117%), shifting from a strong sink to a net source. Emissions in the Waste sector have increased of 1.6 Mt (6.1%) since 1990 (Figure 2–6 and Table 2–3).

Since 2005, emissions from Stationary Combustion, Fugitive Sources, Waste and IPPU have all decreased (by 22 Mt, 7.1 Mt, 3.4 Mt and 2.3 Mt, respectively), while Agriculture emissions decreased until 2011 before rebounding and remaining steady in recent years. Emissions from Transport have increased by 27 Mt since 2005 and the LULUCF sector has varied from net emissions of 8.2 Mt in 2005, to net removals of 24 Mt in 2009 and back to net emissions of 9.9 Mt in 2019, representing a net increase of 1.7 Mt between 2005 and 2019 (Figures 2–6 and 2–7).

Several emissions sources, while not major contributors to Canada's overall GHG emissions, have experienced a significant change since 1990. These include a 11 Mt (or 1176%) increase in emissions from the production and consumption of halocarbons, a 5.8 Mt (100%) increase from the non-energy use of fuels and solvents; a 1.4 Mt (121%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers; a 0.31 Mt (421%) increase in emissions from Biological Treatment of Solid Waste and a 0.17 Mt (78%) decrease in emissions from field burning of agricultural residues.

Since 2005, some of the significant changes for emissions sources which are minor contributors to the national total include a 7.3 Mt (or 143%) increase in emissions from

Figure 2–6 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (1990–2019)**



the production and consumption of halocarbons; a 1.2 Mt (85%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers; and a 1.5 Mt (69%) increase of the Agriculture and Forestry Stationary Combustion Sources. Decreases in Nitric Acid Production emissions and SF_6 Used in Magnesium Smelters and Casters, 0.95 Mt (79%) and 0.94 Mt (76%), respectively, can also be noted.

2.3.1. Energy Sector (2019 GHG emissions, 589 Mt)

In 2019, the Energy sector contributed 81% of total GHG emissions. In line with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), sources in the Energy sector are grouped under Stationary Combustion, Transport, Fugitive Sources, and CO_2 Transport and Storage. A detailed description of each category is provided in Chapter 3.

2.3.1.1. Stationary Combustion (2019 GHG Emissions, 319 Mt)

Stationary Combustion accounts for 54% of emissions from the Energy sector. In 2019, emissions totalled 319 Mt, an increase of 15% from the 1990 emissions level of 278 Mt and a decrease of 6.4% from the 2005 emissions level of 341 Mt (Figure 2–8, Table 2–4). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction and Public Electricity and Heat Production, which in 2019 contributed 33% and 22%, respectively, of the total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 13%, 13% and 11%, respectively, of total Stationary Combustion emissions in 2019.

Table 2–3 **Canada's GHG Emissions by Intergovernmental Panel on Climate Change Sector (1990–2019)**

Greenhouse Gas Categories		1990	2005	2014	2015	2016	2017	2018	2019
		Mt CO_2 equivalent							
TOTAL[a, b]		**602**	**739**	**723**	**723**	**707**	**716**	**728**	**730**
ENERGY		**472**	**591**	**584**	**585**	**566**	**578**	**588**	**589**
a.	**Stationary Combustion Sources**	**278**	**341**	**323**	**324**	**311**	**316**	**318**	**319**
	Public Electricity and Heat Production	95	125	84	87	81	78	70	69
	Petroleum Refining Industries	17	20	16	16	16	14	15	15
	Oil and Gas Extraction	31	63	95	97	94	97	104	105
	Mining	4.7	4.3	5.1	4.6	4.3	4.9	6.3	6.4
	Manufacturing Industries	56	48	45	43	42	42	42	42
	Construction	1.9	1.5	1.3	1.3	1.3	1.3	1.4	1.4
	Commercial and Institutional	26	33	31	30	30	32	33	34
	Residential	44	44	41	40	39	41	42	42
	Agriculture and Forestry	2.4	2.2	3.8	3.6	3.8	3.7	3.8	3.7
b.	**Transport**	**145**	**190**	**199**	**201**	**201**	**207**	**215**	**217**
	Aviation	7.5	7.7	7.6	7.6	7.5	7.9	8.7	8.5
	Domestic Aviation (Civil)	7.3	7.5	7.4	7.4	7.3	7.7	8.4	8.3
	Military	0.23	0.26	0.21	0.24	0.26	0.23	0.25	0.24
	Road Transportation	84	130	142	143	145	148	152	153
	Light-Duty Gasoline Vehicles	42	41	34	34	35	34	33	32
	Light-Duty Gasoline Trucks	20	38	43	45	48	49	51	53
	Heavy-Duty Gasoline Vehicles	6.3	12	12	12	13	13	13	14
	Motorcycles	0.09	0.20	0.26	0.27	0.29	0.30	0.30	0.30
	Light-Duty Diesel Vehicles	0.47	0.61	0.86	0.90	0.84	0.84	0.81	0.78
	Light-Duty Diesel Trucks	0.15	0.34	0.64	0.81	0.90	1.1	1.2	1.2
	Heavy-Duty Diesel Vehicles	14	37	50	49	47	49	52	52
	Propane and Natural Gas Vehicles	1.2	0.38	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Railways	6.9	6.6	7.5	7.1	6.5	7.5	7.6	7.7
	Marine	3.1	4.0	3.5	3.4	3.5	3.6	3.8	4.4
	Domestic Navigation	2.2	3.1	3.0	3.1	3.2	3.4	3.6	4.1
	Fishing	0.87	0.87	0.34	0.22	0.23	0.21	0.19	0.21
	Military Water-Borne Navigation	<0.05	<0.05	0.09	0.11	0.08	0.06	<0.05	0.07
	Other Transportation	44	42	39	40	39	40	43	43
	Off-Road Agriculture and Forestry	9.0	11	10	10	10	10	11	11
	Off-Road Commercial and Institutional	1.5	2.4	2.8	2.7	2.6	2.8	2.9	3.0
	Off-Road Manufacturing, Mining and Construction	9.2	10	12	13	12	14	15	14
	Off-Road Residential	0.24	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	Off-Road Other Transportation	17	6.4	4.5	4.8	4.9	5.1	5.3	5.1
	Pipeline Transport	6.9	10	7.9	8.2	8.4	7.4	8.2	8.3
c.	**Fugitive Sources**	**49**	**61**	**63**	**59**	**54**	**55**	**55**	**54**
	Coal Mining	2.8	1.4	1.3	1.1	1.3	1.2	1.3	1.4
	Oil and Natural Gas	46	60	61	58	53	54	53	52
d.	**CO_2 Transport and Storage**	-	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**57**	**54**	**53**	**54**	**53**	**54**	**54**
a.	**Mineral Products**	**8.5**	**10**	**7.8**	**8.0**	**7.9**	**8.6**	**8.7**	**8.8**
	Cement Production	5.8	7.6	5.9	6.2	6.2	6.9	7.0	7.2
	Lime Production	1.8	1.8	1.5	1.4	1.4	1.4	1.4	1.3
	Mineral Product Use	0.86	0.91	0.38	0.41	0.39	0.33	0.32	0.32
b.	**Chemical Industry**	**18**	**10**	**6.4**	**6.7**	**7.0**	**6.4**	**6.8**	**6.8**
c.	**Metal Production**	**24**	**20**	**15**	**14**	**15**	**15**	**15**	**14**
d.	**Production and Consumption of Halocarbons, SF_6 and NF3d**	**1.0**	**5.1**	**11**	**11**	**11**	**12**	**13**	**12**
e.	**Non-Energy Products from Fuels and Solvent Use**	**5.8**	**10**	**13**	**13**	**12**	**11**	**11**	**12**
f.	**Other Product Manufacture and Use**	**0.37**	**0.54**	**0.48**	**0.57**	**0.62**	**0.66**	**0.73**	**0.75**
AGRICULTURE		**47**	**60**	**58**	**58**	**59**	**58**	**59**	**59**
a.	**Enteric Fermentation**	**22**	**31**	**24**	**24**	**24**	**24**	**24**	**24**
b.	**Manure Management**	**6.1**	**8.8**	**7.7**	**7.8**	**7.9**	**7.9**	**7.9**	**7.9**
c.	**Agricultural Soils**	**17**	**19**	**23**	**24**	**25**	**24**	**25**	**24**
d.	**Field Burning of Agricultural Residues**	**0.22**	**<0.05**	**0.05**	**0.06**	**0.05**	**0.05**	**0.05**	**0.05**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**1.2**	**1.4**	**2.5**	**2.6**	**2.5**	**2.4**	**2.6**	**2.6**
WASTE		**26**	**31**	**27**	**27**	**27**	**27**	**27**	**28**
a.	**Solid Waste Disposal (Landfills)**	**21**	**25**	**22**	**22**	**22**	**22**	**23**	**23**
b.	**Biological Treatment of Solid Waste**	**0.07**	**0.24**	**0.31**	**0.31**	**0.31**	**0.32**	**0.37**	**0.38**
c.	**Wastewater Treatment and Discharge**	**0.83**	**0.94**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
d.	**Incineration and Open Burning of Waste**	**0.27**	**0.34**	**0.17**	**0.20**	**0.20**	**0.19**	**0.18**	**0.19**
e.	**Industrial Wood Waste Landfills**	**3.8**	**4.4**	**3.5**	**3.4**	**3.3**	**3.2**	**3.1**	**3.0**
LAND USE, LAND-USE CHANGE AND FORESTRY		**-57**	**8.2**	**-3.5**	**4.0**	**0.10**	**0.70**	**8.4**	**9.9**
a.	**Forest Land**	**-202**	**-134**	**-141**	**-134**	**-136**	**-136**	**-133**	**-133**
b.	**Cropland**	**7.6**	**-10**	**-8.1**	**-7.0**	**-6.3**	**-5.7**	**-4.8**	**-4.2**
c.	**Grassland**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
d.	**Wetlands**	**5.3**	**3.1**	**3.1**	**2.9**	**2.9**	**3.0**	**2.7**	**2.6**
e.	**Settlements**	**1.8**	**1.7**	**2.3**	**2.6**	**2.4**	**2.2**	**2.4**	**2.2**
f.	**Harvested Wood Products**	**130**	**148**	**140**	**139**	**137**	**137**	**141**	**143**

Notes:
Totals may not add up due to rounding.
a. National totals calculated in this table do not include removals reported in LULUCF.
b. This summary data is presented in more detail at open.canada.ca.

Figure 2–7 **Changes in GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2019)**

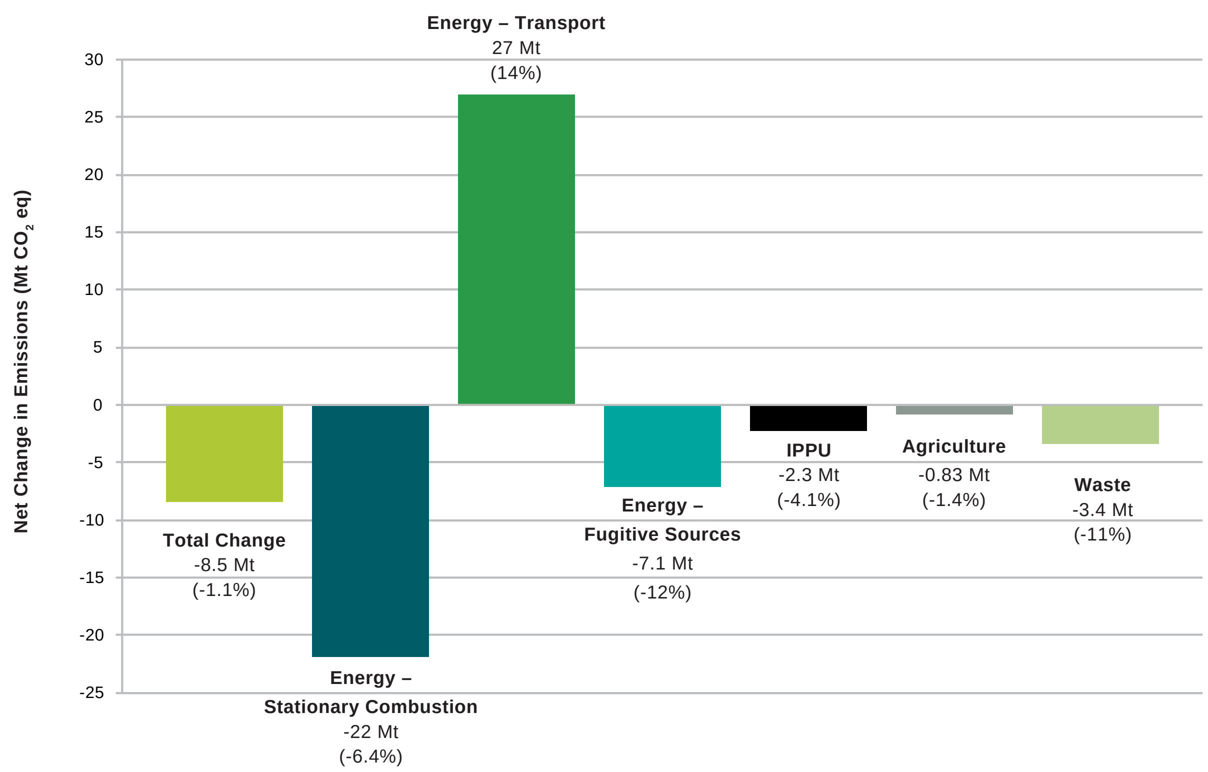
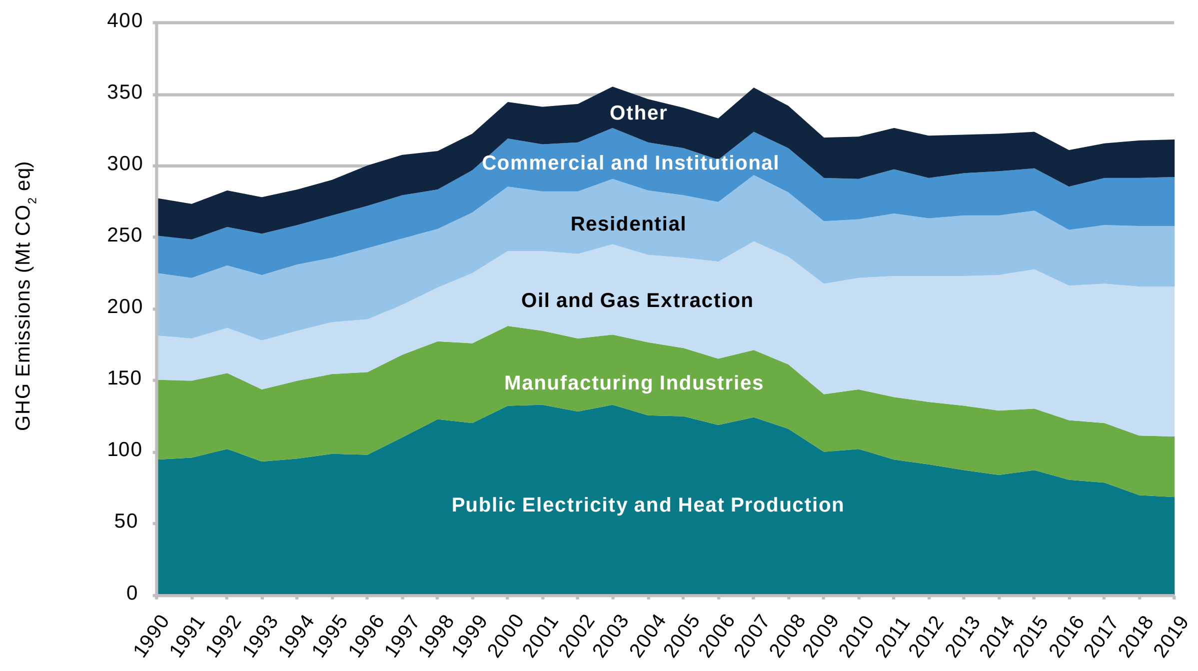


Table 2–4 **GHG Emissions from Stationary Combustion Sources, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)	
GHG Source Category	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Stationary Combustion Sources	**278**	**341**	**323**	**324**	**311**	**316**	**318**	**319**	**15%**	**-6%**
Public Electricity and Heat Production	**95**	**125**	**84**	**87**	**81**	**78**	**70**	**69**	**-27%**	**-45%**
Petroleum Refining	**17**	**20**	**16**	**16**	**16**	**14**	**15**	**15**	**-15%**	**-27%**
Oil and Gas Extraction	**31**	**63**	**95**	**97**	**94**	**97**	**104**	**105**	**241%**	**66%**
Mining	**4.7**	**4.3**	**5.1**	**4.6**	**4.3**	**4.9**	**6.3**	**6.4**	**38%**	**48%**
Manufacturing Industries	**56**	**48**	**45**	**43**	**42**	**42**	**42**	**42**	**-25%**	**-12%**
Iron and Steel	4.9	5.6	6.0	5.7	5.6	5.9	6.3	6.0	21%	7%
Non-Ferrous Metals	3.3	3.7	2.9	3.1	3.2	3.2	2.8	2.8	-14%	-23%
Chemicals	8.3	8.3	12	12	11	10	9	9	14%	13%
Pulp, Paper and Print	14	8.7	6.1	6.0	5.9	6.3	7.0	7.3	-50%	-16%
Cement	4.0	5.4	4.0	3.9	3.9	4.1	4.2	4.2	6%	-22%
Other Manufacturing	21	16	14	13	13	13	12	13	-41%	-23%
Construction	**1.9**	**1.5**	**1.3**	**1.3**	**1.3**	**1.3**	**1.4**	**1.4**	**-28%**	**-6%**
Commercial and Institutional	**26**	**33**	**31**	**30**	**30**	**32**	**33**	**34**	**31%**	**5%**
Residential	**44**	**44**	**41**	**40**	**39**	**41**	**42**	**42**	**-4%**	**-3%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.8**	**3.6**	**3.8**	**3.7**	**3.8**	**3.7**	**53%**	**69%**

Note: Totals may not add up due to rounding.

Figure 2–8 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2019)**



Note: "Other" includes Petroleum Refining, Construction, Mining, Agriculture and Forestry

Public Electricity and Heat Production (2019 GHG emissions, 69 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 27% between 1990 and 2019.

Emissions from this category vary with the characteristics of an instantaneous demand and with fluctuations between low-GHG-emitting and high-GHG-emitting supply sources. Between 1990 and 2019, electricity generation (driven by demand) increased by 34% (StatCan, 1991–2020), from 474 TWh[3] to 633 TWh. Despite the increasing demand over this period, GHG emissions dropped by 27% (26 Mt) between 1990 and 2019. Likewise, between 2005 and 2019 electricity generation rose by 5%, while corresponding emissions fell by 45% (56 Mt). Over both time periods, the principal cause of the decrease in emissions is a considerably less GHG-intensive mix of sources used to generate electricity (Figure 2–9).

Low-emitting non-combustion sources—hydroelectric generation, nuclear power, wind turbines, solar photovoltaic cells and tidal power—accounted for 91% of the increased generation between 1990 and 2019, and for 83% of the total electricity generated in Canada in 2019. Hydroelectric generation alone accounted for 60%, with nuclear following at 17% and non-hydro-based renewables at 6%. The increased level of non-combustion sources in the generation mix in 2019 was the largest contributor to emission reductions since 1990 (23 Mt) and 2005 (36 Mt) (Figure 2–10).

In addition, the fuel mix used for combustion generation has been steadily moving to less GHG-intensive fossil fuels. Between 2005 and 2019, the quantity of electricity generated by natural gas–fired units increased by 55% (16 TWh), while the amount generated by coal and refined petroleum products decreased by about 53% (49 TWh) and 78% (8.4 TWh), respectively. Natural gas combustion is about half as carbon-intensive as coal and approximately 25% less carbon-intensive than most refined petroleum products. The overall impact of the displacement of coal and refined petroleum products by natural gas is a decrease of about 16 Mt between 1990 and 2019, and about 11 Mt between 2005 and 2019.

The efficiency of combustion equipment has also played a role in the GHG emissions reductions. Energy efficiency improvements resulted in an approximately 5.6 Mt reduction in GHG emissions between 1990 and 2019 and an 11 Mt reduction between 2005 and 2019.

3 1 TWh is 1 billion kWh. It is the amount of electricity consumed by about 90,000 households in Canada in approximately one year.

Figure 2–9 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2019 (Mt CO_2 eq)**

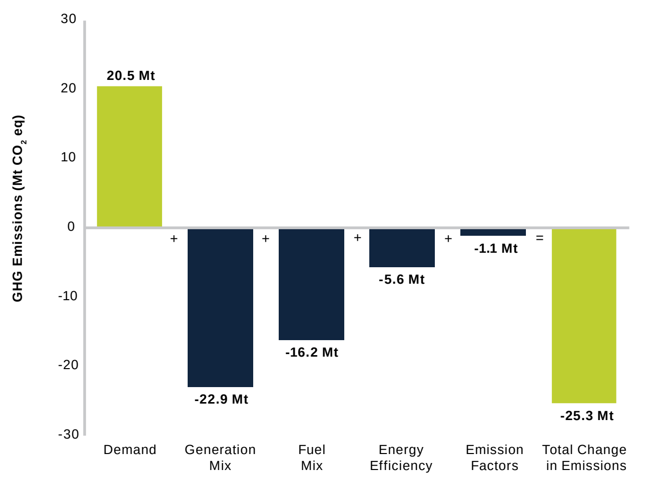
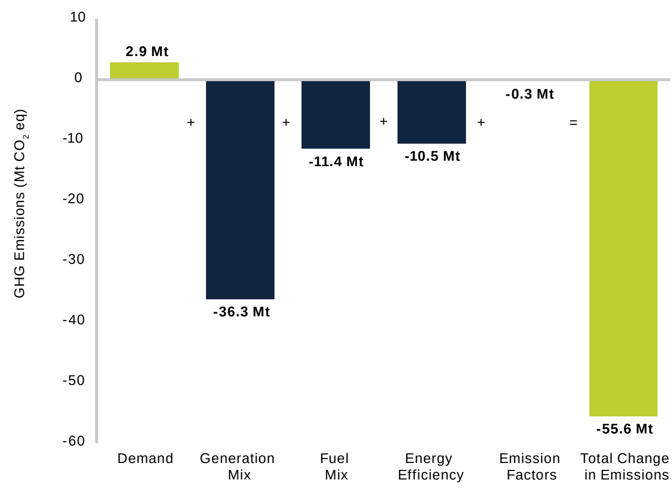


Figure 2–10 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2019 (Mt CO_2 eq)**



Notes:

Demand – Demand refers to the level of electricity generation activity in the utility sector and consists of generation from combustion and non-combustion sources.

Generation mix – The generation mix refers to the relative share of combustion and non-combustion sources in generation activity.

Fuel mix (combustion generation) – Fuel mix refers to the relative share of each fuel used to generate electricity.

Energy efficiency – Energy efficiency refers to the efficiency of the equipment used in combustion-related generation of electricity.

Emission factors – The emission factor effect reflects changes to where fuels are sourced and their energy content over time.

Oil and Gas Extraction (2019 GHG emissions, 105 Mt)

Stationary combustion emissions from Oil and Gas Extraction increased by 74 Mt (240%) between 1990 and 2019 and by 42 Mt (66%) between 2005 and 2019. This category includes emissions associated with fuel combustion from Natural Gas Production and Processing, Conventional Oil Production and Oil Sands Mining, Extraction and Upgrading. Increases in emissions are consistent with a 172% increase in the production of crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, 2020; Husky, 2020) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

In the oil sands industry, the steam-assisted gravity drainage (SAGD) process used to extract crude bitumen involves injecting large amounts of steam into the producing formation. The steam is generally produced by combusting natural gas, resulting in emissions. Since 2005, total natural gas consumption in the Oil and Gas Extraction category has increased by approximately 92% (StatCan, 1991–2020), and SAGD production has increased by almost 1300% (AER, 2020). In general, while increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 280% increase in the production of non-upgraded bitumen in Canada's oil sands area, particularly in SAGD production. In contrast, since 2005, natural gas production has decreased by 8% (StatCan, 1991–2020) and conventional oil production by 4% (StatCan, n.d.[c], n.d.[d]).

Additional information about the Oil and Gas Extraction category is provided in Table 2–12, where emissions are broken down by economic sectors (Natural Gas Production and Processing, Conventional Oil Production and Oil Sands). A short discussion of trends in the oil and gas industry by economic sector is also presented in section 2.4.1.

Manufacturing Industries (2019 GHG emissions, 42 Mt)

Combustion-based GHG emissions from the Manufacturing Industries category include the combustion of fossil fuels by the Iron and Steel; Non-Ferrous Metals; Chemicals; Cement; Pulp, Paper and Print; and Other Manufacturing subcategories.

In 2019, GHG emissions from the Manufacturing Industries category were 42 Mt, which represents a 25% decrease from 1990 and a 12% decrease since 2005.

Within the Manufacturing Industries category, the Other Manufacturing and Pulp, Paper and Print subcategories showed the largest emissions decreases. Emissions from the Other Manufacturing subcategory decreased by 8.6 Mt (41%) between 1990 and 2019, in keeping with a 16% decrease in fuel combustion. Between 1990 and 2019, the Pulp, Paper and Print subcategory decreased by 7.2 Mt (50%), based on a 15% reduction in fuel combustion. In contrast, combustion emissions from chemical industries showed the largest increase in emissions within the category, increasing by 1.2 Mt (14%). This is generally consistent with a 28%[4] growth in the production of chemicals between 1990 and 2019.

Residential, Commercial and Institutional (2019 GHG emissions, 77 Mt)

GHG emissions in the Residential and Commercial and Institutional subcategories come from the combustion of fuels such as natural gas, home heating oil and biomass fuels (non-CO_2 only), primarily to heat residential, commercial and institutional buildings. Emissions in these categories contributed about 77 Mt of GHG emissions in 2019, a 9.5% increase since 1990.

Overall, residential emissions decreased by 1.6 Mt (3.5%) between 1990 and 2019, and 1.5 Mt (3.4%) between 2005 and 2019. Commercial and Institutional emissions increased by 8.2 Mt (31%) between 1990 and 2019, while showing a 1.7 Mt (5.4%) increase between 2005 and 2019. Changes in energy efficiency, new home construction and increases in commercial floor space are the major factors that influenced the changes in energy-related emissions in the Residential and Commercial and Institutional subcategories (Figure 2–11 and Figure 2–12).

In the Residential subcategory, population and floor space per capita are the most significant upward drivers of emissions. Since 1990, the 36% increase in population accounts for an emissions increase of 13 Mt, while a 31%[5] increase in floor space per capita accounts for an emissions increase of 11.4 Mt (Figure 2–11). The sum of these two drivers, i.e., 24.1 Mt, represents the total impact of floor space. These increases have been more than offset by improvements in energy efficiency, which are equivalent to a 22.7 Mt decrease in emissions between 1990 and 2019. It should be noted that this pattern of increasing population and floor space per capita being offset by improvements in energy efficiency can also be demonstrated between 2005 and 2019.

4 Griffin B. 2021. Personal communication (email from Griffin B. to Kay J., Physical Scientist, PIRD, dated January 22, 2021). Canadian Energy and Emissions Data Centre.

5 Wang, J. 2020. Personal communication (email from Wang, J. to Tracey K., Senior Program Engineer, PIRD, dated December 07, 2020). Office of Energy Efficiency, Natural Resources Canada.

Figure 2–11 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Subcategory between 1990 and 2019**

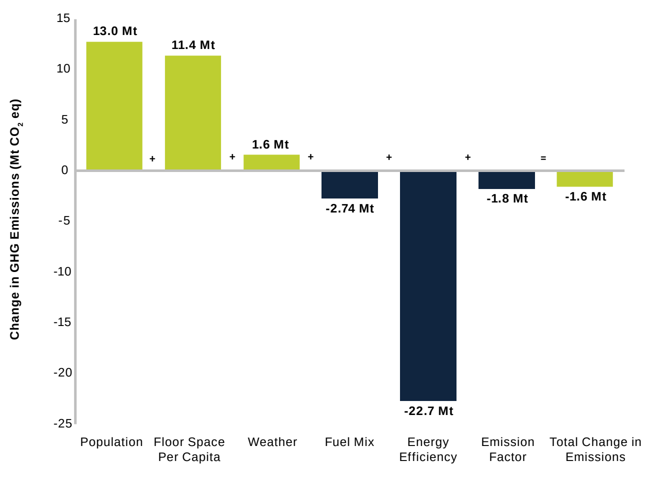
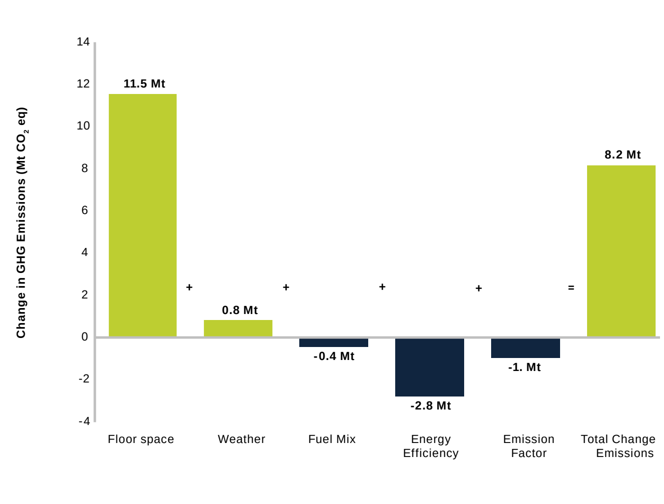


Figure 2–12 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Subcategory between 1990 and 2019**



Notes:

Floor space and population – Floor space refers to the change in total floor area over time. In the case of the residential sector, floor space is further broken down into the change in population and the change in floor space per capita.

Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

Fuel mix – Fuel mix refers to the relative share of each fuel used to provide heating.

Energy efficiency – Energy efficiency refers to the efficiency of the buildings and heating equipment.

Emission factors – The emission factor effect reflects changes to where fuels are sourced and their energy content over time.

In the long term, floor space was the most significant upward driver of emissions in the Commercial and Institutional subcategory, having increased by 49% since 1990.[6] The resulting 11.5 Mt increase in emissions was partially offset by improvements in energy efficiency, equivalent to a 2.8 Mt decrease in GHG emissions (Figure 2–12). A similar offsetting pattern applied over the last decade, which saw emissions fluctuating, but remaining in the area of 30 Mt.

Weather patterns can have a non-negligible effect on emissions when comparing one year with another, as suggested by the close tracking between heating degree-days (HDDs) and GHG emissions (Figure 2–13). The influence that weather can have on space heating requirements and demand for fuels results in emission patterns that mirror inter-annual weather variability.

Other Stationary Combustion Sources (2019 GHG emissions, 26 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining, Mining, Construction, and Agriculture and Forestry subcategories. Of this group, the Mining Industry exhibited increases in emissions of 38% (1.8 Mt), while Petroleum Refining emissions have fallen by about 2.7 Mt (15%) since 1990. The Agriculture and Forestry subcategory exhibited increases in GHG emissions of 53% (1.3 Mt) from 1990 to 2019. The Construction subcategory exhibited decreases in GHG emissions of 28% (0.52 Mt) from 1990 to 2019.

2.3.1.2. Transport (2019 GHG emissions, 217 Mt)

Transport is a large and diverse sector, accounting for 217 Mt of GHG emissions or 37% of Canada's Energy sector emissions in 2019. Transport includes emissions from fuel combustion in six categories: Road Transportation, Aviation, Marine, Railways, Other Transportation (Off-road) and Pipeline Transport (Table 2–5). From 1990 to 2019, Transport emissions rose by 50% (72 Mt), accounting for a significant portion of Canada's emissions growth.

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles (Figure 2–14). Off-road is the second largest subcategory, accounting for 16% of Transport emissions, mainly through diesel fuel combustion. The Aviation, Marine and Railways categories combined contributed to approximately 10% of the Transport emissions in 2019 and, overall, have been stable over the 1990–2019 time series.

6 Kaymak, D. 2020. Personal communication (email from Kaymak D. to Tracey K., Program Engineer, PIRD, dated December 08, 2020). Economic Analysis Directorate, Environment and Climate Change Canada.

Table 2–5 **GHG Emissions from Transport, Selected Years**

CRF Code		GHG Emissions Mt CO_2 eq								Change (%)	
		1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
1.A.3	**Transport**	**145**	**190**	**199**	**201**	**201**	**207**	**215**	**217**	**50%**	**14%**
	Aviation	**7.5**	**7.7**	**7.6**	**7.6**	**7.5**	**7.9**	**8.7**	**8.5**	**14%**	**11%**
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	7.4	7.4	7.3	7.7	8.4	8.3	14%	11%
1.A.5.b	Military	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.2	3%	-7%
	Road Transportation	**84**	**130**	**142**	**143**	**145**	**148**	**152**	**153**	**83%**	**18%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	42	41	34	34	35	34	33	32	-22%	-22%
1.A.3.b.ii	Light-Duty Gasoline Trucks	20	38	43	45	48	49	51	53	161%	39%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	6.3	12	12	12	13	13	13	14	114%	16%
1.A.3.b.iv	Motorcycles	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	232%	47%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.5	0.6	0.9	0.9	0.8	0.8	0.8	0.8	67%	29%
1.A.3.b.ii	Light-Duty Diesel Trucks	0.2	0.3	0.6	0.8	0.9	1.1	1.2	1.2	686%	251%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	14	37	50	49	47	49	52	52	280%	41%
1.A.3.b.v	Propane and Natural Gas Vehicles	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	-99%	-97%
1.A.3.c	**Railways**	**6.9**	**6.6**	**7.5**	**7.1**	**6.5**	**7.5**	**7.6**	**7.7**	**11%**	**17%**
	Marine	**3.1**	**4.0**	**3.5**	**3.4**	**3.5**	**3.6**	**3.8**	**4.4**	**42%**	**10%**
1.A.3.d	Domestic Navigation	2.2	3.1	3.0	3.1	3.2	3.4	3.6	4.1	87%	32%
1.A.4.c.iii	Fishing	0.9	0.9	0.3	0.2	0.2	0.2	0.2	0.2	-75%	-75%
1.A.5.b	Military Water-Borne Navigation	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1	163%	176%
	Other Transportation	**44**	**42**	**39**	**40**	**39**	**40**	**43**	**43**	**-1%**	**3%**
1.A.4.c.ii	Off-Road Agriculture and Forestry	9.0	11	10	10	9.7	10	11	11	24%	-1%
1.A.4.a.ii	Off-Road Commercial and Institutional	1.5	2.4	2.8	2.7	2.6	2.8	2.9	3.0	94%	23%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	9.2	10	12	13	12	14	15	14	56%	38%
1.A.4.b.ii	Off-Road Residential	0.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	417%	0%
1.A.3.e.ii	Off-Road Other Transportation	17	6.4	4.5	4.8	4.9	5.1	5.3	5.1	-70%	-21%
1.A.3.e.i	Pipeline Transport	6.9	10	7.9	8.2	8.4	7.4	8.2	8.3	20%	-18%

Figure 2–13 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and Commercial and Institutional Subcategories, 1990–2019**

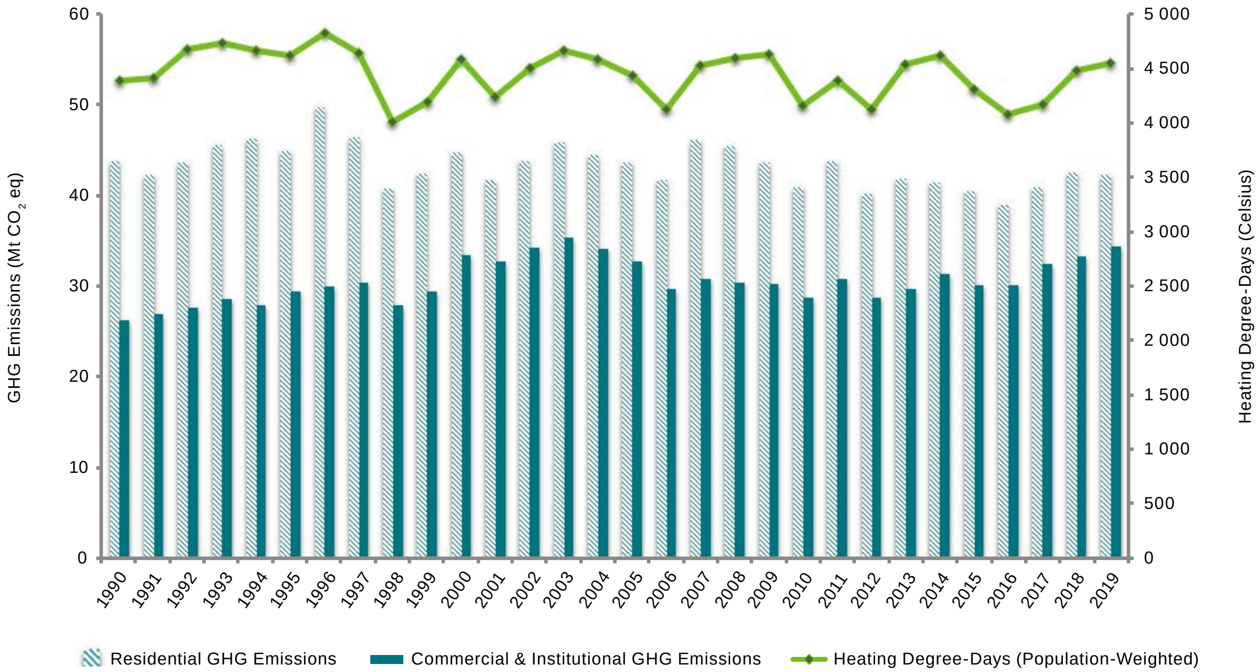
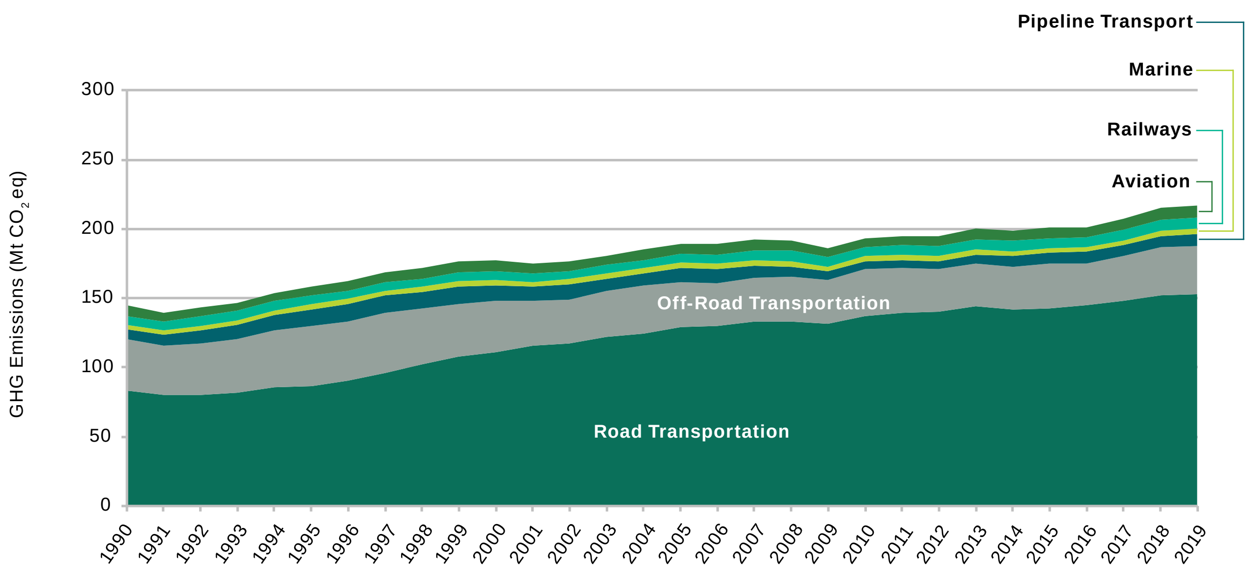


Figure 2–14 **Trends in Canadian GHG Emissions from Transport (1990–2019)**



Road Transportation (2019 GHG emissions, 153 Mt)

The growth in Road Transportation emissions is largely due to more driving as measured in vehicle kilometres travelled in both the light- and heavy-duty subclasses. The total vehicle fleet has increased by 85% since 1990 (42% since 2005) most notably for light-duty trucks and heavy-duty vehicles (Table 2–6). The vehicle fleet grew steadily for most vehicle sectors due to population and economic factors. Absolute growth in vehicles was greater in 2005–2019 compared with the 1990–2005 interval. Since 2005, the overall fleet expansion explains the 26% increase in the total kilometres travelled for the light-duty vehicle fleet, despite a reduction in kilometres driven per vehicle. While no emissions were reported for electric vehicles in the transportation sector, approximately 24 000 fully electric vehicles were in the vehicle fleet in 2019.

Light-Duty Gasoline Vehicles (2019 GHG emissions, 32 Mt)

Total light-duty vehicle emissions are influenced by several factors, including total vehicle kilometres travelled, vehicle type, fuel efficiency, fuel type, emissions control technology and biofuel consumption. Within this category, emissions in 1990 and 2005 are relatively the same, with emissions in 2005 being only 0.4% (167 kt) less than emissions in 1990. This similarity is the net result of the total number of light-duty gasoline vehicles and total kilometres travelled having increased, while the fleet average fuel consumption ratio having decreased between 1990 and 2005. This offsetting is more apparent when comparing emissions in 2005 to emissions in 2019. While the total number of light-duty gasoline vehicles and total kilometres travelled in 2019 increased relative to 2005, the continued decrease in the fleet average fuel consumption ratio resulted in a net 22% (9 Mt) decrease. As new model year vehicles replace older, less efficient vehicles, the overall fleet fuel efficiency improves. This gradual improvement in efficiency offsets emissions increases resulting from increased total kilometres travelled and shifts in vehicle type (Figure 2–15). Implementation of emission control technologies and increased use of biofuels since the 1990s have also resulted in decreased emissions.

Light-Duty Gasoline Trucks (2019 GHG emissions, 53 Mt)

On average, light-duty trucks—including sport utility vehicles (SUVs), many pickups and all minivans—emitted 31% more GHGs per kilometre than cars in 2019. Emissions from Light-Duty Gasoline Trucks in 2019 have increased by 161% (33 Mt) relative to 1990 and 39% (15 Mt) relative to 2005. While a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2019, this was offset by an increase in both vehicle population and associated total kilometres travelled, reflecting the trend towards the increasing use of SUVs, minivans and pickups for personal transportation.

Heavy-Duty Diesel Vehicles (2019 GHG emissions, 52 Mt)

In 2019, emissions from Heavy-Duty Diesel Vehicles contributed 52 Mt to Canada's total GHG emissions (an increase of about 280% from 1990 and 41% from 2005). The trends in data from major for-hire truck haulers in Canada show that freight hauling by heavy trucks has increased substantially over time and that this activity is the primary task performed by heavy-duty vehicles (StatCan, n.d.[e]). Further, the adoption of "just-in-time" delivery by many businesses has resulted in reliance on heavy trucks in the freight transportation sector, which sometimes act as virtual warehouses (NRCan, 2013).

Other Transportation (Off-Road) (2019 GHG emissions, 35 Mt)

Off-road emissions result from the combustion of diesel and gasoline in a wide variety of applications, including heavy mobile equipment used in the construction,

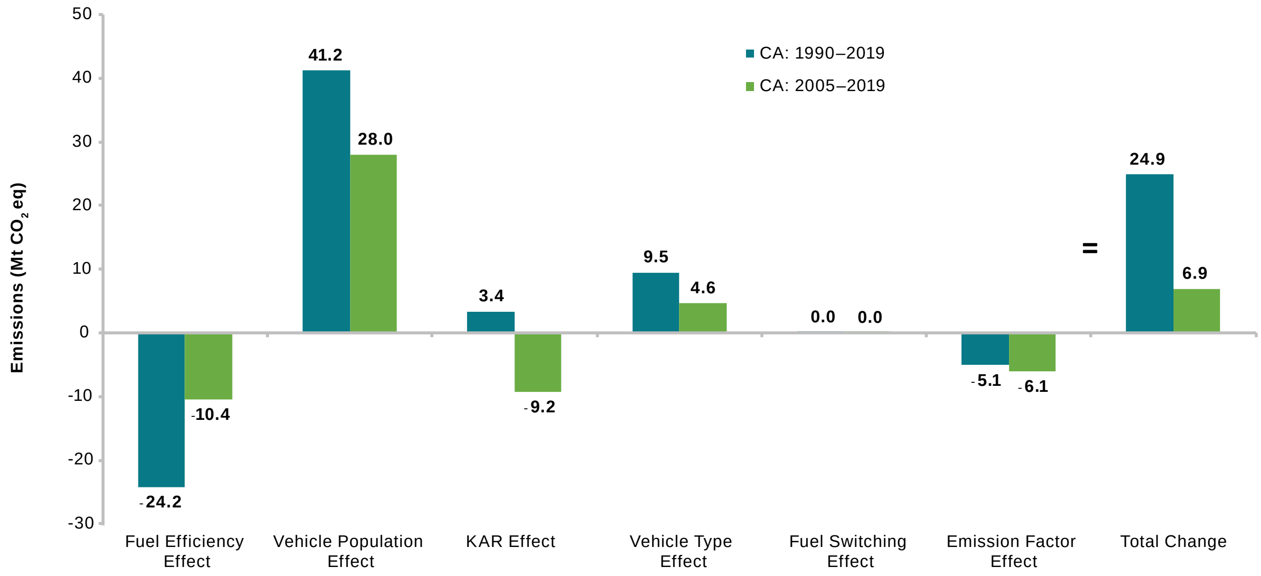
Table 2–6 **Trends in Vehicle Populations for Canada, 1990–2019**

Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 759	3 392	908	15 410
2005	11 009	6 920	1 618	20 061
2014	12 570	11 003	2 303	26 657
2015	12 860	11 783	2 304	27 751
2016	12 376	12 035	2 379	27 611
2017	11 916	12 299	2 459	27 509
2018	11 793	12 879	2 534	28 053
2019	11 610	13 426	2 571	28 461
Change since 1990	8%	296%	183%	85%
Change since 2005	5%	94%	59%	42%

Notes:

Light-duty trucks include most pickups, minivans and sport utility vehicles.
All vehicles also include motorcycles and natural gas and propane vehicles.

Figure 2–15 **Factors Contributing to Change in Light-Duty Vehicle Emissions, 1990–2019 and 2005–2019**



Notes:

Fuel economy, fuel efficiency and fuel consumption ratios are all metrics which describe the efficacy with which a vehicle can obtain energy from fuel, typically presented in either the volume of fuel needed to move a vehicle a prescribed distance (litres/100 km) or the distance a vehicle can travel for a prescribed amount of fuel (miles per gallon - mpg).

Kilometre accumulation rate (KAR) is the average distance travelled by a single vehicle of a given class typically measured over one year, while vehicle kilometres travelled is the total distance travelled by all vehicles of a given class (KAR multiplied by the vehicle population in that class) over that same period.

Total change is the difference in total emissions over the selected time periods, 1990–2019 and 2005–2019.

Fuel efficiency effect refers to the change in emissions due to the change in fuel consumption ratios (expressed as litres/100 km).

Vehicle population effect refers to the change in emissions attributable to the change in the total number of light cars and trucks on Canadian roads.

Kilometre accumulation (KAR) effect refers to the change in emissions due to average annual driving rates.

Vehicle type effect refers to the change in emissions due to the shift between different vehicle types (e.g. cars and trucks).

Fuel switching effect refers to the change in emissions due to the shift between fuels (e.g. motor gasoline vs. diesel fuel).

Overall emission factor effect refers to the change in emissions from emission control technologies on CH_4 and N_2O emissions as well as the use of biofuels.

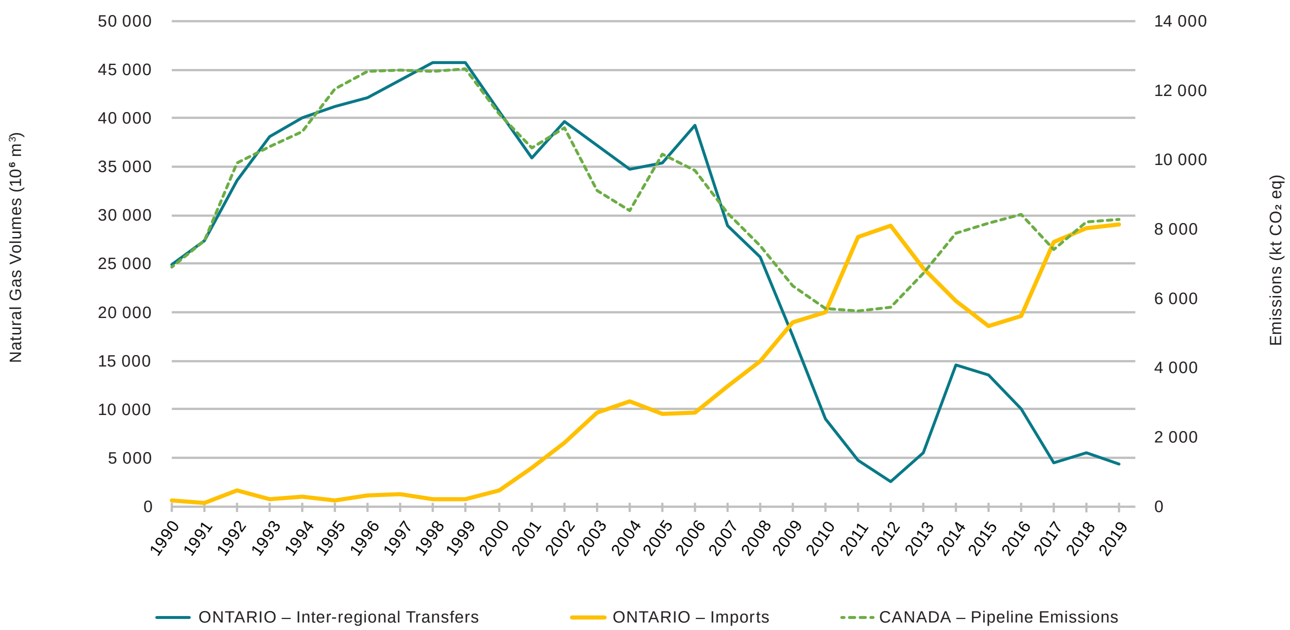
mining and logging industries; agricultural tractors and combines; recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment such as lawnmowers and trimmers. In 2019, off-road manufacturing, mining and construction and off-road agriculture and forestry account for 41% and 32% of off-road emissions, respectively. The net emissions for the whole off-road subcategory have decreased by 5% since 1990 and increased by 9% since 2005.

Other Transportation (Pipeline Transport) (2019 GHG emissions, 8.3 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2019, over 99% of marketable natural gas production occurred in Western Canada: Alberta (69.4%), British Columbia (27.1%) and Saskatchewan (2.9%). While these provinces account for 64% of marketable natural gas consumption, Ontario, the most populous province, accounts for approximately 26% of natural gas consumption but produces less than 0.05% of natural gas (StatCan, 1991–2020). The natural gas demand in Ontario, along with the geographical separation from producing regions, necessitates the long-range transport of natural gas through transmission pipelines. For that reason, the source of the natural gas consumed in Ontario has a large impact on pipeline emissions.

Historically, inter-regional transfers of large quantities of Western Canadian natural gas to Eastern Canada, especially Ontario, has been the main driver in pipeline emissions. The amount of gas transported from west to east has decreased somewhat since 1990. The decrease started in the early 2000s as Western Canadian natural gas was displaced by shale gas imports from the United States (StatCan, 1991–2020) and as more natural gas was consumed in Alberta's Oil Sands industry. In general, as imports into Ontario increase, inter-regional transfers of Western gas decrease, resulting in a decrease in combustion emissions from pipelines (Figure 2–16).

Figure 2–16 **Relationship between Canadian Pipeline Emissions, US Imports into Ontario and Inter-Regional Transfers of Western Canadian Natural Gas**



2.3.1.3. Fugitive Sources (2019 GHG Emissions, 54 Mt)

Fugitive emissions are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels. Released hydrocarbon gases that are disposed of by combustion (e.g. flaring of natural gases at oil and gas production and processing facilities) and post-production emissions, including those from abandoned coal mines and abandoned oil and gas wells, are also considered fugitive emissions. Fugitive Sources are broken down into two main categories: Oil and Natural Gas (97% of fugitive emissions) and Coal Mining (3%).

Overall, fugitive emissions increased from 49 to 54 Mt (10%) between 1990 and 2019 (Table 2–7), contributing 3.8% to the growth in total Canadian emissions between 1990 and 2019. Fugitive emissions from Oil and Natural Gas alone increased by 6 Mt (14%), while releases from Coal Mining decreased by 1.4 Mt (51%), mainly due to mine closures in Eastern Canada.

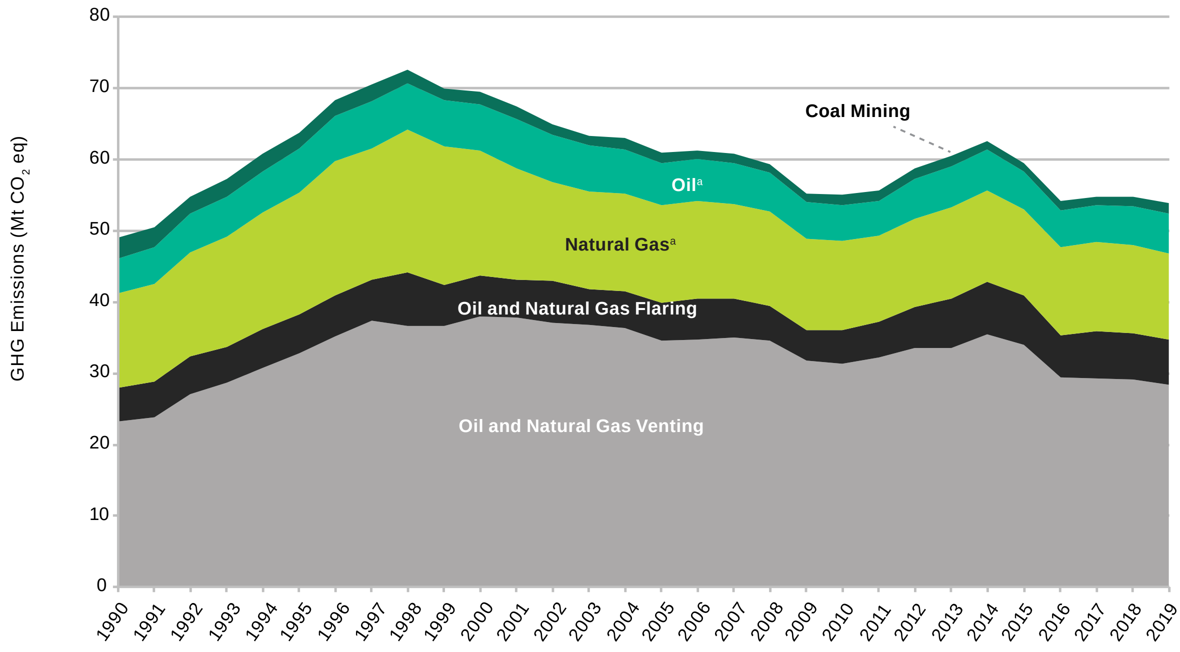
The 14% growth in Oil and Natural Gas fugitive emissions since 1990 (Figure 2–17) is a result of increased activity in the Oil and Gas sector. Since 1990, over 408,000 oil and gas wells have been drilled, and the number of producing oil and gas wells has increased by 180% (CAPP, 2020). As the number of facilities in the oil and gas industry have become more abundant and disperse, the sources of fugitive emissions have increased significantly.

Even though production from the oil sands accounted for approximately 70% of total oil production in Canada in 2019, it accounted for only 20% of total oil and gas fugitive emissions. Since the vast majority of fugitive emissions originate from conventional wells, the increase in bitumen production from the oil sands has little impact on fugitive emissions.

Fugitive emissions peaked in the late 1990s (Figure 2–17); until 2010, the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and regulations resulted in a decreasing trend in emissions. For example, in 1999 the province of Alberta introduced *Directive 060* regulations to reduce flaring and venting emissions from its oil industry by requiring operators to connect to gas gathering systems under specific conditions (AER, 2014). In 2006, leak detection and repair best management practices were added to *Directive 060* to reduce emissions from fugitive equipment leaks. Between 2000 and 2010, these measures contributed to a reduction in fugitive emissions of 8.0 Mt (19%) in Alberta.

In 2010, British Columbia introduced the *Flaring and Venting Reduction Guideline* (BCOGC, 2015), and in 2012, Saskatchewan adopted the *Saskatchewan Upstream Petroleum Industry Associated Gas Conservation Standards* (Directive S-10), both of which are similar to *Directive 060*.

Figure 2–17 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2019)**



Note:
a. These categories represent fugitive releases due to leakage from oil and natural gas systems.

Table 2–7 **GHG Emissions from Fugitive Sources, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Fugitive Sources[a]	**49**	**61**	**63**	**59**	**54**	**55**	**55**	**54**	**10%**	**-12%**
Coal Mining	**2.8**	**1.4**	**1.3**	**1.1**	**1.3**	**1.2**	**1.3**	**1.4**	**-51%**	**0%**
Oil and Natural Gas	**46**	**60**	**61**	**58**	**53**	**54**	**53**	**52**	**14%**	**-12%**
Oil[b]	5.0	5.9	5.6	5.4	5.2	5.2	5.5	5.6	12%	-6%
Natural Gas[b]	13	14	13	12	12	12	12	12	-8%	-12%
Venting	23	35	36	34	29	29	29	28	22%	-18%
Flaring	4.7	5.3	7.3	6.9	5.9	6.6	6.6	6.3	34%	19%

Notes:
a. Totals may not add up due to rounding.
b. These categories represent fugitive releases due to leakage from oil and natural gas systems.

In spite of these efforts, emissions from venting and flaring increased by 6.7 Mt (19%) between 2010 and 2014. Oil producers are only required to connect associated gas production to gas gathering systems beyond specific production volumes and economic indicators. Smaller and more disperse facilities along with low natural gas prices resulted in more associated gas being vented and flared.

From 2014 to 2016, emissions dropped by 7.5 Mt (18%), mainly due to reductions in venting and flaring. Since 2016, emissions have been fairly consistent.

Fluctuations in fugitive emissions since 2012 demonstrate the contrasting effects of better industry practices versus production activity. Although technological improvements and regulations have had a positive effect on emission reductions, they are affected by economics and can be overshadowed by the impacts of changing industry activity (i.e. production, drilling, number of active facilities, etc.), which is the primary driver of emission growth.

2.3.1.4. Trends in CO_2 Transport and Storage

In 2016, CO_2 Capture, Transport and Storage began in Alberta for the purpose of long-term geological storage, where the Quest project captures CO_2 from Shell's Scotford upgrader and transports it 65 kilometres north to a permanent storage site.

All other current and previous CO_2 Transport and Storage in Canada are associated with enhanced oil recovery operations at Weyburn, Saskatchewan. Beginning in 2014, most of the CO_2 captured at the Boundary Dam coal-fired power plant in Saskatchewan was also transported to Weyburn for enhanced oil recovery.

Details of CO_2 capture volumes are presented in Table A10-3 (Annex 10). Consistent with the origin of the captured CO_2 (an upgrading facility and coal power plant), these volumes are subtracted from emissions reported under Mining and Upstream Oil and Gas Production, and Public Electricity and Heat Production, in Alberta and Saskatchewan, respectively.

Emissions from CO_2 transport systems are presented in the annual GHG Emission Summary tables for Canada in Annex 9 and by provincial/territorial regions in Annex 11 of this report.

2.3.2. Industrial Processes and Product Use (2019 GHG emissions, 54 Mt)

The IPPU sector includes GHG emissions that result from manufacturing processes and use of products. Subsectors include Mineral Products; the Chemical Industry; Metal Production; Production and Consumption of Halocarbons, SF_6 and NF_3; Non-Energy Products from Fuels and Solvent Use; and Other Product Manufacture and Use. Emissions from the IPPU sector contributed 54 Mt (7.4%) to Canada's 2019 emissions, compared with 57 Mt (7.7%) in 2005, a decrease of approximately 2.3 Mt or 4.1%. Total emissions in this sector result from activities in several diverse industries; trends in emissions reflect the combined effects of multiple drivers on various industries.

Emission reductions have occurred in Adipic Acid Production (N_2O), Aluminium Production (PFCs), Use of SF_6 in Magnesium Production (SF_6), Iron and Steel Production (CO_2), and Nitric Acid Production (N_2O) since 2005. These reductions were mainly offset by increases observed in Non-Energy Products from Fuels and Solvent Use (CO_2),[7] and Production and Consumption of Halocarbons, SF_6 and NF_3 (HFCs) (Figure 2–18 and Table 2–8). In 2019, the largest contributions to emissions

7 Non-Energy Products from Fuels and Solvent Use includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other categories of the IPPU Sector.

Figure 2–18 **Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2019)**

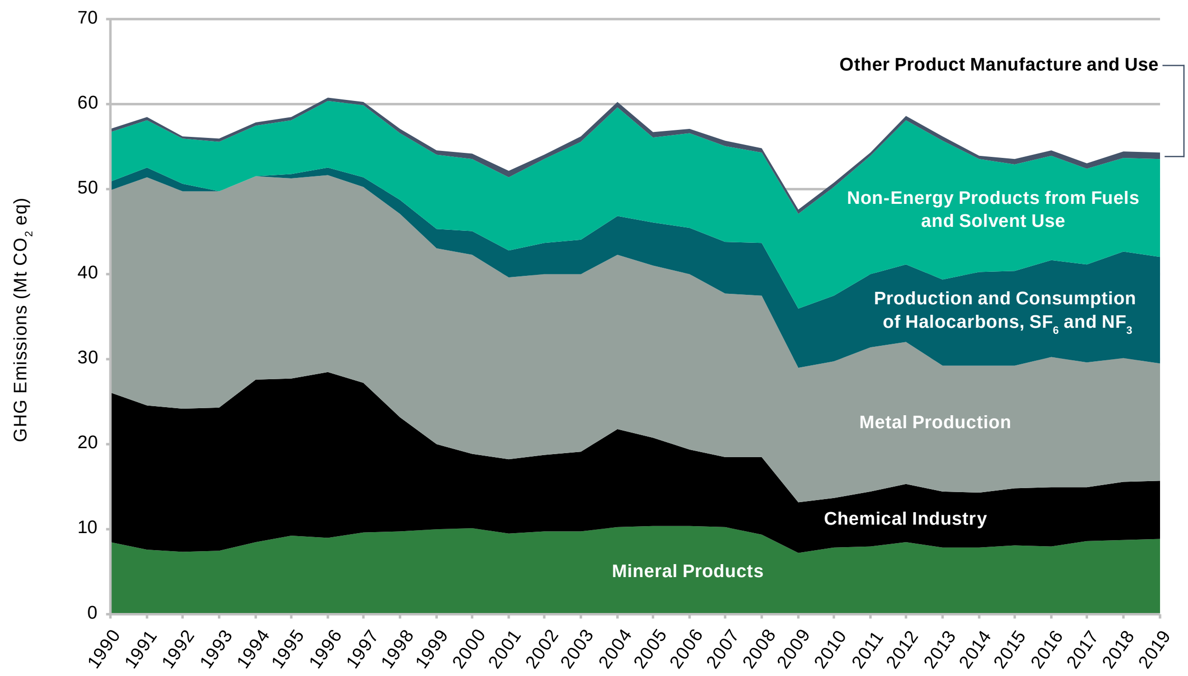


Table 2–8 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Total – Industrial Processes	**57**	**57**	**54**	**53**	**54**	**53**	**54**	**54**	**-5%**	**-4%**
Mineral Products	**8.5**	**10**	**7.8**	**8.0**	**7.9**	**8.6**	**8.7**	**8.8**	**4%**	**-14%**
Cement Production	5.8	7.6	5.9	6.2	6.2	6.9	7.0	7.2	23%	-6%
Lime Production	1.8	1.8	1.5	1.4	1.4	1.4	1.4	1.3	-26%	-24%
Mineral Product Use	0.9	0.9	0.4	0.4	0.4	0.3	0.3	0.3	-63%	-65%
Chemical Industry	**18**	**10**	**6.4**	**6.7**	**7.0**	**6.4**	**6.8**	**6.8**	**-61%**	**-35%**
Ammonia Production	2.8	2.7	2.6	2.9	2.8	2.6	2.5	2.6	-9%	-7%
Nitric Acid Production	1.0	1.2	0.2	0.2	0.3	0.2	0.3	0.3	-73%	-79%
Adipic Acid Production	10	2.5	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.5	4.0	3.7	3.6	3.9	3.5	4.1	4.0	14%	1%
Metal Production	**24**	**20**	**15**	**14**	**15**	**15**	**15**	**14**	**-42%**	**-32%**
Iron and Steel Production	10	10	8.9	8.5	9.2	8.5	8.9	8.3	-21%	-20%
Aluminium Production	10	8.7	5.8	5.7	6.0	6.0	5.5	5.3	-49%	-39%
SF_6 Used in Magnesium Smelters and Casters	3.0	1.2	0.2	0.2	0.1	0.1	0.1	0.3	-90%	-76%
Production and Consumption of Halocarbons, SF_6 and NF_3	**1.0**	**5.1**	**11**	**11**	**11**	**12**	**13**	**12**	**1176%**	**143%**
Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**13**	**13**	**12**	**11**	**11**	**12**	**100%**	**16%**
Other Product Manufacture and Use	**0.4**	**0.5**	**0.5**	**0.6**	**0.6**	**0.7**	**0.7**	**0.8**	**101%**	**38%**

Note: Totals may not add up due to rounding.

in the sector originated from Metal Production (14 Mt), followed by the Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) and Non-Energy Fuel Use, accounting for approximately 12 Mt each (Table 2–8).

2.3.2.1. Mineral Products
(2019 GHG Emissions, 8.8 Mt)

Mineral Products include Cement Production, Lime Production and uses of carbonates (magnesite, soda ash and limestone). Although emissions in this subsector have varied over the years, in 2019 they had more or less returned to their 1990 levels.

Cement production dominates this category, accounting for 81% of emissions from Mineral Products in 2019. Fluctuations over the years largely result from variations in clinker production, especially circa 2009, with some gradual recovery with the opening of a new facility in Québec in 2017.

2.3.2.2. Chemical Industry
(2019 GHG Emissions, 6.8 Mt)

A decrease of 3.6 Mt (35%) from 2005 to 2019 is observed in emissions from the Chemical Industry as a whole. The main driver of emission reductions in this industry was the discontinuation of adipic acid production since 2009; this alone represents a decrease of 2.5 Mt from 2005.[8] N_2O emissions abatement installations at a Nitric Acid Production facility are mainly responsible for a decrease of 0.95 Mt (79%) from the subsector since 2005. Other changes included a small decrease (0.18 Mt) in Ammonia Production and a small increase in Petrochemical and Carbon Black Production (0.045 Mt).

2.3.2.3. Metal Production
(2019 GHG Emissions, 14 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 6.4 Mt (32%) between 2005 and 2019.

The aluminium industry decreased its PFC emissions by 3.2 Mt (85%), while maintaining its production relatively constant between 2005 and 2019 (AAC, 2019), largely due to technological improvements. The Magnesium Production industry also showed a decrease in emissions as a result of the replacement of SF_6 with alternatives and the closure of plants over the years. Primary magnesium production in Canada ceased in 2009.

From 2005 to 2019, emissions in the iron and steel industry decreased by 2.0 Mt (19.9%). The main driver behind the decrease in emissions was reductions in overall production levels (StatCan, 2004–2012; CSPA, 2013–2019).

8 Hendriks J. 2013. Personal communication (email from Hendriks J., Invista to the Pollutant Inventories and Reporting Division, Environment Canada, dated November 22, 2013).

2.3.2.4. Production and Consumption of Halocarbons, SF_6 and NF_3 (2019 GHG Emissions, 12 Mt)

There is currently no production of HFCs, PFCs, SF_6 and NF_3 in Canada. HFC-23 was generated as a by-product of HCFC-22 production, which ended in 1992. Hence, all emissions in the category are associated with the consumption of HFCs, PFCs, SF_6 and NF_3 only. The consumption of HFCs accounted for a 7.3 Mt increase (143%) from 2005 to 2019. This can be explained by the replacement of ODSs by HFCs within the refrigeration and air-conditioning markets since the Montreal Protocol came into effect in 1996. The other sources of emissions (PFCs, SF_6, NF_3) in this subsector do not have a significant impact on emissions trends as the next largest source (PFCs) has emissions of less than 1% of the HFC emissions value.

2

2.3.2.5. Non-Energy Products from Fuels and Solvent Use (2019 GHG Emissions, 12 Mt)

The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector, with emissions increasing by 1.6 Mt (16%) from 2005 to 2019. The observed change is mostly attributable to the emissions from the feedstock use of waxes, paraffin and unfinished products, which increased by 1.7 Mt (340%) over the period.

2.3.3. Agriculture Sector (2019 GHG Emissions, 59 Mt)

In 2019, emissions from the Agriculture sector accounted for 59 Mt or 7.9% of total GHG emissions in Canada, a decrease of 0.8 Mt or 1% from 2005 levels, but corresponding to an increase of 12 Mt or 26% since 1990 (Figure 2–19 and Table 2–9). In 2019, the Agriculture sector accounted for 24% of national CH_4 emissions and 78% of national N_2O emissions, up from 54% of the national N_2O emissions in 1990.

Generally, agricultural emissions result from losses and inefficiencies in production processes, either losses of nutrition energy during animal digestion or losses of nutrient nitrogen to the atmosphere or surface waters. All emissions reported in the Agriculture sector are from non-energy sources. Emissions from energy used during the agricultural production process and the energy and fugitive emissions occurring during the production of nitrogen fertilizers and other agricultural chemicals are discussed in Chapter 3 (Energy) and Chapter 4 (IPPU) of this report.

The main economic sectors in Canadian agriculture are livestock and crop production. GHG emissions from the livestock sector include CH_4 emissions from enteric fermentation and emissions of CH_4 and N_2O from the storage and handling of animal manure. The crop production sector includes N_2O emissions from the application of inorganic nitrogen fertilizers, crop residue decomposition, animal manure and biosolids applied as fertilizers and crop management practices; CH_4 and

Figure 2–19 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2019)**

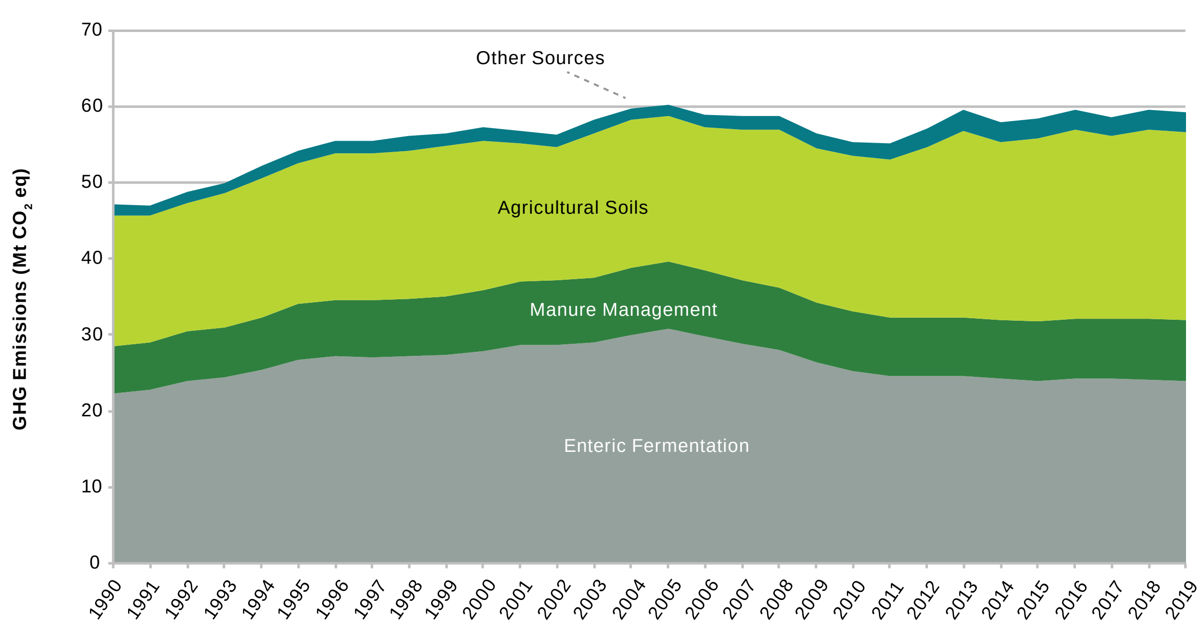


Table 2–9 **GHG Emissions from Agriculture, Selected Years**

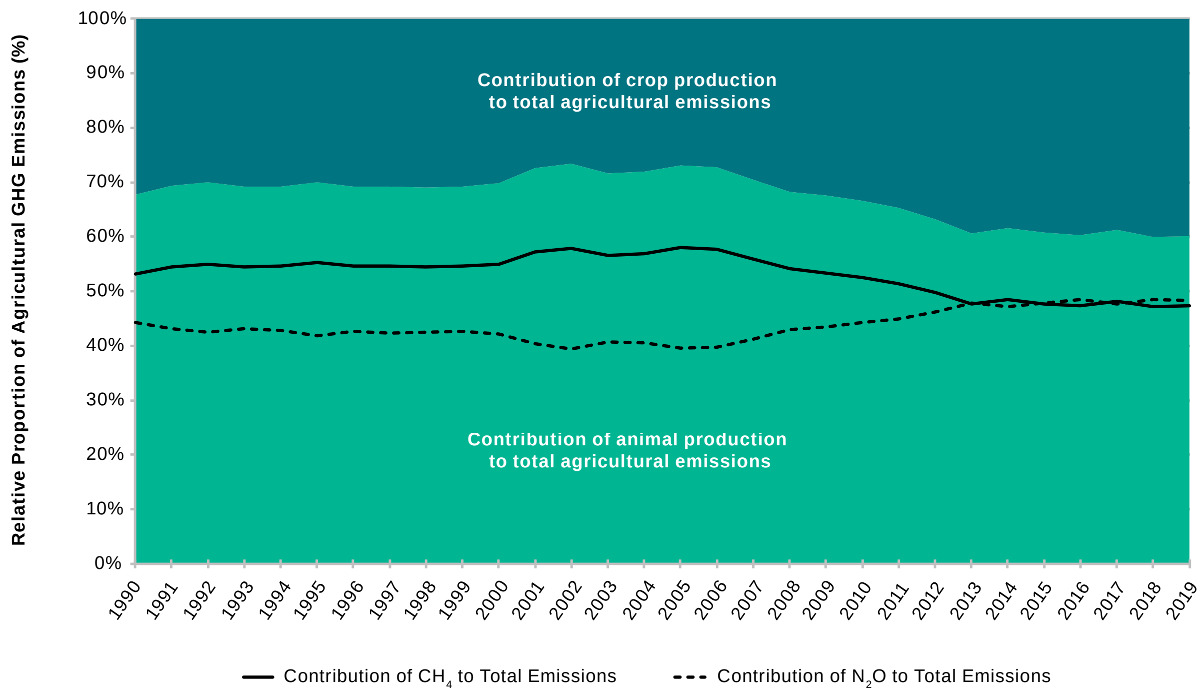
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Agriculture	**47**	**60**	**58**	**58**	**59**	**58**	**59**	**59**	**26%**	**-1%**
Enteric Fermentation	22	31	24	24	24	24	24	24	7%	-22%
Manure Management	6.1	8.8	7.7	7.8	7.9	7.9	7.9	7.9	29%	-10%
Agricultural Soils	17	19	23	24	25	24	25	24	43%	30%
Field Burning of Agricultural Residues	0.22	0.04	0.05	0.06	0.05	0.05	0.05	0.05	-78%	15%
Liming, Urea Application and Other Carbon-containing Fertilizers	1.2	1.4	2.5	2.6	2.5	2.4	2.6	2.6	121%	85%

Note: Totals may not add up due to rounding.

N_2O emissions from the burning of agricultural residues; and CO_2 emissions from agricultural use of lime and urea-based nitrogen fertilizers. In Canada, the livestock sector is dominated by beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oilseeds.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and continuous increases in the application of inorganic nitrogen fertilizers in the Prairie provinces. Beef, swine and poultry populations in Canada in 2019 are 6%, 37% and 52% higher, respectively, than in 1990. Since 2005, grazing cattle populations have declined relative to the production of annual crops, and this decline, together with the continued increase in fertilizer use, is driving an important change in the emissions profile of agriculture, with emissions from livestock dropping to their lowest proportion of total agricultural emissions (60%), considerably lower than the proportion in 2005 (73%) (Figure 2–20). As a result of this shift, total agricultural emissions now consist of slightly higher proportions of N_2O (mainly from crop production) than CH_4 (from livestock production), which is unprecedented. The shift in the industry from grazing cattle production to the production of annual crops is also reflected in a decreased carbon sink in agricultural soils observed in a land management change from perennial to annual crops reported in the LULUCF sector (Liang et al. 2020).

Figure 2–20 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH_4 and N_2O, or attributed to Livestock and Crop Production (1990–2019)**



2.3.3.1. Enteric Fermentation (2019 GHG Emissions, 24 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2019, emissions increased from 22 Mt to 24 Mt, or 7%. Emissions increased from 1990 to 2005 mainly as a result of an increase in the population and weight of beef cattle, driven by high commodity prices. Beef populations peaked in 2005, and subsequently declined by 27% due to a sharp decrease in prices after an outbreak of bovine spongiform encephalopathy (BSE, or mad cow disease) in 2003. In recent years, animal commodity prices remained strong, and animal populations and livestock emissions have stabilized.

At the same time, emissions associated with dairy cows have fallen by approximately 13% since 1990, mainly due to a 23% reduction in the dairy cow population from 1990 to 2019 (StatCan, n.d.[f]). However, the average dairy cow today also consumes more feed and produces 52% more milk than in 1990, because of improved genetics and changes in feeding and/or management practices. As a result, the average dairy cow today emits more GHGs, and emission reductions associated with the decline in the dairy population have been partly offset by a 23% increase in per-animal emissions since 1990.

2.3.3.2. Manure Management (2019 GHG emissions, 7.9 Mt)

Emissions from animal manure management systems increased from 6.1 Mt in 1990 to 7.9 Mt in 2019 (or by 29%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH_4 (14% total agricultural CH_4) and N_2O (14% total agricultural N_2O). The management of beef and poultry manure produces mainly N_2O, whereas pork manure produces mainly CH_4. Emissions from dairy manure have shifted from mainly N_2O to mainly CH_4 due to changes in manure storage practices. As a result, CH_4 emissions correspond closely to changes in populations and practices in the swine and dairy sectors, increasing from 2.5 Mt in 1990 to 3.9 Mt (58%). N_2O emissions closely follow the trend in beef populations, increasing from 3.7 Mt in 1990 to 4.9 Mt (34%) in 2005 and subsequently declining to 4.0 Mt (10%) in 2019. As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N_2O emissions from manure.

2.3.3.3. Agricultural Soils (2019 GHG Emissions, 24 Mt)

Emissions from Agricultural Soils originate from the application of inorganic and organic (manure and biosolids) nitrogen fertilizers and from crop residue decomposition; these emissions can be modified by crop management practices. Emissions increased from 17 Mt in 1990 to 24 Mt in 2019, an increase of 43%, due mainly to an increase in inorganic nitrogen fertilizer use.

Total emissions from the application of inorganic nitrogen fertilizers increased from 6.8 Mt in 1990 to 14 Mt in 2019, an increase of 98%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.6 Mt N over the same period. The increase in N fertilizer sales occurred mainly during two periods: between 1991 and 1997 and between 2007 and 2019. The first period was a result of the intensification of cropping systems and the reduction of summer fallow on the Canadian Prairies. The second period reflected an increase in grain prices that encouraged farmers to use more nutrient inputs and convert lands from perennial to annual crop production, coinciding with a reduction in grazing cattle operations on the Canadian Prairies. The increase in fertilizer use since 1990 also resulted in a 1.7 Mt (205%) increase in emissions of CO_2 from urea-based carbon-containing fertilizers.

Emissions from crop residue decomposition ranged from a minimum of 3.3 Mt in 2002 (a drought year) to a maximum of 6.5 Mt in 2017, depending mainly on weather conditions and their impact on crop yield. Though crop production demonstrates high inter-annual variability, production has tended to increase over the reporting period and, as a result, so have emissions from crop residue.

In 1990, cropland management practices, specifically summer fallow and irrigation, contributed 1.3 Mt to total emissions from soils. The adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) and intensification of cropping systems (92% reduction in summer fallow areas) have reduced emissions by 1.0 Mt in 2019.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2019 Net GHG Emissions, 9.9 Mt, Not Included in National Totals)

The LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, including those associated with land-use change. Emissions of GHGs from sources and removals by sinks are estimated and reported for five categories of managed lands: Forest Land, Cropland, Grassland, Wetlands and Settlements, and for the Harvested Wood Products category, which is closely linked to Forest Land and Forest Conversion. The net LULUCF flux is calculated as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere.

In 2019, LULUCF was estimated to emit 9.9 Mt to the atmosphere, compared with net removals of 57 Mt in 1990 and net emissions of 8.2 Mt in 2005. The long-term trend in net emissions/removals is mainly driven by the decrease in net CO_2 removals from Forest Land

Table 2–10 **GHG Emissions and Removals from LULUCF, Selected Years**

Sectoral Category	Net GHG Flux (Mt CO_2 eq)[a]								Change (Mt CO_2 eq)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Land Use, Land-Use Change and Forestry TOTAL	**-57**	**8.2**	**-3.5**	**4.0**	**0.1**	**0.7**	**8.4**	**9.9**	**67**	**1.7**
a. Forest Land	-200	-130	-140	-130	-140	-140	-130	-130	69	0.7
b. Cropland	7.6	-10	-8.1	-7.0	-6.3	-5.7	-4.8	-4.2	-12	6.2
c. Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d. Wetlands	5.3	3.1	3.1	2.9	2.9	3.0	2.7	2.6	-2.7	-0.5
e. Settlements	1.8	1.7	2.3	2.6	2.4	2.2	2.4	2.2	0.4	0.4
f. Harvested Wood Products	130	150	140	140	140	140	140	140	12	-5.1

Notes:

Totals may not add up due to rounding.

a. Negative sign indicates net removals of CO_2 from the atmosphere.

from 1990 to 2007 (Table 2–10), partially attenuated by increasing net CO_2 removals in Cropland until 2006 and a decrease in emissions from the conversion of forest to other land use over the first two decades of the time series. Net emissions/removals from the LULUCF sector have fluctuated over recent years, decreasing from net emissions of 8.2 Mt in 2005 to net removals of 24 Mt in 2009, and have since increased to net emissions of 9.9 Mt in 2019. Relative to the strong sink observed in the land sector throughout the 1990's, Canada's recent tendency towards net emissions to the atmosphere from the land sector are driven by a diminished Forest Land sink from low level insect disturbance and sustained forest harvest, decreases in perennial cover and woody biomass in Cropland and recent increases in rates of deforestation in some sectors.

National totals are reported to the United Nations Framework Convention on Climate Change (UNFCCC) with and without emissions and removals in the LULUCF sector. The estimated net GHG fluxes in the LULUCF sector when included account for a decrease of 9.4% in 1990 and increases of 1.1% in 2005 and 1.4% in 2019 of Canada's total GHG emissions (Figure 2–6).

2.3.4.1. **Forest Land and Harvested Wood Products (2019 GHG Emissions, 4.6 Mt)**

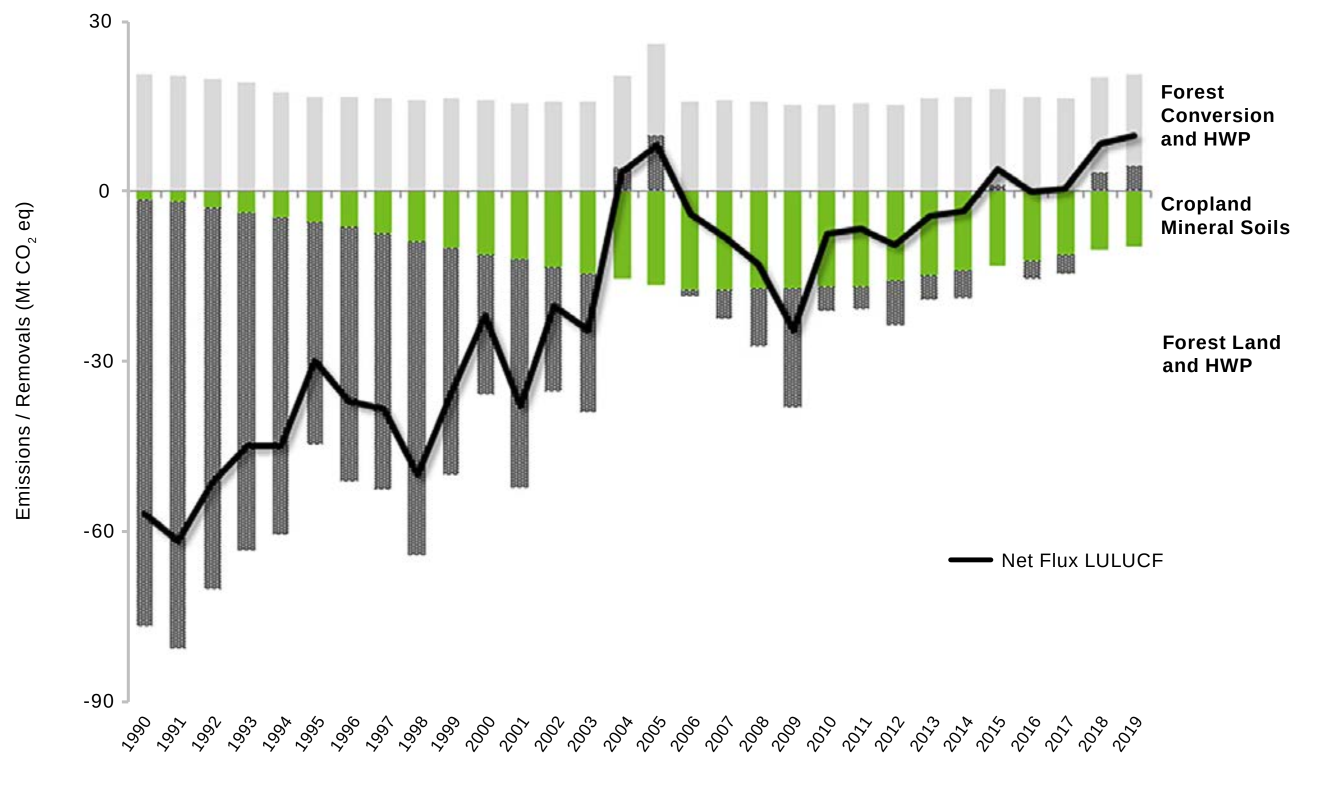
The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products (HWP) originating from domestic harvest. The total net flux from managed forests and resulting HWP amounted to an estimated emission of 4.6 Mt in 2019 (Figure 2–21), which combines net removals of 133 Mt from Forest Land and net emissions of 138 Mt from HWP from forest harvest.

Net removals from Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—decreased from 200 Mt in 1990 to 130 Mt in 2007. The predominant anthropogenic trend directly associated with human activities in managed forests is the 34% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year 2004. Since 2005, net removals have fluctuated between 140 and 130 Mt. Harvest levels gradually increased since 2009 but have remained relatively constant in recent years, with 2019 levels still 25% below their peak in 2004. This recent trend is the combined effect of shifting global markets for traditional forest products as well as growing demand for non-traditional products, e.g. bioproducts (NRCan, 2020).

The decrease in forest removals nationally is dominated by trends in the Montane Cordillera and Boreal Plains. Severe insect outbreaks in the Montane Cordillera in the early 2000s and subsequent high rates of harvest on impacted forest stands reset large areas of previously productive forest to younger age-classes, when trees absorb and store less biomass carbon. In addition, forest stands in the Montane Cordillera ecozone were affected by insect infestations that caused low levels of tree mortality over large areas and increased emissions of CO_2 from decomposition. On the Boreal Plains, sustained harvest, insect outbreaks and fire combined to reset large areas of previously productive forest to younger age-classes. The combination of reduced net rates of storage of CO_2 in biomass and increased emissions of CO_2 from decomposition resulted in a net decrease in removals from forest of these regions—largely between 1998 and 2007—that was large enough to influence the national trend. More recently, insect infestations that have impacted large areas in the Boreal Shield East and Atlantic Maritime in the 2010s are starting to have an effect on the net emissions and removals in these regions that will likely continue over the next few decades. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, disturbances nevertheless influence reported GHG fluxes.

Emissions from HWP reflect the long-term storage of carbon in wood harvested in Canada's forests. Approximately one-third of HWP emissions (30% in 2019) result from long-lived wood products reaching the end of their economic life decades after the wood was harvested.

Figure 2–21 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2019**



End-of-life emissions for short-lived products, namely pulp and paper and bioenergy products, accounted for 27% and 41% of HWP emissions, respectively, in 2019. Short-lived wood products more closely track recent trends in forest harvest rates. Emissions from HWP fluctuated between 120 Mt in 2009, the lowest harvest year, and a peak of 150 Mt in 1995.

2.3.4.2. Forest Conversion (2019 GHG Emissions, 16 Mt)

Forest conversion[9] is not a reporting category per se, since it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands and Land Converted to Settlements. It also includes the emissions from HWP resulting from forest conversion activities since 1990. Emissions due to forest conversion fell from 21 Mt in 1990 to 16 Mt in 2019.

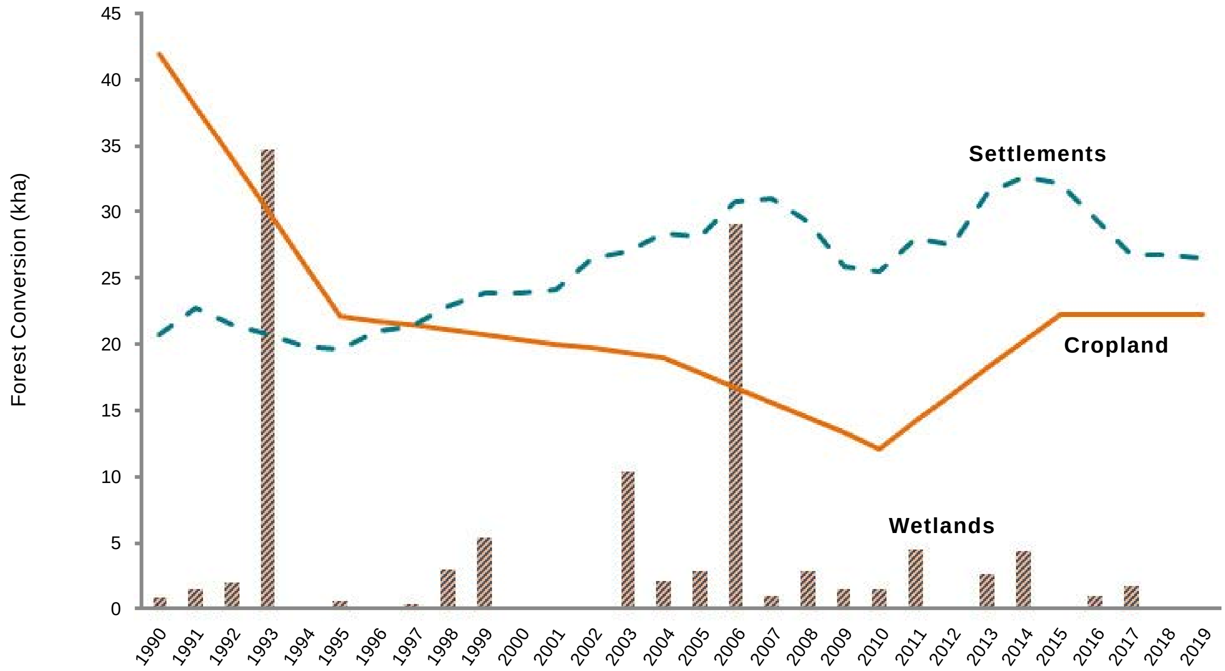
The conversion of forests to other land use is still a prevalent practice in Canada; it is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. Since 1990, 1.5 million hectares of forest have been converted to other land uses in Canada. Geographically, the highest average annual rates of forest conversion occur in the Boreal Plains (23 kha per year) and the Boreal Shield East (8 kha per year), which account for 45% and 15%, respectively, of the total loss of forest area in Canada.

With a current annual conversion rate of 26 kha, Forest Land Converted to Settlements now accounts for the largest share of forest loss, comprising 54% in 2019, up from 33% in 1990 and slightly down from 57% in 2005. Forest clearing for agricultural expansion (Cropland) is the second largest driver of forest conversion, accounting for 46% of all forest area lost in 2019. Annual rates dropped from 42 kha in 1990 to 12 kha in 2010, predominantly in the Boreal Plains, Subhumid Prairies and Montane Cordillera of Western Canada, following a period of active agricultural expansion in previous decades. After 2010, these annual rates have however increased to levels around 22 kha observed in mid-1990s due to a more recent agricultural expansion mostly in the Boreal Plains, Subhumid Prairies and Mixedwood Plains.

Forest conversion to Wetlands is mainly driven by hydroelectric development (flooded land), which is episodic, corresponding to the occasional impoundment of large reservoirs (e.g. LaForge-1 in 1993 and Eastmain-1 in 2006, Figure 2–22). Cumulative areas

9 Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 16 Mt reported in this section is included in the sums associated with the other land-use category totals.

Figure 2–22 **Trends in Annual Rates of Forest Conversion to Cropland, Wetlands and Settlements**



of forest converted for the creation of hydro reservoirs since 1990 and the associated infrastructure equal 187 kha, accounting for 12% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

2.3.4.3. Cropland (2019 GHG Removals, 4.2 Mt)

The Cropland category includes the effect of agricultural practices on CO_2 emissions from, and removals by, arable soils as well as the immediate and long-term impacts of forest and grassland conversion to cropland.

Cropland emissions showed a steady decrease from net CO_2 emissions of 7.6 Mt in 1990 to net removals of 12 Mt in 2006, a total change of 19 Mt. This trend is a result of changes in agricultural land management practices in Western Canada that enhanced soil carbon conservation, such as the extensive adoption of conservation tillage practices (≈17 million hectares of cropland since 1990) and a 98% reduction in summer fallow by 2019.

Since 2011, net removals have gradually declined to 4.2 Mt. The main drivers of this trend are an increasing net conversion from perennial to annual crops on the Prairies since 2006 and declining rates in the adoption of conservation tillage. Further the practice of summerfallow was largely abandoned in the 80’s, 90’s and early 2000s and as a result there is a decrease in the contribution of these historical land management conversions to the soil sink.

The increase in the conversion of perennial to annual crops since 2006 coincided with a reduction in grazing cattle populations on the Prairies indicative of the ties between agricultural production systems and soil carbon (Liang et al., 2020). The decline in emissions from Forest Land Converted to Cropland contributed to the trend of the increasing removals during the period from 1990 to 2010, but has since increased to mid-1990s levels (see section 2.3.4.2).

2.3.4.4. Other LULUCF Sources/Sinks (2019 GHG emissions, 4.8 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 2.6 Mt, 2.2 Mt and 0.001 Mt, respectively, to their combined net emissions of 4.8 Mt reported in 2019, down from 7.2 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 4.3 Mt on average throughout the reporting period) and Land Converted to Settlements. The Wetlands category includes emissions from peatlands managed for peat extraction and from flooded lands (hydroelectric reservoirs). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher emissions over the 1990–1993 period. More specific details on the trend in emissions from Forest Land Converted to Settlements and flooded lands can be found in section 2.3.4.2.

2.3.5. Waste Sector (2019 GHG Emissions, 28 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 28 Mt (3.8%) to Canada's total emissions in 2019, comparable to emission levels of 26 Mt in 1990 (4.3% of total emissions) and of 31 Mt (4.2%) in 2005 (Figure 2–23 and Table 2–11). In 2019, landfilling (including municipal solid waste and industrial wood waste disposal) accounted for 26 Mt (or 94% of total Waste sector emissions), while Biological Treatment of Solid Waste (composting and anaerobic digestion), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste (excluding CO_2 emissions from incineration of biomass material) contributed 0.4 Mt, 1.0 Mt and 0.2 Mt, respectively.

2.3.5.1. Solid Waste Disposal and Industrial Wood Waste Landfills (2019 GHG Emissions, 26 Mt)

The Solid Waste Disposal category reports CH_4 emissions from municipal solid waste (MSW) landfills and the Industrial Wood Waste Landfill category reports these emissions from wood waste landfills.

GHG emissions from landfills are released in landfill gas (LFG) generated by the anaerobic decomposition of buried organic waste. LFG consists mostly of CO_2 and CH_4, though only the release of CH_4 is reported. The CH_4 production rate at a landfill is a function of several factors, including the mass and composition of waste being landfilled, and the moisture entering the site from rainfall. The net amount of CH_4 released from landfill sites is further influenced by the presence of oxidizing landfill covers, and the increasing use of LFG capture technologies.

In 2019, emissions from MSW landfills were 23 Mt, while emissions from wood waste landfills were 3.0 Mt. Emissions from MSW landfills have increased by 10% since 1990, and decreased 8% since 2005. Emissions from wood waste landfills have increased by 22% since 1990 and 32% since 2005. The amount of CH_4 generated by MSW landfills has steadily increased from 1990, primarily as a result of a growing population producing more waste. This increase has been offset by an increase in the capture of LFG at landfills. In 2019, 38% of the LFG generated in landfills was recovered through LFG capture technologies or oxidized through cover material, compared with 15% in 1990 (Figure 2–24). In contrast, LFG capture is believed not to occur at industrial wood waste landfills. The decreasing emission trend is directly related to the decreasing amount of wood waste sent to dedicated landfills due to the repurposing of residual wood waste.

2.3.5.2. Other Waste sources (2019 GHG Emissions, 1.6 Mt)

Over the 1990–2019 time series, emissions from the Biological Treatment of Solid Waste (anaerobic digestion and composting), Wastewater Treatment and Discharge (municipal and industrial wastewater treatment), and Incineration and Open Burning subcategories collectively increased by 36% (Figure 2–22 and Table 2–11).

An increase in Wastewater Treatment and Discharge emissions reflects the increase in the Canadian population. A decrease in total incineration emissions (MSW, sewage sludge, hazardous and clinical waste) was due mainly to declines in emissions from the closure of aging MSW incinerators. Since 1990, many municipalities in Canada have opened centralized composting facilities to reduce the quantity of organics sent to landfills. These practices have contributed to an increase in the emissions from the Biological Treatment of Solid Waste subcategory by 421% since 1990 and 61% since 2005.

Figure 2–23 **Trends in Canadian GHG Emissions from Waste (1990–2019)**

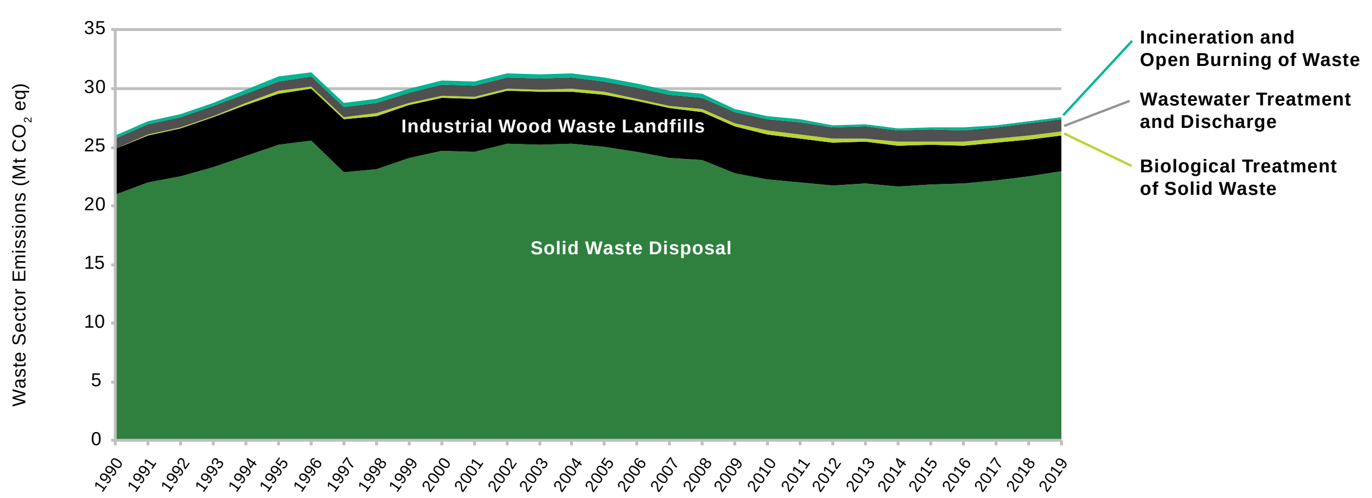
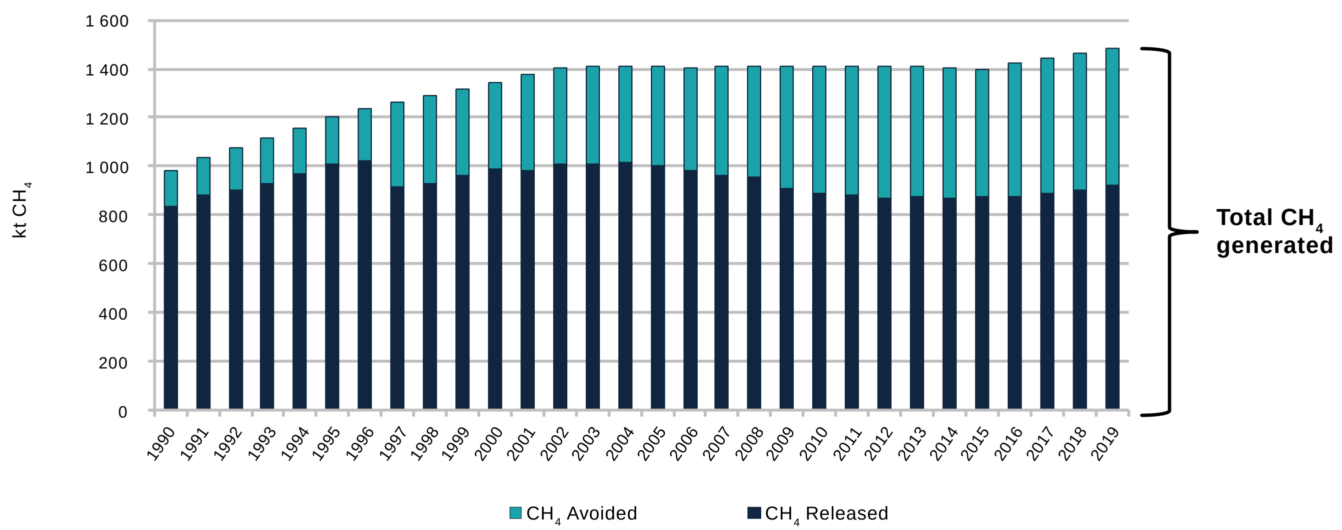


Table 2–11 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Waste Sector	**26**	**31**	**27**	**27**	**27**	**27**	**27**	**28**	**6%**	**-11%**
Biological Treatment of Solid Waste	0.07	0.24	0.31	0.31	0.31	0.32	0.37	0.38	421%	61%
Incineration and Open Burning of Waste	0.27	0.34	0.17	0.20	0.20	0.19	0.18	0.19	-31%	-45%
Industrial Wood Waste Landfills	3.8	4.4	3.5	3.4	3.3	3.2	3.1	3.0	-22%	-31%
Solid Waste Disposal	21	25	22	22	22	22	23	23	10%	-8%
Wastewater Treatment and Discharge	0.83	0.94	1.0	1.0	1.0	1.0	1.0	1.0	23%	9%

Note: Totals may not add up due to rounding.

Figure 2–24 Methane Generated, Avoided and Released from MSW Landfills



Note: Avoided CH_4 represents the amount of CH_4 that is not released from the landfill because it is captured (and either flared or utilized), and/or oxidized as it passes through the landfill cover.

2.4. Emissions by Canadian Economic Sector

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC: Energy, IPPU, Agriculture, LULUCF and Waste. While this categorization is consistent with the UNFCCC reporting guidelines, reallocating emissions into economic sectors is more suitable for the purposes of analyzing trends and policies relative to a particular economic activity (e.g. producing electricity, farming or driving a car). This section reports emissions according to the following Canadian economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry,[10] Buildings, Agriculture, and Waste and other.

This reallocation simply recategorizes emissions under different headings but does not change the overall magnitude of Canadian emissions estimates. It takes the relevant proportion of emissions from various IPCC subcategories to create a comprehensive emissions profile for a specific economic sector. This is the approach that has been taken for reporting emissions projections and progress towards Canada's GHG reduction targets in *Canada's 2019 Greenhouse Gas and Air Pollutant Emissions Projections* report, past *Canada's Emissions Trends* reports, in Canada's National Communications and in Biennial Reports to the UNFCCC. Examining the historical path of Canadian GHG emissions by economic sector results in a better understanding of the connection between economic activities and emissions for the purposes of analyzing trends and for policy and public analysis. This approach is also more closely aligned with the sectoral categories of the Pan-Canadian Framework on Clean Growth and Climate Change, allowing Canada to track progress of its key policies and measures to reduce emissions.

10 The Heavy Industry sector represents emissions arising from metal and non-metal mining activities, as well as smelting and refining, pulp and paper, iron and steel, cement, lime and gypsum, and chemicals and fertilizers.

For example, the Transport sector represents emissions arising from the cars, trucks, trains, aircraft and ships fulfilling mobility requirements of people, as well as mobility service emissions from heavy-duty trucks and other commercial vehicles. However, unlike the IPCC categorization, the Transport sector does not contain off-road transportation emissions related to farming, mining, construction, forestry, pipelines or other industrial activities. These off-road emissions related to industrial activities are allocated to their corresponding economic sectors. For example, if there were any upward trend in farming or mining activity, emissions arising from the increased use of mobile farming machinery or mining trucks would be reflected in the economic sector estimates for Agriculture or Heavy Industry (mining).

Annex 10 (available at open.canada.ca) contains a series of tables which show the distribution of national emissions allocated on the basis of the Canadian economic sector from which they originate for all years in the time series (1990–2019) and the relationship between economic and IPCC categories or sectors. Each Canadian economic sector includes all applicable emissions from energy-related and non-energy-related processes. Specifically, the Oil and Gas sector represents all emissions that are created in the extraction, distribution, refining and upgrading of oil and gas products; the Electricity sector represents all emissions from electric utility generation and transmission for residential, industrial and commercial users; the Transport sector represents all emissions arising from the tailpipes of domestic passenger and freight transport; the Heavy Industry sector represents emissions arising from metal and non-metal mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement; the Buildings sector represents emissions arising directly from residential homes and commercial buildings; the Waste and other sector represents emissions that arise from solid and liquid waste, waste incineration, and coal production, light manufacturing, construction and forestry activities; and finally, the Agriculture sector represents all emissions arising from farming activities, including those related to energy combustion for farming equipment as well as those related to crop and animal production. Similar tables for provinces and territories can be found in Annex 12 (available at open.canada.ca).

2.4.1. Emissions Trends by Canadian Economic Sector

Emission trends since 2005 have remained consistent with previous editions of the inventory, with; emission increases in the Oil and Gas and Transport sectors being offset by decreases in other sectors, notably Electricity and Heavy Industry.

Oil and Gas

In 2019, the Oil and Gas sector produced the largest share of GHG emissions in Canada (26%). Between 1990 and 2019, emissions from this sector increased by 89 Mt. While fluctuations due to economic conditions (e.g. crude oil and natural gas prices) have caused short-term increases and decreases in emissions between 1990 and 2019, in general, emissions from this sector have increased steadily over the long-term. The majority of this increase (68 Mt) is due to massive expansion in Canada's oil sands. Since 1990, oil sands production has increased by over 750% and emissions have increased by over 460% (see following text box).

Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 25% of total emissions in 2019. Between 1990 and 2010, emissions rose by 47 Mt (39%); since then, emissions from this sector have continued to increase gradually. Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Electricity

In 2019, the Electricity sector (excluding industrial and commercial cogeneration) contributed 8.4% to total Canadian emissions. Emissions from the Electricity sector increased in parallel with the rising demand for electricity both domestically and to satisfy exports to the United States over the earlier years of the reporting period, but have fallen significantly during the latter years. Section 2.3 discusses the main historical drivers of emissions trends associated with electricity generation.

Heavy Industry

The Heavy Industry sector experienced some fluctuation in emissions over the reporting period. Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 12% in 2005. In more recent years, emissions have fallen further as a result of reduced economic activity and the continued evolution of Canadian production towards other sectors and services, representing a decrease of 10 Mt (12%) between 2005 and 2019.

Buildings

While residential fuel use has remained relatively steady since 1990, increases in the service industry have resulted in emissions increases from 71 Mt to 91 Mt (27%). GHG emissions from the Buildings sector have increased with population growth and commercial development but, like all sectors of the economy, decreased in the 2008–2009 recessionary period and have remained relatively steady since then.

Agriculture and Waste and Others

Emissions from the Agriculture sector continued a slow upward trend throughout the reporting period, rising from 57 Mt in 1990 to 73 Mt in 2019. This rise in emissions is due primarily to increases in livestock and crop production. Emissions from the Waste and others sector remained relatively stable. Overall, emissions decreased over the time series, from a high of 58 Mt in 1990 to 51 Mt in 2019.

TRENDS IN THE OIL AND GAS SECTOR

Emissions in the Canadian Oil and Gas (O&G) economic sector include fugitive, industrial process and all combustion-related emissions (stationary combustion, off-road transportation, utility and industrial generation of electricity and steam), excluding the amount of CO_2 captured, to provide a complete emissions profile of the industry.

In 2019, the largest contributor to O&G emissions was the Oil Sands category (83 Mt, or 43%), followed by Natural Gas Production and Processing (53 Mt, or 28%), Conventional Oil Production (25 Mt, or 13%) and Petroleum Refining (19 Mt, or 10%). The primary drivers of emissions within the O&G sector are production growth and emissions intensity (defined as the average amount of GHG emissions generated per barrel of oil equivalent).

Production Growth

From 1990 to 2019, the production of total crude oil increased by 174% (StatCan, n.d.[c], n.d.[d]). The increase was driven almost entirely by Canada's oil sands operations, which accounted for 96% of total production growth. Total oil sands output (non-upgraded bitumen and synthetic crude oil production) has increased by over 750% since 1990. Consistent with the production increases, emissions from total crude oil production increased by 73 Mt (about 203%), with emissions from oil sands alone increasing by 68 Mt (468%).

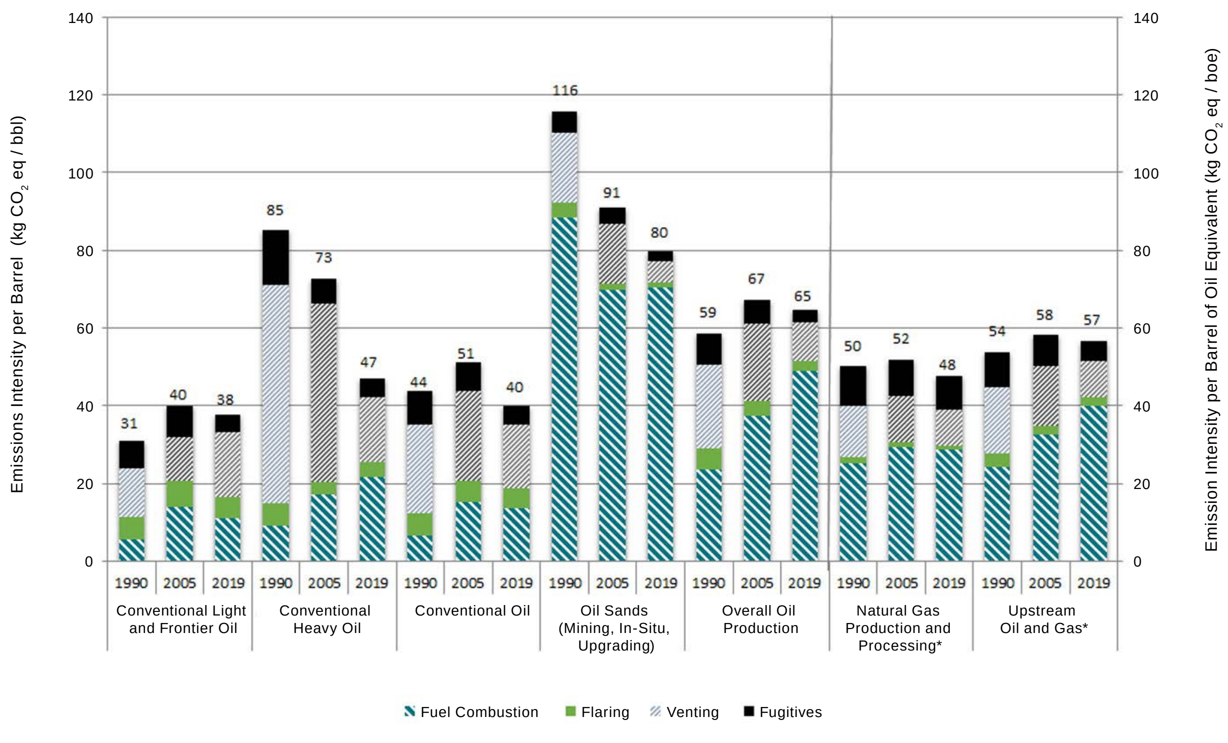
Emissions Intensity

The emissions intensity of overall oil production in Canada increased by about 10% between 1990 and 2019, from 59 to 65 kg CO_2 eq per barrel (Figure 2–25). Contributors to this trend in emissions intensity include decreasing reserves of easily removable crude oil, along with increasing reliance on reserves requiring more energy- and GHG-intensive extraction methods. These include crude bitumen and reserves of heavier or more difficult-to-obtain conventional oils, such as those from offshore sources or those extracted using enhanced oil recovery operations such as steam-assisted gravity drainage (SAGD). The increased use of horizontal wells and multi-stage fracturing techniques also increases emissions and the amount of energy required for drilling and well-completion activities. While fuel combustion emissions have increased by approximately 109% per barrel of oil extracted (23 kg CO_2-eq per bbl in 1990 to 49 kg CO_2-eq per bbl in 2019), venting, flaring and fugitive emissions have decreased by 56%, 50% and 59%, respectively. These reductions are due to increased oil sands production, which produces much fewer fugitive emissions per barrel than conventional oil production, and initiatives such as Alberta's *Directive 60* (AER, 2014), British Columbia's *Flaring and Venting Reduction Guideline* (BCOGC, 2015), Saskatchewan's *Directive S-10* and the Canadian Association of Petroleum Producers (CAPP) *Best Management Practice for Fugitive Emissions* (CAPP, 2007).

The rising quantity of petroleum extracted from Canada's oil sands has had the largest impact on increasing the emissions intensity of overall oil production. However, the intensity of oil sands operations themselves has declined steadily from 116 kg CO_2 eq per barrel in 1990 to 80 kg CO_2 eq per barrel in 2019. The emissions intensity in the oil sands has continued to decline as the industry has reduced the fuel combustion requirements per barrel of oil extracted. Emissions vented per barrel extracted at in-situ bitumen facilities has also decreased due to the impact of Alberta's *Directive 60*. Furthermore, over time, more crude bitumen has been produced without the additional processing step of upgrading to synthetic crude oil (SCO), which has also contributed to decreasing the overall emissions intensity. This was particularly evident between 2010 and 2019, when non-upgraded bitumen production increased by over 140% while SCO production increased by only 37%. The additional energy required to process the crude bitumen (and resulting emissions) is therefore transferred downstream, mainly to export markets where the bitumen is processed at petroleum refineries. Since 2015, CO_2 emissions from the hydrogen plant at the Scotford Upgrader have been captured and transported to an underground storage site. In 2019, 1.13 Mt of CO_2 was captured at Scotford, reducing the emissions intensity of overall oil sands operations by approximately 1.3%.

2

Figure 2–25 **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2019)**



Notes:

Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.

*Calculated on a barrel of oil equivalent (boe) basis by converting production volumes to energy basis and then dividing by energy content of light crude oil (6.1215 GJ/bbl). [1 barrel (bbl) = 0.159 m^3]

Production data from: StatCan 1991–2020, n.d.[c], n.d.[d] and AER 2020.

Table 2–12 Trends in GHG Emissions by Canadian Economic Sector

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
NATIONAL GHG TOTAL	**602**	**739**	**723**	**723**	**707**	**716**	**728**	**730**
Oil and Gas	**102**	**160**	**190**	**190**	**181**	**183**	**191**	**191**
Upstream Oil and Gas	82	137	170	169	160	163	172	172
Natural Gas Production and Processing	34	61	58	55	52	50	53	53
Conventional Oil Production	21	29	32	31	27	27	27	25
Conventional Light Oil Production	11	13	19	18	16	17	17	17
Conventional Heavy Oil Production	9.7	14	12	12	9.4	8.6	7.8	6.9
Frontier Oil Production	0.26	1.7	1.7	1.5	1.7	1.8	1.9	1.9
Oil Sands (Mining, In-situ, Upgrading)	15	35	70	72	69	76	81	83
Mining and Extraction	2.2	5.6	10	11	11	13	15	15
In-situ	4.1	12	35	38	37	41	43	43
Upgrading	8.4	17	24	24	21	23	24	25
Oil, Natural Gas and CO_2 Transmission	12	12	9.8	10	11	10	10	11
Downstream Oil and Gas	20	23	21	21	21	19	19	20
Petroleum Refining	18	22	20	19	20	18	18	19
Natural Gas Distribution	1.6	1.3	1.2	1.2	1.2	1.2	1.1	1.1
Electricity	**95**	**118**	**76**	**79**	**74**	**72**	**62**	**61**
Transport	**120**	**160**	**171**	**172**	**174**	**179**	**184**	**186**
Passenger Transport	71	90	89	92	94	95	97	99
Cars, Trucks and Motorcycles	64	82	81	83	86	86	88	89
Bus, Rail and Aviation	7.1	8.2	8.7	8.7	8.6	9.0	9.7	9.6
Freight Transport	31	60	74	72	70	74	78	78
Heavy Duty Trucks, Rail	26	54	69	67	66	69	72	72
Aviation and Marine	4.6	5.3	4.6	4.5	4.6	4.8	5.1	5.6
Other: Recreational, Commercial and Residential	18	10	8.5	8.7	8.6	9.1	9.3	9.2
Heavy Industry	**97**	**87**	**79**	**77**	**76**	**75**	**77**	**77**
Mining	6.7	6.6	7.8	7.7	7.1	7.7	9.0	8.8
Smelting and Refining (Non-Ferrous Metals)	17	14	10	10	11	11	9.8	10
Pulp and Paper	15	9.0	6.6	6.4	6.5	6.8	7.7	8.3
Iron and Steel	16	16	16	14	15	15	16	15
Cement	10	13	10	10	10	11	11	11
Lime and Gypsum	2.9	3.5	2.6	2.5	2.5	2.6	2.6	2.4
Chemicals and Fertilizers	29	25	26	26	24	21	21	21
Buildings	**71**	**84**	**85**	**83**	**81**	**86**	**90**	**91**
Service Industry	28	40	42	41	41	44	45	47
Residential	44	44	42	42	40	42	44	44
Agriculture	**57**	**72**	**71**	**71**	**72**	**71**	**73**	**73**
On-Farm Fuel Use	11	12	13	13	13	13	14	14
Crop Production	15	16	22	23	24	23	24	24
Animal Production	32	44	36	35	36	36	36	36
Waste and Others	**58**	**57**	**50**	**50**	**50**	**50**	**51**	**51**
Waste	26	31	27	27	27	27	27	28
Coal Production	4.0	2.3	2.4	2.3	2.4	2.2	2.5	2.6
Light Manufacturing, Construction and Forest Resources	28	24	21	21	21	21	22	21

Notes:

Totals may not add up due to rounding.

Please refer to Annex 10 for a description of the relationship between these Canadian economic sectors and the IPCC sectors and categories. This Annex provides detailed tables showing the correspondence between emissions allocated to both breakdowns.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

Estimates presented here are under continual improvement. Historical emission estimates may be changed in future publications as new data becomes available and methods and models are refined and improved.

CHAPTER 3

ENERGY (CRF SECTOR 1)

3.1. Overview

In 2019, the Energy sector accounted for 589 Mt (81%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy sector emissions total includes, with exceptions, all GHG (carbon dioxide [CO_2], methane [CH_4] and nitrous oxide [N_2O]) emissions from fuel combustion, fugitive sources, and carbon capture, transport and storage activities.[1]

Emissions resulting from stationary fuel combustion include the use of fossil and biomass (excluding peat) fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sectors. Canada does not use peat as a combustion fuel. Data from the non-energy use of peat appears in the Land Use, Land-use Change, and Forestry (LULUCF) sector (Chapter 6.1) and the fuel used to harvest and produce peat is included in the Agriculture/Forestry/Fishing sub-category within Other Sectors (1.A.4). Only the CH_4 and N_2O emissions from the combustion of biomass fuels, such as biodiesel, residential fuel wood and spent pulping liquor, are included in the Energy sector, while CO_2 emissions appear as a memo item in the Common Reporting Format (CRF) tables.

1 The Industrial Processes and Product Use sector reports emissions associated with the non-energy use of fossil fuels/fossil fuels used as feedstock.

GHG emissions from the combustion (and evaporation) of fuel for the majority of transport activities, such as Domestic Aviation, Road Transportation, Railways, Domestic Navigation, Pipeline Transport and Other Transportation (Off-road), are included in the Transport category. Emissions from international aviation and international navigation activities appear as a memo item in the CRF tables. Off-road emissions from vehicles and machinery along with fishing vessels appear in separate and distinct mobile subcategories within Manufacturing Industries and Construction (1.A.2) or Other Sectors (1.A.4) according to CRF table allocation. Military aviation and navigation is reported under the Other (1.A.5) subcategory. Note that emissions presented in Chapter 3 are consistent with the Intergovernmental Panel on Climate Change (IPCC) and CRF categorization, which differs from the emissions allocation presented in Chapter 2, Annex 9 and Annex 11's summary tables, where emissions from off-road transportation, fishing, military aviation and military navigation are included under the general transport.

Fugitive emissions associated with the fossil fuel industry are intentional (e.g. venting) or unintentional (e.g. leaks, accidents) releases of GHGs that may result from production, processing, transmission and storage activities. The Fugitive Emissions category includes

Table 3–1 **GHG Emissions from Energy**

GHG Source Category	GHG Emissions kt CO_2 eq													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Energy Sector	**472 000**	**513 000**	**592 000**	**591 000**	**569 000**	**577 000**	**575 000**	**583 000**	**584 000**	**585 000**	**566 000**	**578 000**	**588 000**	**589 000**
Fuel Combustion Activities (1.A)	**423 000**	**449 000**	**522 000**	**530 000**	**514 000**	**522 000**	**516 000**	**522 000**	**522 000**	**525 000**	**512 000**	**523 000**	**533 000**	**535 000**
Energy Industries (1.A.1)	143 000	152 000	203 000	209 000	200 000	198 000	198 000	196 000	195 000	201 000	191 000	191 000	189 000	189 000
Manufacturing Industries and Construction (1.A.2)	71 400	74 000	72 500	63 800	60 400	63 800	62 600	63 200	63 000	62 000	59 200	61 300	63 600	63 900
Transport (1.A.3)	124 000	130 000	151 000	163 000	165 000	166 000	168 000	173 000	172 000	173 000	175 000	179 000	185 000	187 000
Other Sectors (1.A.4)	84 100	92 700	96 100	94 400	88 400	94 000	87 300	90 100	91 300	88 800	86 500	91 600	95 000	95 900
Other (Not Specified Elsewhere) (1.A.5)	262	259	293	286	284	271	302	288	296	342	335	290	287	316
Fugitive Emissions from Fuels (1.B)	**49 000**	**64 000**	**69 000**	**61 000**	**55 000**	**56 000**	**59 000**	**61 000**	**63 000**	**59 000**	**54 000**	**55 000**	**55 000**	**54 000**
CO_2 Transport and Storage (1.C)	**NO**	**NO**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.10**	**0.22**	**0.27**	**0.27**	**0.28**	**0.28**

Notes:

NO = Not occurring

Totals may not add up due to rounding.

emissions from flaring activities by the oil and gas industry, since their purpose is not to produce heat or to generate mechanical work (IPCC 2006).

Some CO_2 emissions are captured (e.g. during electricity generation or hydrogen production at refineries), transported and injected for long-term geologic storage or enhanced oil recovery (EOR). In addition, Canada imports CO_2 for EOR operations. Volumes captured appear in the industry category where they occur. CRF category 1.C includes releases of CO_2 to the atmosphere from CO_2 pipeline/distribution infrastructure and injection equipment used for the purpose of long-term geological storage. Fugitive estimates in CRF category 1.B include emissions from the use of CO_2 for EOR operations.

Continuous methodological improvements and revised activity data resulted in several recalculations of GHG emissions in the Energy sector; see Table 3–2. Each section of Chapter 3 contains a general list, with explanations, of activities resulting in revised emission estimates; Chapter 8 provides a summary of recalculations for all sectors.

Overall, recalculations resulted in a decrease of 8.5 Mt compared to last year's submitted value for 2018. Recalculations occurred for the following reasons.

Activity data – Revisions to fuel data in the *Report on Energy Supply and Demand* (RESD) generally result in a recalculation of most combustion sources. Revisions to activity data are a result of quality control checks, revised data or new information, and are as follows:

- Revisions to the 2018 RESD data have been incorporated (as per standard practice) as an update to the 2018 preliminary data[2] along with corrections to some historical data utilized in last year's national inventory submission to the UNFCCC, and consist of:
  - revised natural gas data in the RESD, between 2005 and 2018.

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2019 is preliminary and is subject to revision in late 2021.

- Revisions to the volumes of flared gas subtracted from stationary combustion to avoid double counting between 1990 and 2018.
- Revisions to various activity data used in the oil and gas fugitive emissions models (refer to the recalculation discussion in section 3.3.2 for more details).
- Revisions to the quantity of residential firewood combusted between 1990 and 2018.
- Revisions to the activity data for 2015 calendar year and new activity data for the 2016, 2017 and 2018 calendar years were incorporated into the marine consumption-based model.
- Revisions/additions to the Base of Aircraft Data (BADA) were incorporated into the aviation bottom-up model. Updated from BADA 3.7 to BADA 3.15.

Methodology – Changes to the following methods resulted in recalculations:

- An updated method for estimating emissions from reported venting and flaring in Alberta using detailed gas composition data and facility reported volumes of vented and flared gas (refer to Annex 3, section A3.2.2.1.2 for a detailed description of the new method).
- An updated aviation methodology is now being used to better define aircraft movements and refine the emissions released during different flight modes/phases.

Emission Factors – Implementation of improved emission factors, based on new information, resulted in recalculations. Revisions include:

- Stationary fuel combustion for petroleum coke and still gas (refinery gas) (see Annex 6, section A6.1, for more details).
- CO_2 emission factor for non-marketable natural gas stationary fuel combustion in Alberta based on detailed gas composition data (see Annex 6, section A6.1.1.1 for more details).
- CO_2 emission factor for aviation gasoline was corrected to match the value published in original reference. In addition, the application of CH_4 emission factor for aviation turbo fuel was revised to use aircraft specific values where applicable and default to the IPCC default emission factor when required.

Table 3–2 **GHG Emission Change Due to Recalculations**

IPCC Categories	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
1 Energy Sector	GHG Emissions (Mt CO_2 eq)												
2018 Inventory Inventory Report	479	520	600	593	567	575	577	587	591	590	574	584	596
2019 Inventory Inventory Report	472	513	592	591	569	577	575	583	584	585	566	578	588
Total change due to recalculations	**-7.1**	**-6.7**	**-8.3**	**-2.2**	**2.5**	**2.2**	**-1.9**	**-4.4**	**-7.2**	**-5.2**	**-7.2**	**-5.7**	**-8.5**
1.A – Fuel Combustion	-7.1	-6.7	-8.4	-2.2	2.1	2.0	-2.0	-4.3	-7.0	-4.4	-6.5	-5.1	-7.8
1.B – Fugitive and 1.C – CO_2 Transport & Storage	0.0	0.1	0.1	0.0	0.4	0.2	0.1	-0.2	-0.2	-0.8	-0.7	-0.6	-0.7

Note: Totals may not add up due to rounding.

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3.2. Fuel Combustion Activities (CRF Category 1.A)

Emission sources in the Fuel Combustion Activities category include all GHG emissions from the combustion of fossil fuels and CH_4 and N_2O emissions from biomass fuels. Major categories include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (i.e. the residential and commercial subcategories). Annex 3.1, Methodology and Data for Estimating Emissions from Fossil Fuel Combustion, presents the methods used to calculate emissions from fuel combustion. The estimation methodologies are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) Tier 2 approach, with country-specific emission factors and parameters.

In 2019, about 535 Mt (74 %) of Canada's GHG emissions were from the combustion of fossil and biomass fuels (Table 3–1). Overall, GHG emissions from Fuel Combustion Activities have increased by 26.7% since 1990. Between 1990 and 2019, emissions from the Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors (1.A.4) categories increased by 16.8% (45.6 Mt), and emissions from the Transport (1.A.3) category increased by 50.7% (62.7 Mt) (see Figure 3–1).

3.2.1. Comparison of the Sectoral Approach with the Reference Approach

A full discussion of reference and sectoral approach analysis is included in Annex 4 and Table A4-1 summarizes the results.

3.2.2. International Bunker Fuels

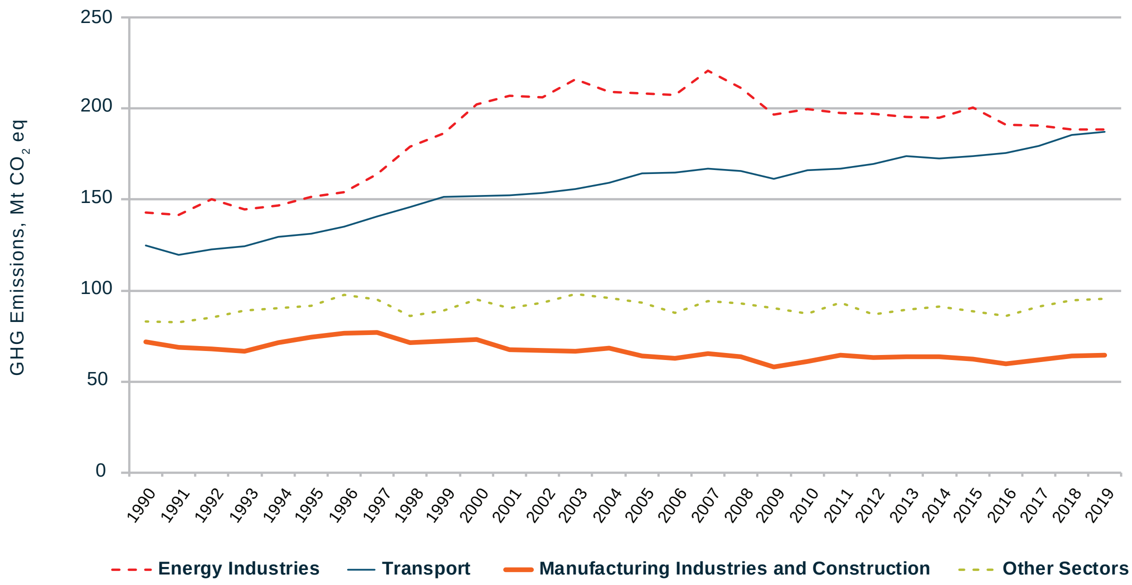
Emissions from fuels used for international navigation and international aviation are reported separately under the memo item International Bunkers, following 2006 IPCC Guidelines and UNFCCC reporting guidance.

3.2.2.1. International Aviation (CRF Category 1.D.1.a)

Emissions (Table 3–3) were calculated using the same methods listed in the Domestic Aviation section (see section 3.2.6.2). Fuel-use data are reported in the RESD (Statistics Canada 1990–) as being sold to domestic and foreign airlines. However, with the Aviation Greenhouse Gas Emission Model (AGEM), flight-by-flight aircraft movements are used to determine whether a flight stage is domestic or international. This method greatly improves the allocation between domestic and international flights.

Exercise care when comparing emission estimates in this category against those reported by the International Energy Agency (IEA). The method employed in the national inventory uses detailed domestic and international movements based on the flight's origin and destination. The fuel consumption values (broken down into domestic and international sectors) reported to the

Figure 3–1 **GHG Emissions from Fuel Combustion**



IEA by Canada are based on the assumption that all fuel sold to Canadian carriers is domestic and that all fuel sold to foreign carriers is international. Given that many movements by Canadian carriers are international in nature and that the reporting requirements for these two separate reports (UNFCCC, IEA) do not align, the reported values also will not align.

3.2.2.2. International Navigation (CRF Category 1.D.1.b)

Emissions (Table 3–4) were calculated using the same methods listed in the Domestic Navigation section (see section 3.2.6.2). Fuel-use data are reported in the RESD (Statistics Canada 1990–) as being sold to domestic or foreign flag vessels. However, with the Marine Emission Inventory Tool (MEIT), vessel movements determine whether a voyage is domestic or international, as defined by the 2006 IPCC Guidelines. This method greatly improves the allocation between domestic and international movements.

Similar to the Aviation subcategory, take careful consideration when comparing fuel consumption (in energy terms) in this subcategory against those of the RESD and IEA due to different approaches. The method employed in the national inventory uses detailed domestic and international movements based on a vessels port of origin and destination. The fuel consumption values reported to the IEA by Canada are based on vessel flag (domestic or foreign). Furthermore, due to design and operating procedures of marine vessels, it is common for vessels to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD contains only domestic fuel transactions, it is possible to have more fuel consumed in the marine sector than the amounts reported for Canada.

3.2.3. Feedstocks and Non-Energy Use of Fuels

Aside from combustion for generating heat or work, fossil fuels are also used for non-energy purposes, such as reducing iron or producing waxes, solvents, and lubricants, and as feedstock (for the production of fertilizers, rubber, plastics and synthetic fibres). Emissions from the non-energy use of fossil fuels are included in the Industrial Processes and Product Use sector (Chapter 4 of this report).

3.2.4. Energy Industries (CRF Category 1.A.1)

3.2.4.1. Source Category Description

The Energy Industries category has three subcategories: Public Electricity and Heat Generation, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries.

In 2019, the Energy Industries category accounted for 189 Mt (25.9%) of Canada's total GHG emissions, with a 31.9% increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 36.4% (68.6 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries

Table 3–3 **GHG Emissions from Domestic and International Aviation**

GHG Source Category	GHG Emissions, kt CO_2 eq									
	1990	2005	2012	2013	2014	2015	2016	2017	2018	2019
International Aviation	5 800	10 100	10 700	11 100	11 000	11 400	12 000	13 200	15 000	15 100
Domestic & Military Aviation	7 510	7 720	7 600	7 880	7 590	7 590	7 520	7 940	8 660	8 540
Total	**13 300**	**17 800**	**18 300**	**19 000**	**18 600**	**19 000**	**19 500**	**21 100**	**23 700**	**23 600**

Note: Totals may not add up due to rounding.

Table 3–4 **GHG Emissions from Domestic and International Navigation**

GHG Source Category	GHG Emissions (kt CO_2 eq)									
	1990	2005	2012	2013	2014	2015	2016	2017	2018	2019
International Navigation	7 250	9 540	8 270	8 680	8 680	8 430	7 480	7 630	7 820	8 780
Domestic, Fishing & Military Navigation	3 070	3 980	3 580	3 530	3 480	3 430	3 510	3 650	3 830	4 360
Total	**10 300**	**13 500**	**11 900**	**12 200**	**12 200**	**11 900**	**11 000**	**11 300**	**11 600**	**13 100**

Note: Totals may not add up due to rounding.

Table 3–5 **Energy Industries GHG Contribution**

GHG Source Category	GHG Emissions, kt CO_2 eq													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Energy Industries TOTAL (1.A.1)	**143 000**	**152 000**	**203 000**	**209 000**	**200 000**	**198 000**	**198 000**	**196 000**	**195 000**	**201 000**	**191 000**	**191 000**	**189 000**	**189 000**
Public Electricity and Heat Generation	94 500	98 800	132 000	125 000	102 000	94 500	91 300	87 500	83 800	87 000	80 500	78 400	69 800	68 600
Petroleum Refining	17 400	16 300	17 300	20 100	19 000	18 300	17 500	16 600	16 000	15 900	16 300	14 500	14 600	14 700
Manufacture of Solid Fuels and Other Energy Industries[a]	31 200	36 900	53 300	63 700	78 800	85 100	88 700	91 800	95 400	98 000	94 000	98 000	105 000	105 000

Notes:

Totals may not add up due to rounding.

a. In accordance with the UNFCCC Common Reporting Format tables, Manufacture of Solid Fuels and Other Energy Industries includes stationary combustion emissions from coal mines. However, in Annexes 9 and 11, these emissions are included in the Mining category.

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subcategories contributed 7.8% (14.7 Mt) and 55.9% (105 Mt), respectively (Table 3–5). Chapter 2, Emissions Trends has further discussion of trends in emissions from the Energy Industries category.

The Energy Industries category includes all GHG emissions from stationary fuel combustion sources related to utility electricity generation and combined heat and power generation, as well as the production, processing and refining of fossil fuels.

Although actually associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing and refining of fossil fuels are reported as fugitive emissions (refer to section 3.3, Fugitive Emissions from Fuels [CRF Category 1.B]).

Public Electricity and Heat Generation (CRF Category 1.A.1.a)

In accordance with the 2006 IPCC Guidelines, the Public Electricity and Heat Generation subcategory includes the GHG emissions associated with the production of electricity and heat from the combustion of fuel in public or privately owned utility thermal power plants whose primary activity is supplying electricity to the public. The estimated GHG emissions from this subcategory do not include emissions from non-utility industrial generation; rather, these emissions are allocated to specific industrial sectors under the Manufacturing Industries and Construction category.

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated by wind, tidal and solar resources is small relative to that generated by Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators only emit small quantities of GHGs,[3] generally from diesel generators used as a backup power supply. In the case of nuclear facilities, uranium fuel production and processing occurs at separate facilities, so any GHG emissions associated with these facilities are reported under Manufacturing Industries and Construction. Emissions from the mining of uranium are reported under Mining. The GHG estimates in the Public Electricity and Heat Generation category therefore only reflect emissions from combustion-derived electricity. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers burn coal, petroleum coke, refined petroleum products (RPPs), natural gas or biomass, while gas turbines use natural gas or RPPs. Reciprocating engines can use natural gas and/or a combination of RPPs.

Petroleum Refining (CRF Category 1.A.1.b)

The Petroleum Refining subcategory includes emissions from the production of petroleum products from a raw feedstock. Conventional or synthetic crude oil is refined into petroleum products such as heavy fuel oil, residential fuel oil, aircraft fuel, gasoline and diesel by distillation and other processes. These processes use heat from combusting either internally generated fuels (such as still gas and petroleum coke) or purchased fuels (such as natural gas). The Fugitive Emissions from Fuels category (section 3.3) includes CO_2 generated as a by-product during the production of hydrogen in the steam reforming of natural gas, as well as other fugitive emissions from refinery operations.

3 In the case of hydroelectric generation facilities, emissions from their associated hydro reservoirs (due to the flooding of land) are reported in the Land Use, Land Use Change and Forestry Sector.

Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)

The Manufacture of Solid Fuels and Other Energy Industries subcategory comprises stationary fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. Emissions associated with pipeline transmission are reported in the Pipeline Transport subcategory (1.A.3.e.i) and off-road transport emissions in the mining and oil and gas extraction industries are reported in Manufacturing Industries and Construction – Off-road Vehicles and Other Machinery (1.A.2.g.vii).

Upgrading facilities are responsible for producing synthetic crude oil from a feedstock of bitumen produced by oil sands mining, extraction and in-situ recovery activities (e.g. thermal extraction). The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel. Upgrading facilities also rely on natural gas as well as internally generated fuels such as still gas and petroleum coke for their operation, which result in both combustion- and fugitive-related emissions.

3.2.4.2. Methodological Issues

The methodology described in Annex 3.1 calculates emissions for all source categories, using primarily fuel consumption data reported in the RESD (Statistics Canada 1990–). The method is consistent with the IPCC Tier 2 approach, with country-specific emission factors.

Public Electricity and Heat Generation (CRF Category 1.A.1.a)

StatCan fuel-use data in the RESD differentiates industrial electricity generation from utility generation, but aggregates industrial generation data into one category titled Transformed to Electricity by Industry. The GHG emissions from industrial electricity generation are reallocated to their respective industrial subcategories using the detailed industry information that feed the RESD. See Annex 3.1 for methodological details.

The 2006 IPCC Guidelines divide the Public Electricity and Heat Generation subcategory into three additional subcategories: Electricity Generation (1.A.1.a.i), Combined Heat and Power Generation (1.A.1.a.ii), and Heat Plants (1.A.1.a.iii). StatCan does not differentiate fuel-use data in the RESD using these subcategories; rather, they aggregate data into one category titled Transformed to Electricity by Utilities. The GHG emissions from the RESD Transformed to Electricity by Utilities category are disaggregated into the Electricity Generation and Combined Heat and Power Generation CRF subcategories using the RESD input data.[4] See Annex 3.1 for methodological details.

StatCan aggregates fuel-use data for industrial wood wastes and spent pulping liquors combusted for energy purposes into one national total. Emissions of CH_4 and N_2O from the combustion of biomass are reallocated to their respective categories using the RESD input data. CO_2 emissions from biomass combustion are not included in totals but rather reported separately in the UNFCCC CRF tables as a memo item.

Petroleum Refining (CRF Category 1.A.1.b)

The calculation of emissions for this subcategory uses all fuel use attributed to the petroleum refining industry and includes all petroleum products reported as producer-consumed/own consumption as well as purchases of natural gas for fuel use by refineries. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. Subtracting fuel-use and emission data associated with flaring avoids double counting. See Annex 3.2, section A3.2.2.7, for more details.

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Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)

Emissions for this subcategory are calculated using all fuel use attributed to fossil fuel producers. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. To avoid double counting, Stationary Combustion Sources do not include fuel-use and emission data associated with flaring. See Annex 3.2, section A3.2.2.7, for more details.

Fossil fuel producers often combust unprocessed, non-marketable natural gas. This has a higher CO_2 emission factor than marketable natural gas (see Annex 6), since it contains a larger percentage of complex hydrocarbons, resulting in higher carbon content. Likewise, the energy content of non-marketable natural gas is higher than that of marketable natural gas.

3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is ±4% for CO_2, CH_4 and N_2O combined and ±3% for CO_2 alone.

Uncertainties for the Energy Industries category are dependent on data collection methods and the representativeness of a specific fuels emission factor. Data collection for taxation purposes means commercial fuel volumes and properties are generally accurate,

4 The RESD 'input data' is that data obtained from the surveys that feed the RESD. (The RESD aggregates and summarizes the data from these surveys.)

with greater uncertainty surrounding both the reported quantities and the properties of non-marketable fuels (e.g. own use of natural gas from producing wells and still gas consumption by refineries). For example, in the Petroleum Refining subcategory, the CO_2 emission factors for non-marketable fuels such as still gas, petroleum coke and catalytic coke have a greater impact on the uncertainty estimate than the CO_2 factors for commercial fuels. Coal CO_2 emission factors were developed using statistical methods and 95% confidence intervals.

The estimated uncertainty for CH_4 (±127%) and N_2O (±225%) emissions for the Energy Industries category is influenced by the uncertainty associated with the emission factors (ICF Consulting 2004). Additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting. The estimates for the Energy Industries category are consistent over time and calculated using the same methodology. Section 3.2.4.5, Recalculations, includes a discussion of RESD activity data.

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Approximately 40% of the 2019 emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory are associated with the consumption of non-marketable natural gas for natural gas production and processing, conventional crude oil production, and in-situ bitumen extraction. The uncertainty estimate for emissions from the combustion of this fuel is influenced by the CO_2 (-1.2 to + 1.7% for Alberta; ±6% for all other provinces) and CH_4 (0% to +240%) emission factor uncertainties for the consumption of unprocessed natural gas. Emissions estimates for the natural gas industry used provincially weighted natural gas emission factors since plant-level information on the composition of consumed unprocessed natural gas (which will vary from plant to plant) is unavailable.

3.2.4.4. QA/QC and Verification

The completed quality control (QC) checks were consistent with the 2006 IPCC Guidelines. Elements of the QC checks included a review of the estimation model, activity data, emission factors, time-series consistency, transcription accuracy, reference material, conversion factors and unit labelling, and sample emission calculations.

As described in Chapter 1, Canada has a reporting program that has collected GHG emission data from facilities that released emissions of 10 kt CO_2 eq or more starting in 2017 and from those that released emissions of 50 kt CO_2 eq or more between 2004 and 2016. Where coverage of a specific sector is complete, or close to complete, the GHG reporting program data allows for a comparison between industry-reported values and Canadian inventory emission estimates. This is possible for the Petroleum Refining and Public Electricity subcategories, and oil sands mining and upgrading, due to near complete coverage of these industries.

3.2.4.5. Recalculations

Several improvements and activity data revisions have contributed to increased data accuracy and better comparability, as well as consistency with the 2006 IPCC Guidelines and UNFCCC reporting guidelines. There were revisions, for all years, to emission estimates for the Energy Industries category, with estimates for 2018 decreasing by 3.3 Mt CO_2 eq compared to the previous submission.

Revisions to the Public Electricity and Heat Production subcategory occurred back to 1990, because of changes to emission factors, which affect the entire time series. Emission estimates for 2018 decreased by 0.1 Mt CO_2 eq because of these improvements.

Recalculations to estimates for the Manufacture of Solid Fuels and Other Energy Industries subcategory occurred back to 1990 as a result of several revisions:

- Updated CO_2 emission factor (EF) for Alberta producer consumption of non-marketable natural gas. The new CO_2 EF ranges from 12% to 14% lower than the old EF, depending on the year. The new EFs are based on detailed gas composition data for the province of Alberta (see Annex 6, section A6.1.1.1 for more details).
- Revisions to Alberta non-marketable natural gas producer consumption volumes in the RESD for the years 2005–2018 resulted in an increase in natural gas volume of between 2 to 42%, depending on the year. These volume revisions, coupled with the CO_2 EF change caused decreases in natural gas emissions in Alberta from 1990–2004 and 2016–2018 (ranging from 3 to 4.5 Mt CO_2 eq) and increases in emissions from 2005–2015 (ranging from 1 to 5.1 Mt).
- Activity data revisions to producer consumption of non-marketable natural gas volumes in Saskatchewan from 1990–2013 and in British Columbia from 2006–2012. These revisions resulted in decreases in emissions from combustion of producer consumed natural gas in 1990 (1.5 Mt) and from 1992–2005 (ranging from 0.2 Mt to 1.8 Mt). Emissions increased in 1991 (0.2 Mt) and from 2006–2013 (ranging from 0.4 to 1.3 Mt).
- Revisions to the volumes of flared or vented gas in Alberta and Saskatchewan that are subtracted from producer consumption of natural gas resulted in increases in emissions from 1990–1995 and 1997–2004 (ranging from 0.2 Mt to 0.7 Mt), virtually no change in 1996 (1 kt decrease) and decreases in emissions from 2005–2018 (ranging from 0.1 to 1.2 Mt). As described in Annex 3.2, section A3.2.2.7, flaring and venting emissions are estimated separately using the various fugitive models and are reported as fugitives, while the producer consumed natural gas volumes reported in the RESD and included in stationary combustion emission estimates include the amount of flared and vented gas. Therefore, subtraction of the volumes of flared and vented gas as well as the associated emissions, from the combustion estimates, avoids a double count.

Updates to CO_2 emission factors for petroleum coke and still gas (refinery gas) resulted in recalculations for industries consuming those fuels (such as petroleum refineries). Revised CO_2 emission factors provided improved accuracy, based on newly compiled refinery information prepared by the Canadian Energy and Emissions Data Centre (CEEDC) located at Simon Fraser University. CEEDC collects annual refinery information such as fuel consumption data, CO_2 emission factors and heat contents to develop annual, nationally weighted CO_2 emission factors. This process accounts for year-to-year variations in fuel composition and facility production. In addition, the CEEDC update also addressed reporting gaps from some facilities since 2001 and some error corrections. Historically, these data gaps were filled using data from similar sized facilities, however, this was not always a good proxy due to operational differences. Refer to Table 3–6: Revised Still Gas and Petroleum Coke EF, to see the impact of new CO_2 EFs relative to the old factors.

Table 3–6 **Revised Still Gas and Petroleum Coke Emission Factors**

Year	Still Gas Emission Factor (kg / 1 000 m³)		Petroleum Coke Emission Factor (kg / 1 000 l)	
	2020 Submission	2021 Submission	2020 Submission	2021 Submission
1990	1 740	1 740	3 770	3 770
1991	1 740	1 740	3 770	3 770
1992	1 740	1 740	3 770	3 770
1993	1 740	1 740	3 770	3 770
1994	1 760	1 760	3 800	3 800
1995	1 800	1 800	3 790	3 790
1996	1 800	1 800	3 740	3 740
1997	1 780	1 780	3 760	3 750
1998	1 680	1 680	3 760	3 770
1999	1 800	1 800	3 780	3 780
2000	1 680	1 680	3 710	3 710
2001	1 650	1 650	3 760	3 760
2002	1 670	1 660	3 810	3 800
2003	1 700	1 690	3 830	3 840
2004	1 710	1 690	3 810	3 810
2005	1 720	1 710	3 810	3 870
2006	1 750	1 740	3 820	3 780
2007	1 760	1 750	3 820	3 810
2008	1 710	1 690	3 820	3 830
2009	1 720	1 710	3 820	3 840
2010	1 840	1 830	3 830	3 850
2011	1 830	1 820	3 810	3 810
2012	2 080	1 720	3 810	3 830
2013	2 100	1 740	3 830	3 800
2014	2 110	1 740	3 810	3 730
2015	2 140	1 760	3 830	3 750
2016	2 160	1 780	3 790	3 750
2017	2 180	1 800	3 810	3 780
2018	2 220	1 850	3 780	3 740
2019		1 800		3 760

3.2.4.6. Planned Improvements

Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Statistics Canada (StatCan) continue to collaborate on improvements to the quality of the national energy balance and the disaggregation of fuel-use data via a Trilateral Energy Working Group. Shared quality control responsibilities across working group members (for the RESD and some feeder surveys[5]) also contributes to annual improvements in the national energy balance and, in turn, the National Inventory. StatCan is responsible for implementing improvements, conducting feasibility assessments of projects and recommending approaches to collect new data. Discussions of recalculations resulting from improvements to the energy balance are found in their respective sections or in the general overview section of this chapter.

StatCan has assessed and modernized some surveys to better capture supply and demand of fossil and renewable fuels. These updates will improve the quality and enhance the transparency of RESD data. Examples of refinements and updates include: 1) the monthly refined petroleum production survey, to capture information from an expanded pool of respondents, beyond refineries, to include terminals, 2) the monthly oil product pipeline survey, to collect additional information on fossil fuels transported via pipelines, and 3) a new monthly renewable fuels survey, which collects details on types of biodiesel and ethanol produced in Canada. StatCan is also working to improve the data collection methods regarding the movement of fossil, and renewable, fuels via rail and marine vessels.

Priority for emission factor improvements has been on fuels with the largest contribution to combustion emissions, such as coal, gasoline, diesel and natural gas. In recent years, new test results and studies have provided the basis for updates to the coal, gasoline and diesel CO_2 emission factors and heating values. Annex 6 of this report presents the results of these improvement activities.

An assessment of regional (provincial and territorial) natural gas energy conversion factors from 1990 onward, using data reported to StatCan, concluded that the available information was insufficient to reliably track variations in energy density across Canada, particularly in natural gas producing regions. Western Canada produces the vast majority of natural gas and ships this product to eastern Canada and to the USA. An improvement project to collect representative natural gas data across Canada, for use in updating CO_2 emission factors and high heat values (HHV) is underway. The first stage of the project identified key natural gas transmission and distribution points, from which information about a representative compositional

5 For example, the Industrial Consumers of Energy (ICE) Survey

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mix for natural gas consumed across Canada could be assessed. The second stage of the project involved working with industry to collect the necessary fuel volume and composition data for each of these points. Members of the Canadian Energy Partnership for Environmental Innovation (which includes natural gas transmission and distribution companies) support this project and many have provided detailed data for the years 2005 to 2018. Industry interest, and voluntary participation, in updating natural gas CO_2 emission factors and HHVs, along with efforts to ensure sufficient and transparent information, has been critical to the success of this project. Following the completion of data collection and quality assessment, 2021 will see the development of representative emission factors and heating values, with planned application to future inventories.

In addition, work is under way to investigate the possibility of developing a bottom-up inventory for the Public Electricity and Heat Generation subcategory, consistent with Tier 3 methods. Further research and investigation is necessary to ensure correct allocation of emissions from privately owned combined heat and power plants and heat plants.

3.2.5. Manufacturing Industries and Construction (CRF Category 1.A.2)

3.2.5.1. Source Category Description

This category is composed of emissions from the combustion of purchased fossil fuels by all mining, manufacturing and construction industries. The following subsections present the six UNFCCC assigned subcategories under the Manufacturing Industries and Construction category.

In 2019, the Manufacturing Industries and Construction category accounted for 63.9 Mt (8.8%) of Canada's total GHG emissions, with a 10% (7.4 Mt) decrease in overall emissions since 1990 (refer to Table 3–7 for more details). Within the Manufacturing Industries and Construction category, 34.2Mt (53.5%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction, off-road (associated with the manufacturing, mining and construction) along with other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, the Chemicals (9.4 Mt, 14.7%), Pulp, Paper and Print (7.31 Mt, 11.4%), Iron and Steel (5.97 Mt, 9.3%), Non-metallic Minerals (4.22 Mt, 6.6%); and Non-ferrous Metals (2.83 Mt, 4.4%) subcategories. GHG emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory due to a lack of disaggregated fuel-use data.

GHG emissions resulting from fuel combustion for the generation of electricity or steam by an industry are assigned to the corresponding industrial subcategory (see Annex 3.1). The Industrial Processes and Product Use sector reports GHG emissions from the non-energy use of fossil fuels, such as metallurgical coke for iron ore reduction, other fuels for feedstocks and chemical reagents.

3.2.5.2. Methodological Issues

Calculation of GHG emissions from fuel combustion for each subcategory within the Manufacturing Industries and Construction category uses the methodology described in Annex 3.1, including the off-road method, which is consistent with an IPCC Tier 2 approach. GHG emissions generated from the use of transportation fuels (e.g. diesel and gasoline) appear under Off-road Vehicles

Table 3–7 **Manufacturing Industries and Construction GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Manufacturing Industries and Construction TOTAL (1.A.2)	**71 400**	**74 000**	**72 500**	**63 800**	**60 400**	**63 800**	**62 600**	**63 200**	**63 000**	**62 000**	**59 200**	**61 300**	**63 600**	**63 900**
Iron and Steel	4 950	5 780	6 210	5 550	4 980	5 290	5 500	5 580	6 030	5 700	5 560	5 940	6 300	5 970
Non-ferrous Metals	3 310	3 220	3 580	3 660	3 070	3 420	2 970	3 100	2 920	3 110	3 190	3 220	2 790	2 830
Chemicals	8 260	10 300	10 700	8 330	9 920	11 100	11 000	11 600	12 400	12 000	10 700	9 600	9 300	9 400
Pulp, Paper and Print	14 500	12 800	12 600	8 650	5 970	6 220	5 990	6 230	6 090	5 950	5 950	6 320	6 970	7 310
Food Processing, Beverages and Tobacco[a]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 970	4 160	4 640	5 410	4 080	4 310	4 030	3 850	4 000	3 910	3 920	4 150	4 160	4 220
Other	36 400	37 700	34 900	32 200	32 400	33 500	33 200	32 900	31 500	31 300	29 900	32 100	34 100	34 200
Mining (excluding fuels) and Quarrying[b]	4 170	4 400	4 290	3 960	5 070	5 130	5 600	4 810	4 520	4 110	3 810	4 430	5 810	5 910
Construction	1 880	1 180	1 080	1 450	1 520	1 370	1 390	1 290	1 300	1 300	1 280	1 290	1 360	1 360
Off-road Manufacturing, Mining and Construction	9 160	12 400	11 300	10 400	12 600	13 200	12 000	12 300	12 200	13 100	12 200	13 500	14 500	14 300
Other Manufacturing	21 200	19 700	18 200	16 400	13 200	13 800	14 200	14 400	13 500	12 800	12 600	12 800	12 500	12 600

Notes:

IE = Included elsewhere

Totals may not add up due to rounding.

a. Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.

b. In accordance with UNFCCC Common Reporting Format tables, combustion emissions from coal mines are excluded from Mining (excluding fuels) and Quarrying. However, in Annexes 9 and 11, these emissions are included in the Mining category.

and Other Machinery (1.A.2.g.vii) of the Manufacturing Industries and Construction category. CH_4 and N_2O emissions from the combustion of biomass were also included in the relevant subcategory of Manufacturing Industries and Construction. CO_2 emissions from biomass combustion are not included in totals but appear separately in the UNFCCC CRF tables as a memo item.

See the following for methodological issues specific to each manufacturing subcategory.

Iron and Steel (CRF Category 1.A.2.a)

There are currently three integrated iron and steel facilities producing all the coal-based metallurgical coke in Canada. These facilities are structured such that by-product gases from the integrated facilities (e.g. coke oven gas, blast furnace gas) are used in a variety of processes throughout the facility (e.g. boilers, blast furnace, coke oven) and, for that reason, emissions from coke production are included in the Iron and Steel subcategory. StatCan reports all coke oven gas produced and consumed at these integrated facilities in the RESD. Determining the specific amount of coke oven gas flared is not feasible, but since StatCan includes the amount of fuel flared in the RESD consumption totals, these fugitive emissions appear as combustion estimates in the inventory.

The Industrial Processes and Product Use sector reports all emissions associated with the use of metallurgical coke as a reagent for the reduction of iron ore in blast furnaces.

Non-Ferrous Metals (CRF Category 1.A.2.b)

The RESD provides all fuel-use data for this subcategory.

Chemicals (CRF Category 1.A.2.c)

The Industrial Processes and Product Use sector reports emissions resulting from fuels used as feedstocks.

Pulp, Paper and Print (CRF Category 1.A.2.d)

The RESD provides all fuel-use data for this subcategory.

Food Processing, Beverage and Tobacco (CRF Category 1.A.2.e)

Fuel-use data for this subcategory is not available in a disaggregated form. GHG emissions from this subcategory are included in the Other Manufacturing subcategory.

Non-Metallic Minerals (CRF Category 1.A.2.f)

The RESD provides all fuel-use data for this category, with the exception of waste fuel, which comes from annual industry data supplied by the CEEDC.

Other (Mining, Construction and Other Manufacturing) (CRF Category 1.A.2.g)

This subcategory covers the remaining industrial sector emissions, including the mining, construction, vehicle manufacturing, textiles, food, beverage and tobacco subcategories.

Related on-site off-road emissions are reported here under Off-road Vehicles and Other Machinery (1.A.2.g.vii) including off-road emissions attributable to mining, construction, and oil and gas operations.

3.2.5.3. Uncertainties and Time-Series Consistency

The estimated uncertainty for the Manufacturing Industries and Construction category is ±2% for CO_2, CH_4 and N_2O combined.

The underlying fuel quantities and CO_2 emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption.

As mentioned in the uncertainty discussion for the Energy Industries category, additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting 2004).

The estimates for the Manufacturing Industries and Construction category have been prepared in a consistent manner over time using the same methodology. Section 3.2.4.5, Recalculations, presents a discussion on updated RESD fuel-use data.

3.2.5.4. QA/QC and Verification

The completed QC checks were consistent with the 2006 IPCC Guidelines. Elements of the QC checks included a review of the estimation model, activity data, emission factors, time-series consistency, transcription accuracy, reference material, conversion factors and unit labelling, and sample emission calculations.

QC checks completed on the entire stationary combustion GHG estimation model and time series included the following areas: emission factors, activity data and CO_2, CH_4 and N_2O emissions. No mathematical or reference errors were found during the QC checks. The data, methodologies and changes related to the QC activities are documented and archived.

3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2018 decreasing by 1.7 Mt CO_2 eq over the previous submission, because of the following changes:

- revised RESD data
- revised emission factors for petroleum coke and still gas

Revisions to the Manufacturing Industries and Construction category occurred back to 1990. Changes to emission factors affect the entire time series, while changes to the activity data, in the form of updates in the RESD, affects 2018. The revised RESD data resulted in a 1.9 Mt decrease in emissions for 2018.

The revised emission factors resulted in decreases to emissions ranging from -0.04 Mt to 0.2 Mt between 1990 and 2017, and a 0.2 Mt increase in emissions in 2018.

3.2.5.6. Planned Improvements

ECCC, NRCan, and StatCan continue to collaborate on improvements to the quality of the national energy balance and to the disaggregation of fuel-use data via a Trilateral Energy Working Group. Refer to 3.2.4.6, Planned Improvements for a bit more detail on StatCan and the Trilateral Energy Working Group's activities.

There are several planned updates to off-road emissions modelling inputs. Refer to 3.2.6.6, Planned Improvements for further details.

In addition, the UNFCCC Expert Review Team (ERT) recommended that Canada report the GHG emissions associated with the 1.A.2.e Food Processing, Beverage and Tobacco sector separately from subcategory 1.A.2.g, Other. However, StatCan does not currently have the needed information to further disaggregate fuel-use data to this level of detail. Investigations of additional data sources and methods continue, with the goal of reallocating the data, as needed.

3.2.6. Transport (CRF Category 1.A.3)

In 2019, transport-related GHG emissions total 187 Mt, accounting for about 26% of Canada's total GHG emissions (Table 3–8). The most significant emission growth since 1990 has been observed in light-duty gasoline trucks (LDGTs), light-duty diesel trucks (LDDTs) and heavy-duty diesel vehicles (HDDVs), with growth of 161% (33 Mt) for LDGTs, 686% (1.1 Mt) for LDDTs and 280% (38 Mt) for HDDVs. A long-term decrease in emissions has occurred from light-duty gasoline vehicles (LDGVs, i.e. cars) and propane and natural gas vehicles, for a combined decrease of 10 Mt since 1990. Emissions from the Transport category have

Table 3–8 **Transport GHG Emissions**

GHG Source Category	GHG Emissions (kt CO_2 eq)												
	1990	1995	2000	2005	2011	2012	2013	2014	2015	2016	2017	2018	2019
Transport	**124 000**	**130 000**	**151 000**	**163 000**	**166 000**	**168 000**	**173 000**	**172 000**	**173 000**	**175 000**	**179 000**	**185 000**	**187 000**
Domestic Aviation[a]	7 280	6 470	7 530	7 460	6 360	7 350	7 670	7 380	7 350	7 270	7 710	8 420	8 300
Road Transportation	83 800	86 600	111 000	130 000	139 000	140 000	144 000	142 000	143 000	145 000	148 000	152 000	153 000
Light-Duty Gasoline Vehicles	41 600	40 400	40 400	41 400	36 500	35 400	35 600	34 200	34 500	34 600	33 700	33 000	32 400
Light-Duty Gasoline Trucks	20 300	23 900	31 800	38 100	41 400	41 900	43 300	43 400	45 300	48 100	49 200	51 100	53 100
Heavy-Duty Gasoline Vehicles	6 320	7 170	10 500	11 700	12 100	12 800	13 400	12 400	12 300	13 000	13 300	13 400	13 500
Motorcycles	90	78	123	203	251	260	262	260	271	287	296	296	298
Light-Duty Diesel Vehicles	467	400	600	605	793	798	855	857	901	842	842	811	779
Light-Duty Diesel Trucks	153	156	338	344	482	473	531	641	812	903	1 080	1 180	1 210
Heavy-Duty Diesel Vehicles	13 600	13 600	26 500	36 800	47 600	48 700	50 000	49 800	48 500	46 900	49 300	51 900	51 800
Propane and Natural Gas Vehicles	1 160	903	522	381	40	30	18	9	8	9	10	10	10
Railways	6 920	6 260	6 530	6 580	7 390	7 560	7 290	7 470	7 120	6 540	7 490	7 650	7 700
Domestic Navigation[a, b]	2 170	2 430	2 700	3 080	2 880	2 940	2 990	3 050	3 100	3 200	3 380	3 600	4 070
Other Transportation[c]	23 600	28 300	23 000	16 500	10 100	10 000	11 000	12 400	13 000	13 300	12 500	13 500	13 300
Off-Road	16 700	16 300	11 700	6 390	4 450	4 310	4 300	4 540	4 830	4 920	5 120	5 260	5 050
Pipeline Transport	6 900	12 000	11 300	10 200	5 650	5 730	6 720	7 890	8 160	8 420	7 420	8 190	8 290

Notes:

Totals may not add up due to rounding.

a. Excludes emissions from military equipment, reported in the Other (Not Specified Elsewhere) (CRF Category 1.A.5) categories.

b. Excludes emissions from fishing vessel which are reported in the Agriculture/Forestry/Fishing categories.

c. Excludes off-road emissions reported in the Manufacturing Industries and Construction and Other Sectors categories.

increased 51% and have contributed the equivalent of 49% of the total overall growth in emissions observed in Canada.

3.2.6.1. Source Category Description

The Transport category comprises the combustion of fuel by all forms of transportation in Canada. The category is divided into six distinct subcategories:

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Pipeline Transport
- Other Transportation (Off-road)

3.2.6.2. Methodological Issues

Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3-1 in Annex 3.1. However, because of the many different types of vehicles, activities and fuels, the emission factors are numerous and complex. In order to cope with this complexity, transport emission estimates are calculated using the Motor Vehicle Emissions Simulator (MOVES) model, NONROAD and the Aviation Greenhouse Gas Emission Model (AGEM). These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC 2006) and are used to calculate all transport emissions with the exception of those associated with marine navigation, railways, and pipelines (i.e. the energy necessary to transport liquid or gaseous products through pipelines). Refer to Annex 3.1 for a detailed description of Transport methodologies.

Domestic Aviation (CRF Category 1.A.3.a)

This subcategory includes all GHG emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines (IPCC 2006), military air transportation emissions are reported in the Other (Not specified elsewhere) – Mobile subcategory (CRF category 1.A.5.b). Emissions from transport fuels used at airports for ground transport are reported under Other Transportation/Other (1.A.3.e.ii). Emissions arising from flights that have their origin in Canada and destination in another country are considered international in nature and are reported separately under Memo Items – International Bunkers (CRF category 1.D.1.a).

The methodology for the Domestic Aviation subcategory follows a modified IPCC Tier 3 approach. Emissions estimates employ a mix of country-specific, aircraft-specific and IPCC default emission factors. The estimates are generated using AGEM and are calculated using the reported quantities of aviation gasoline and turbo fuel consumed that are published in the RESD (Statistics Canada 1990–). The majority of aircraft fuel sales reported in the RESD represents aircraft fuels sold to Canadian airlines, foreign airlines, and public administration and commercial/institutional sectors.

Road Transportation (CRF Category 1.A.3.b.i-v)

The methodology used to estimate road transportation GHG emissions is a detailed IPCC Tier 3 method, as outlined in IPCC (2006). MOVES calculates energy consumption by a range of vehicle classifications based on country-specific fleet information and driving rates, which are then applied to country-specific emission factors.

Railways (CRF Category 1.A.3.c)

The procedure used to estimate GHG emissions from the Railways subcategory adheres to an IPCC Tier 2 methodology for CO_2 emissions and an IPCC Tier 1 methodology for CH_4 and N_2O emissions (IPCC 2006). Fuel sales data from the RESD (Statistics Canada 1990–) reported under railways are multiplied by country-specific emission factors.

Total emissions from steam train operations are considered insignificant and are not included in the inventory. Assessment of Canadian operations, found that they collectively produce about 0.5 kt CO_2 eq, below specified UNFCCC reporting requirements of 0.05% of total emissions and less than 500 kt threshold.

Domestic Navigation (CRF Category 1.A.3.d)

This subcategory includes all GHG emissions from domestic marine transport. Emissions arising from fuel used for international voyages are reported as international bunkers and are reported separately under Memo Items – International Bunkers (CRF Category 1.D.1.b). Emissions from fuel consumed by fishing vessels are reported under Agriculture/Forestry/Fishing – CRF Category 1.A.4.c. Emissions from fuel consumed by military vessels are reported under Other (Not specified elsewhere) – Mobile subcategory (CRF category 1.A.5.b).

The methodology complies with an IPCC Tier 2 technique for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions (IPCC 2006). Fuel consumption data from the RESD is reconciled with the fuel consumption data from the MEIT and the results are multiplied by country-specific or IPCC default emission factors.

Pipeline Transport (CRF Category 1.A.3.e.i)

Pipelines[6] represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel hydrocarbon-based products. In the case of natural gas pipelines, the fuel used is primarily natural gas. While oil pipelines tend to

6 Transporting either oil and/or gas through high-pressure pipeline systems.

use electric motors to operate pumping stations, some consumption of refined petroleum, such as diesel fuel, occurs as a backup during power failures.

An IPCC Tier 2 methodology with country-specific emission factors and fuel consumption data from the RESD is applied.

Other Transportation (Off-road)
(CRF Category 1.A.3.e.ii)

This subcategory comprises vehicles and equipment not licensed to operate on roads or highways and not allocated to one of the following categories:

- Manufacturing Industries and Construction/Other/Off-road Vehicles and Other Machinery (1.A.2.g.vii)
- Other Sectors/Commercial-Institutional/Off-road Vehicles and Other Machinery (1.A.4.a.ii)
- Other Sectors/Residential/Off-road Vehicles and Other Machinery (1.A.4.b.ii)
- Other Sectors/ Agriculture-Forestry-Fishing/Off-road Vehicles and Other Machinery (1.A.4.c.ii)

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Non-road or off-road transport[7] (ground, non-rail vehicles and equipment) includes GHG emissions resulting from fuel combustion. Vehicles in this subcategory include airport ground support equipment, railway maintenance equipment, and off-road recreational vehicles.

Off-road emissions are calculated using an IPCC Tier 3 approach. Emissions are based on country-specific emission factors, equipment populations and usage factors.

3.2.6.3. Uncertainties and Time-Series Consistency

Transport

The overall uncertainty of the 2019 estimates for the Transport category (not including pipelines) was estimated to be ±1.3% for CO_2, CH_4 and N_2O combined.

Emissions from Domestic Aviation

The uncertainty associated with overall emissions from domestic aviation was estimated to be ±5.8%. The Domestic Aviation subcategory only contributed approximately 4% to total Transport GHG emissions and therefore did not significantly influence overall uncertainty levels.

Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be within the range of ±1.3%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions, as well as biofuel activity data, did not significantly influence the analysis because of their comparatively minor contributions to the inventory.

Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be ±21%. The greatest influence was exerted by the high N_2O emission factor uncertainty (-50% to +200%), whereas the relatively low uncertainties in diesel fuel activity data and CO_2 emission factors contributed very little. It is important to note that railway emissions only accounted for approximately 4% of the Transport category GHG inventory and therefore did not significantly influence the overall uncertainty results.

Emissions from Domestic Navigation

The uncertainty associated with emissions from the Domestic Navigation category was estimated to be ±2.9%. The high N_2O emission factor uncertainty (-40% to +140%) represented the largest contribution to uncertainty, while CO_2 emission factor uncertainties were insignificant. Since domestic navigation emissions only made up 2% of the Transport category GHG inventory, they did not substantially alter the overall uncertainty results.

Emissions from Pipeline Transport

In general, the CH_4 emission uncertainty for pipeline transport ranges from ±40%. Table A2-1 and Table A2-2 show specific uncertainties from pipelines, by GHGs.

Emissions from Off-road

The Off-road subcategory includes equipment consuming gasoline, diesel, propane and natural gas. The uncertainty associated with the off-road transport sources was estimated to be ±1.4%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions.

3.2.6.4. QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (see Chapter 1) were performed on all categories in Transport, not just those designated as "key." No significant mathematical errors were found.

In addition, certain verification steps were performed during the model preparation stage. Since MOVES uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Interdepartmental relationships exist among ECCC, Transport Canada, StatCan, and NRCan to facilitate the sharing of not only

7 Referred to as non-road or off-road vehicles. The terms "non-road" and "off-road" are used interchangeably.

raw data but also derived information such as vehicle populations, fuel consumption ratios (FCRs) and kilometre accumulation rates (KARs). For example, KARs were validated using the Canadian Vehicle User Survey, and independent survey of drivers managed by Transport Canada. This broader perspective fosters a better understanding of actual vehicle use and should promote better modelling and emission estimating.

3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2018 period as follows.

- RESD fuel: Revised preliminary 2018 RESD data as well as the motor gasoline and diesel fuel volumes for 2016 and 2017.
- Aviation methodology update: An updated aviation methodology is now being used to better define aircraft movements and refine the emissions released during different flight modes/phases. (refer to Annex 3, section A3.1.4.2.2 for more details)
- Marine activity data update: Revisions to the activity data (Marine Emissions Inventory Tool) for the 2015 calendar year and new activity data for the 2016, 2017 and 2018 calendar years were incorporated into the marine consumption-based model. The 2015 revisions and expansion of the vessel based activity data for the 2016 to 2018 calendar years provide the marine model with precise fuel consumption values throughout a vessel's movements. This level of precision increases the accuracy between the amounts of fuel consumed for all marine IPCC categories (refer to Annex 3, section A3.1.4.2.3 for more details).

Table 3–2 summarizes the net impact of these recalculations.

3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priorities include implementing several updates to both off-road and on-road emissions modelling inputs. For off-road, these updates include revising vehicle and equipment population data, modifying how these vehicles and equipment are regionally distributed and revising annual hours of use rates for select vehicles and equipment. These improvements will not be exclusive to off-road vehicles and equipment assigned to the Transport category. Off-road vehicles and equipment assigned to Other Sectors (CRF Category 1.A.4) and Manufacturing Industries and Construction (CRF Category 1.A.2) will also be improved upon. For on-road, these updates include revising on-road vehicle population data, updating KARs for recent years and potentially adopting the latest version of MOVES.

3.2.7. Other Sectors (CRF Category 1.A.4)

3.2.7.1. Source Category Description

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential and Agriculture/Forestry/Fishing. The Commercial/Institutional subcategory also includes GHG emissions from the public administration subcategory (i.e. federal, provincial and municipal establishments). GHG emissions for these subcategories are from fuel combustion, primarily related to space and water heating.

Biomass combustion is a significant source of emissions in the Residential subcategory, where firewood provides a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO_2 as well as technology-dependent CH_4 and N_2O emissions. The main types of residential wood combustion devices are stoves, fireplaces, furnaces and other equipment (e.g. pellet stoves). Biomass used to generate electricity is a small source of emissions in the Commercial/Institutional subcategory. Emissions from CH_4 and N_2O were included in the subcategory estimates, with CO_2 emissions reported separately in the CRF tables as memo items and not included in Energy sector totals.

In 2019, the Other Sectors category contributed 95.9 Mt (13.2%) of Canada's total GHG emissions, with an overall growth of about 14.1% (11.9Mt) since 1990. Within the Other Sectors category, the Residential subcategory contributed emissions of about 43.5 Mt (45.3%), followed by the Commercial/Institutional subcategory with emissions of 37.3 Mt (38.9%) and the Agriculture/Forestry/Fishing subcategory with 15.1 Mt (15.8%). Since 1990, GHG emissions have grown by 34.6% (9.6 Mt) in the Commercial/Institutional subcategory and 22.7% (2.8Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 1.3% (0.55 Mt). Refer to Table 3–9 for additional details. Chapter 2 has further discussion of trends for the Other Sectors category.

3.2.7.2. Methodological Issues

Emission calculations for these source categories use the methodology described in Annex 3.1, which is an IPCC Tier 2 approach, with country-specific emission factors. See below for methodological issues specific to each category. Emissions from the combustion of transportation fuels (e.g. diesel and gasoline) are estimated using methods described in the Transport category.

Commercial/Institutional (CRF Category 1.A.4.a)

Emissions estimates in this category use RESD commercial and public administration fuel-use data. In the case of landfill gas (LFG), ECCC collects production volumes. CH_4 and N_2O emissions from the combustion of LFG are included in this category, with CO_2 emissions

Table 3–9 **Other Sectors GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Other Sectors TOTAL (1.A.4)	**84 100**	**92 700**	**96 100**	**94 400**	**88 400**	**94 000**	**87 300**	**90 100**	**91 300**	**88 800**	**86 500**	**91 600**	**95 000**	**95 900**
Commercial/Institutional	27 700	31 400	35 500	35 000	31 400	33 400	31 200	32 400	34 100	32 800	32 700	35 300	36 100	37 300
Commercial and Other Institutional	26 200	29 400	33 400	32 600	28 700	30 700	28 700	29 700	31 300	30 100	30 100	32 500	33 200	34 400
Off-road Commercial & Institutional	1 520	1 990	2 080	2 400	2 680	2 730	2 520	2 720	2 760	2 720	2 550	2 820	2 900	2 960
Residential	44 000	45 300	45 500	44 900	42 000	45 100	41 400	43 000	42 600	41 700	40 100	42 100	43 700	43 500
Stationary Combustion	43 800	44 900	44 700	43 700	40 800	43 800	40 200	41 800	41 400	40 500	39 000	40 900	42 500	42 200
Off-road Residential	241	380	775	1 250	1 170	1 300	1 220	1 180	1 210	1 220	1 170	1 190	1 230	1 240
Agriculture/Forestry/Fishing	12 300	16 100	15 100	14 400	15 000	15 400	14 700	14 700	14 600	14 300	13 700	14 300	15 200	15 100
Agriculture and Forestry	2 410	2 770	2 570	2 190	3 110	3 680	3 780	3 790	3 840	3 630	3 810	3 700	3 760	3 690
Off-Road Agriculture/ Forestry/Fishing	9 920	13 310	12 520	12 260	11 880	11 750	10 960	10 960	10 780	10 650	9 890	10 570	11 420	11 430

Note: Totals may not add up due to rounding.

excluded from totals and reported separately in the UNFCCC CRF tables as a memo item. In the case of waste incineration for energy purposes, ECCC collects consumption quantities of municipal solid waste, and estimates quantities of medical waste. See Annex 3, section A3.6.3 for further details. The CO_2, CH_4 and N_2O combustion emissions from the non-biogenic portion of the waste are included, along with CH_4 and N_2O emissions from the biogenic portion of the waste. National GHG totals exclude CO_2 emissions from the biogenic portion of the waste; these numbers appear separately in the UNFCCC CRF tables as a memo item.

Related on-site off-road emissions are reported under Off-road Vehicles and Other Machinery (1.A.4.a.ii) in accordance with CRF categorization. Emissions from commercial and industrial lawn and garden maintenance, snow removal equipment, pumps, compressors, welders and generator sets are also included here.

Residential (CRF Category 1.A.4.b)

Emissions estimates in this category use RESD residential fuel-use data, with the exception of biomass data which StatCan, ECCC and NRCan collects using a periodic stand-alone survey. Annex 3.1 details the methodology for biomass combustion from residential firewood. The CH_4 and N_2O emissions from firewood combustion are reported here, and CO_2 emissions, while not accounted for in the national residential GHG total, are reported as a memo item.

Related on-site off-road emissions are reported under Off-road Vehicles and Other Machinery (1.A.4.b.ii) in accordance with CRF categorization. Emissions from residential lawn and garden maintenance equipment are also included here.

Agriculture/Forestry/Fishing (CRF Category 1.A.4.c)

This subcategory includes emissions from fuel combustion in the agriculture, forestry and fishing industries. Emissions estimated for this category are from fishing boats, on-site machinery operation and heating, and use RESD marine, agriculture and forestry fuel-use data. While emissions associated with fishing vessels are included here, emissions from land-based fish processing activities are currently included under the Other Manufacturing (i.e. food processing) subcategory. Annex 3.1.4.2.3, Domestic Navigation, discusses the method to reallocate RESD data and estimate emissions from fishing vessels operating in Canadian waters.

Related on-site off-road emissions for agriculture and forestry are reported under Off-road Vehicles and Other Machinery (1.A.4.c.ii) in accordance with CRF categorization.

3.2.7.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Other Sectors category is ±6% for CO_2, CH_4 and N_2O combined and ±1% for CO_2 alone.

The underlying fossil fuel quantities and non-biomass CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and accurately tracked quantities, as compared to residential biomass data. The overall non-CO_2 emissions uncertainty is 9% for the Residential subcategory, compared to 2% for the Commercial subcategory; this is due to the higher uncertainty associated with residential firewood emission factors (CH_4 with -90% to +1500% and N_2O with -65% to +1000%) than with fossil-fuel-based CH_4 and N_2O emission factors (ICF Consulting 2004). As stated with respect to the Energy Industries category, for some of the emission factor uncertainty ranges and probability density functions, additional expert elicitation will improve the associated CH_4 and N_2O uncertainty estimates.

These estimates use the same methodology and are consistent over the time series. Section 3.2.4.3, Recalculations, presents a discussion of fuel-use data.

3.2.7.4. QA/QC and Verification

The Other Sectors category underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. QC checks found no mathematical, referencing or data errors. The data, methodologies, and changes related to the QC activities are documented and archived.

3.2.7.5. Recalculations

Revised methods and activity data contributed to recalculations and improved accuracy of the emissions for the Other Sectors category, specifically:

- revised RESD data
- revised residential firewood data
- revised municipal solid waste data
- reallocated fishing vessels emissions from the Domestic Navigation category (1.A.3.d)

Revisions to the Other Sectors category occurred back to 1990. Changes to the activity data, in the form of updates to the RESD, affects 2010 to 2018. The revised RESD data resulted in a 0.5 Mt decrease in emissions for 2018.

The revised municipal solid waste data ranged from -52.4 to 2.1 kt over the entire time series.

The revised residential firewood data resulted in a decrease in emissions ranging from 1.6 to 2.9 Mt between 1990 and 2018. Refer to the recalculations discussion in the overview, section 3.1, for additional details.

3.2.7.6. Planned Improvements

Although improvements were implemented to the RESD (as presented in the recalculation discussion in the overview section of 3.1), ECCC, NRCan, and StatCan continue to work jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information. Refer to 3.2.4.6, Planned Improvements for a bit more detail on the StatCan and the Trilateral Energy Working Group's activities.

Several updates to off-road emissions modelling inputs are also planned. Refer to 3.2.6.6, Planned Improvements for further details.

Additional improvement plans for the Other Sectors category include studies on biomass parameters, such as moisture content, energy content, and emission factors.

3.2.8. Other (Not Specified Elsewhere) (CRF Category 1.A.5)

The UNFCCC reporting guidelines assign military fuel combustion to this CRF category. Emissions generated by military aviation are estimated by AGEM and are included under this category (1.A.5.b). Emissions generated by military water-borne navigation are estimated by MEIT and are included under this category (1.A.5.b). As in previous submissions, emissions related to military vehicles have been included in the Transport category, whereas stationary military fuel use has been included in the Commercial/Institutional subcategory (section 3.2.7) in accordance with the RESD fuel data (Statistics Canada 1990–). See Table 3–10 for additional data.

3.3. Fugitive Emissions from Fuels (CRF Category 1.B)

Fugitive emissions from fossil fuels are intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels.

Fugitive emissions include released gas that is combusted before disposal (e.g. flaring of natural gases at oil and gas production facilities). However, combustion emissions associated with heat generated for internal use (e.g. heating) or sale are reported in the appropriate fuel combustion category.

The two categories reported in the inventory are fugitive releases associated with solid fuels (coal mining and handling, and abandoned coal mines) and releases from activities related to the oil and natural gas industry.

In 2019, the Fugitive Emissions from Fuels category accounted for 54 Mt (7.4%) of Canada's total GHG emissions, with 10% (4.9 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased 13.7% to 52 Mt, and those from coal decreased to 1.4 Mt (50%) since 1990. The oil and gas production, processing, transmission and distribution activities contributed 97% of the fugitive emissions. Refer to Table 3–11 for more details.

Table 3–10 **Other (Not Specified Elsewhere) GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Other (Not Specified Elsewhere) TOTAL (1.A.5)	**262**	**259**	**293**	**286**	**284**	**271**	**302**	**288**	**296**	**342**	**335**	**290**	**287**	**316**

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Table 3–11 **Fugitive GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Fugitive Emissions from Fuels (1.B)	**49 000**	**64 000**	**69 000**	**61 000**	**55 000**	**56 000**	**59 000**	**61 000**	**63 000**	**59 000**	**54 000**	**55 000**	**55 000**	**54 000**
Solid Fuels – Coal Mining (1.B.1)	**2 800**	**2 300**	**1 700**	**1 400**	**1 400**	**1 400**	**1 400**	**1 500**	**1 300**	**1 100**	**1 300**	**1 200**	**1 300**	**1 400**
a. Underground – Mining activities	1 500	700	100	90	90	90	70	90	50	30	NO	60	100	160
b. Abandoned Underground Mines	190	400	550	170	150	140	140	140	50	50	70	70	60	60
c. Surface – Mining activities	1 100	1 200	1 100	1 100	1 100	1 100	1 200	1 300	1 200	1 100	1 200	1 100	1 200	1 200
Oil and Natural Gas (1.B.2)	**46 000**	**62 000**	**68 000**	**60 000**	**54 000**	**54 000**	**57 000**	**59 000**	**61 000**	**58 000**	**53 000**	**54 000**	**53 000**	**52 000**
a. Oil[a]	5 000	6 200	6 600	5 900	5 100	4 900	5 700	5 700	5 600	5 400	5 200	5 200	5 500	5 600
b. Natural Gas[a]	13 000	17 000	18 000	14 000	12 000	12 000	12 000	13 000	13 000	12 000	12 000	12 000	12 000	12 000
c. Venting and Flaring[b]	28 000	38 000	44 000	40 000	36 000	37 000	39 000	40 000	43 000	41 000	35 000	36 000	36 000	35 000
i. Venting	23 000	33 000	38 000	35 000	31 000	32 000	34 000	33 000	36 000	34 000	29 000	29 000	29 000	28 000
ii. Flaring	4 740	5 370	5 760	5 300	4 740	4 980	5 780	6 960	7 270	6 870	5 900	6 560	6 560	6 340

Notes:

NO = Not occurring

Totals may not add up due to rounding.

a. All other fugitives except venting and flaring.

b. Both oil and gas activities.

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3.3.1. Solid Fuels (CRF Category 1.B.1)

3.3.1.1. Source Category Description

The only reported fugitive emissions from solid fuel transformation in Canada come from active and abandoned coal mines. Combustion emissions in CRF category 1.A.2.a., include fugitive emissions from coke manufacturing (flaring). Because of a lack of data, emissions from briquette manufacturing are included in coal mining, where briquette manufacture occurs. Other sources of solid fuel transformation emissions are unknown and assumed insignificant.

Coal Mining and Handling

Sources of mining emissions include exposed coal surfaces, coal rubble and the venting of CH_4 from within the deposit. Post-mining activities such as preparation, transportation, storage and final processing prior to combustion also release CH_4. In 2016, there were no producing underground mines in Canada.

Abandoned Underground Mines

Abandoned underground coal mines are sites where active mining and ventilation management have ceased but fugitive methane emissions continue to occur. In 2019, emissions from abandoned mines were 60 kt CO_2 eq. The decrease in emissions between 2013 and 2014 reflected a return to production of a mine in Nova Scotia. The increase from about 50 kt CO_2 eq in 2015 to 70 kt CO_2 eq in 2016 resulted from two previously active underground mines that ceased operations at the beginning of 2016. See Table 3–11 for additional data.

Solid Fuel Transformation

Solid fuel transformations include activities such as the production of charcoal, or activated carbon, from coal. There is currently only one facility in Canada engaged in this activity and emissions were determined to be negligible.

3.3.1.2. Methodological Issues

Coal Mining and Handling

King (1994) developed an inventory of fugitive emissions from coal mining operations and this provides the bases for some of the coal mining fugitive emissions estimates. Dividing the emission estimates from King (1994) by the known coal production values provided appropriate emission factors. These factors are available in Annex 3.2.

King (1994) estimated emission rates from coal mining using a modified procedure from the Coal Industry Advisory Board. It is a hybrid IPCC Tier 2 and Tier 3 methodology, depending on the availability of mine-specific data. The separate estimates of underground and surface mining activity emissions both include post-mining activity emissions. Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, provides a more detailed description of the methodology.

In late February 2014, a field-testing campaign measured fugitive emissions of CH_4, CO_2, and VOCs at four coal mines:

- Sites 1 and 2: two subbituminous coal mines in central Alberta
- Site 3: one bituminous coal mine in northeast BC
- Site 4: one bituminous coal mine in northwest Alberta

Methane (CH_4) emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo Services and Clearstone Engineering 2014). The CH_4 emission factors of 7 of the 23 producing mines in Canada were updated using data from this field-testing. Annex 3.2 has additional discussion of the methodology.

Abandoned Underground Mines

The 2006 IPCC Guidelines provide a suggested set of parameters and equations for estimating emissions from abandoned coal mines. Estimates were generated using a hybrid IPCC Tier 2 and Tier 3 methodology. The Tier 3 emission factors and rates used for these estimates are mine-specific values which are currently also used to estimate coal mining fugitive emissions for active mines. Activity data used in the model is from provincial ministries and agencies.

Methane emission rates follow time-dependent decline curves (IPCC 2006) influenced by various factors. The most prominent factors are:

- time since abandonment
- coal type and gas absorption characteristics
- mine flooding
- methane flow characteristics of the mine
- openings and restrictions such as vent holes and mine seals

Changes in the number of abandoned mines and the effects of the applied decline curve drive yearly variations in emissions. See Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, for further discussion of the methodology.

3.3.1.3. Uncertainties and Time-Series Consistency

Coal Mining and Handling

The estimated range of CH_4 uncertainty for fugitive emissions from coal mining is -30% to +130% (ICF Consulting 2004). The production data have low uncertainty (±2%), while emission factors have high uncertainty (-50% to +200%). In the absence of specific data or study, Canada's country-specific emission factors use IPCC default uncertainty values.

Abandoned Underground Mines

The assumed uncertainty for emissions estimates from abandoned coal mines is the IPCC (2006) default of -50 to +200%.

3.3.1.4. QA/QC and Verification

The CH_4 emissions from coal mining were a key category and underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. Checks included a review of activity data, time-series consistency, emission factors, reference material, conversion factors and units labelling, as well as sample emission calculations. QC checks revealed no mathematical errors. All QC activities, data and methods were documented and archived.

Abandoned underground mines were also subject to QC checks as noted above.

3.3.1.5. Recalculations

Coal Mining and Handling

This category required no recalculations.

Abandoned Underground Mines

This category required no recalculations.

3.3.1.6. Planned Improvements

Coal Mining and Handling

There are currently no planned improvements.

Abandoned Underground Mines

There are currently no planned improvements.

3.3.2. Oil and Natural Gas (CRF Category 1.B.2)

3.3.2.1. Source Category Description

Fugitive emissions in the Oil and Natural Gas category include emissions from oil and gas production, processing, oil sands mining, bitumen extraction, in-situ bitumen production, heavy oil/bitumen upgrading, petroleum refining, natural gas transmission and storage, and natural gas distribution. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries, and Pipeline Transport subcategories.

The Oil and Natural Gas category has three main components: upstream oil and gas (UOG), oil sands/bitumen, and downstream oil and gas.

Upstream Oil and Gas

UOG includes all fugitive emissions from the exploration, production, processing and transmission of oil and natural gas, excluding those from oil sands mining and heavy oil/bitumen upgrading activities. Emissions may be the result of designed equipment leakage (bleed valves, fuel gas-operated pneumatic equipment), imperfect seals on equipment (flanges and valves), use of natural gas to produce hydrogen, and accidents, spills and deliberate vents.

The emission sources fall into these major groups.

Oil and Gas Well Drilling and Associated Testing: Oil and gas well drilling is a minor emission source. The emissions are from drill stem tests, release of entrained gas in drilling fluids and volatilization of invert drilling fluids.

Oil and Gas Well Servicing and Associated Testing: Well servicing is also a minor source of fugitive emissions mainly from venting and flaring. Emissions from fuel combustion for well servicing and testing are included in Stationary Combustion emissions. Venting and flaring emissions are divided into three service operation types: unconventional service work (i.e. hydraulic fracturing), conventional service work (e.g. well repairs and inspections, cementing operations) and blowdown treatments for shallow natural gas wells. Although flaring and venting volumes are reported directly to provincial regulators, the provincial data sources do not consistently allocate the volume records to the correct subsector. For example, well completion emissions resulting from flowback at hydraulically fractured wells may be reported under well drilling, servicing, testing or production phases. It is assumed that there is no significant potential for fugitive emissions from leaking equipment. Fugitive emissions from absolute open flow tests are assumed negligible.

Natural Gas Production: Natural gas is produced exclusively at gas wells or in combination with conventional oil, heavy oil and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities and gas batteries. The majority of emissions result from equipment leaks, such as leaks from seals; however, venting from the use of fuel gas to operate pneumatic equipment and line-cleaning operations are also significant sources.

Light/Medium Oil Production: Light and medium crude oils have a density of less than 900 kg/m^3. Fugitive emissions arise from wells, flow lines and batteries (single, satellite and central). The largest sources of emissions are the venting of solution gas and evaporative losses from storage facilities.

Heavy Oil Production: Heavy oil has a density above 900 kg/m^3. Production of this viscous liquid requires special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources for both types are wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

In-situ Bitumen Production: Crude bitumen is a highly viscous, dense liquid that cannot be removed from a well using primary production means. Enhanced heavy oil recovery is required to recover the hydrocarbons from the formation (e.g. cold heavy oil production with sand, cyclic steam stimulation, steam-assisted gravity drainage, and experimental methods, such as toe-to-heel air injection, vapour extraction process and combustion overhead gravity drainage). The sources of emissions are wells, flow lines, batteries and cleaning plants. The main source of emissions is the venting of casing gas.

Natural Gas Processing: Natural gas is processed before entering transmission pipelines to remove water vapour, contaminants and condensable hydrocarbons. There are four different types of natural gas plants: sweet plants, sour plants that flare waste gas, sour plants that extract elemental sulphur, and straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function to other gas plants. The largest source of emissions is equipment leaks.

Natural Gas Transmission: Pipelines move virtually all of the natural gas produced in Canada from the processing plants to the gate of the local distribution systems. The volumes transported by truck are insignificant and assumed to be negligible. Emission sources in the gas transmission system include process vents and equipment leaks. Process vent emissions include emissions from activities such as compressor start-up and purging of lines during maintenance. The largest source of emissions is equipment leaks.

Liquid Product Transfer: The transport of liquid products from field processing facilities to refineries or distributors produces emissions from the loading and unloading of tankers, storage losses, equipment leaks and process vents. The transport systems included are liquefied petroleum gas (LPG) systems (both surface transport and high-vapour-pressure pipeline systems), pentane-plus systems (both surface transport and low-vapour-pressure pipeline systems) and crude-oil pipeline systems.

Accidents and Equipment Failures: Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional UOG industry. The major sources are emissions from pipeline ruptures, well blowouts and spills. Emissions from the disposal and land treatment of spills are not included owing to insufficient data.

Surface Casing Vent Blows and Gas Migration: At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared or vented. The vented emissions are estimated in this section. At some wells, particularly in the Lloydminster (Alberta) region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone that was penetrated but not produced. The emissions from the gas flowing to the surface through the surrounding strata have been estimated.

Abandoned Oil and Gas Wells

Oil and gas wells are required to be plugged with cement prior to abandonment to prevent both gas leakage from the well and migration of oil and gas to the surrounding strata. In spite of the well abandonment regulations, wells exist that were not properly decommissioned. This occurs for a number of reasons, including abandonment prior to the enactment of regulations and bankruptcy of the well owner. While emissions arise from both plugged and unplugged wells, emissions from unplugged wells are significantly higher than from plugged wells. Table 3–12 presents emission estimates from abandoned oil and gas wells.

Oil Sands / Bitumen

This component includes emissions from oil sand open pit mining operations and heavy oil/bitumen upgrading to produce synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulphurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH_4 from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

Downstream Oil and Gas

Downstream oil and gas includes all fugitive emissions from the production of refined petroleum products and the distribution of natural gas to end consumers. Reported emissions fall into the two major groups described below.

Petroleum Refining: There are three main sources of fugitive emissions from refineries: process, unintentional fugitive and flaring. Process emissions result from the production of hydrogen as well as from process vents. Unintentional fugitive emissions result from equipment leaks, wastewater treatment, cooling towers, storage tanks and loading operations. Flaring emissions result from the combustion of hazardous waste gas streams (such as acid gas) and fuel gas (or natural gas). The Energy Industries category reports GHG emissions from the combustion of fuel for energy purposes.

Natural Gas Distribution: The natural gas distribution system receives high-pressure gas from the gate of the transmission system and distributes this through local pipelines to the end user. The major emission sources are fugitive emissions from main and service pipelines and meter/regulator stations.

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive emission estimates from the UOG industry are based on two separate studies that follow the same methodology: the Canadian Association of Petroleum Producers' (CAPP) study titled *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005)—referred to here as the CAPP study—and an update to this inventory, which was completed in 2014 for Environment Canada by Clearstone Engineering Ltd.—referred to here as the UOG study (EC 2014).

The CAPP study provides a detailed emission inventory for the UOG industry for the year 2000. Similarly, the UOG study estimates emissions for the years 2005 and 2011. For both studies, the respective emission inventories were developed using an IPCC Tier 3 bottom-up assessment, beginning at the individual facility and process unit level and aggregating the results to ultimately provide emission estimates by facility and geographic area. The Canadian UOG sector assets and operations are vast. As such, the inventory of 2011 emissions included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and ultimately markets. The resulting 2011 inventory database contains more than 7.5 million point-source emission records. The inventory includes emission estimates from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases.

Significant amounts of data were collected and used by both studies, including the number and type of active facilities and facility-level activity data such as volumes of gas produced, vented and flared. An inventory of

Table 3–12 **GHG Emissions from Abandoned Oil and Gas Wells**

GHG Source Category	GHG Emissions (kt CO_2 eq)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Abandoned Oil and Gas Wells	**40**	**50**	**60**	**80**	**120**	**140**	**150**	**170**	**180**	**200**	**220**	**240**	**260**	**270**
Abandoned Oil Wells[a]	30	30	40	50	70	80	80	90	100	120	130	140	150	160
Abandoned Gas Wells[b]	20	20	20	30	50	60	70	70	80	80	90	100	110	120

Notes:

Totals may not add up due to rounding.

a. Included in CRF category 1.B.2.a – Fugitive emissions from fuels – Oil and natural gas – Oil

b. Included in CRF category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

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equipment was derived based on typical facility layouts and average number of pieces of equipment by facility type. Emission factors came from a variety of sources, including published reports, equipment manufacturers' data, observed industry values, measured vent rates, simulation programs and other industry studies. Volume 5 of the CAPP study (CAPP 2005) and Volume 4 of the UOG study (EC 2014) lists data and emission factors.

The 1990–1999 fugitive emissions were estimated using annual industry activity data and the 2000 emission results. Volume 1 of the CAPP study presents the 1990–1999 estimates and method. The 2001–2004 fugitive emissions were estimated using the 2000 (CAPP 2005) and 2005 (EC 2014) emission results along with annual industry activity data and interpolation techniques. Similarly, the 2006–2010 emissions were estimated using the 2005 and 2011 (EC 2014) emission results with annual industry activity data and interpolation techniques. From 2012 on, the 2011 (EC 2014) emission results are used in conjunction with annual activity data to estimate emissions. Annex 3.2 provides a more detailed description of the methodology.

Abandoned Oil and Gas Wells

Emissions from abandoned wells are estimated using an IPCC Tier 1 approach. The CH_4 emission factors are from a study on abandoned oil and gas wells in the United States titled *Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States* (Townsend-Small et al. 2016). Annual counts of abandoned wells are determined from provincial databases. See Annex 3.2, section A3.2.2.6, for more details.

Natural Gas Transmission and Storage

Fugitive emissions from natural gas transmission for 1990–1996 are from the study titled *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999). This study follows a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were derived based on length of natural gas pipeline and leakage rates developed using results from the original study. For the year 2000 onwards, emissions are based on data from the UOG study (EC 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies. Emissions data for the natural gas transmission and storage industry were compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). CEPEI provided the data for the years 2000–2004, 2006–2010 and 2012–2014 following an IPCC Tier 3 approach. Emission estimates for 2015–2019 are derived using length of natural gas transmission pipeline and the amount of gas deposited into and withdrawn from storage. Annex 3.2 details the complete methodology.

Oil Sands/Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction and heavy oil/bitumen upgraders are from two separate reports: *An Inventory of GHGs, CACs and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006), prepared by Clearstone Engineering Ltd. (referred to here as the bitumen study) and an update to the study that was completed in 2017 by Clearstone Engineering Ltd. for ECCC titled *An Inventory of GHGs, CACs and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC 2017) (referred to here as the oil sands study).

Each operator in the oil sands mining and upgrading industry used an IPCC Tier 3 approach to develop detailed emission estimates. Facility inventories were reviewed to ensure that all estimates were complete, accurate and transparent. The completed QA/QC and an uncertainty analysis followed IPCC Good Practice Guidance (IPCC 2000).

The bitumen study (CAPP 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC 2017) is the basis for the 2004–2019 fugitive emission estimates. An oil sands estimation model (referred to here as the oil sands model) was developed to allow annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2003 onwards. The oil sands model was developed using relevant parameters and results from the oil sands study, along with annual activity data. The activity data required by the model comes from the following sources: *Alberta Mineable Oil Sands Plant Statistics* by the Alberta Energy Regulator (AER 2020) and annual reports from Husky Energy Inc. (Husky 2020). Annex 3 also presents a summary of the estimation method of the oil sands model.

Emissions for oil sands facilities not included in the oil sands study, such as the Horizon Liquid Extraction Plant and the Fort Hills Mine, were estimated using emission factors from similar facilities or emission data reported to the Greenhouse Gas Reporting Program (GHGRP). See Annex 3 for more details.

The Scotford upgrader operated by Shell Canada Energy began capturing CO_2 emissions from its hydrogen production plant in 2015. The captured CO_2, which is transported and injected into storage, is subtracted from the CO_2 venting emission estimates for this facility.

Downstream Oil and Gas Production

Calculating fugitive emissions from refineries uses information contained in the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004). Refer to the CPPI report for full details on the study. The CEEDC and Canadian refineries provided historical fuel, energy and emission data, for the years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 and 2003 onward were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD (Statistics Canada 1990–). Annex 3 provides a detailed description of the methodology used to estimate emissions from 1991 to 1993 and 2003 onward.

Natural Gas Distribution

The emission estimates for the 1990–1999 period were derived from a study prepared for the Canadian Gas Association (CGA 1997). The study estimated the emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions in the study were calculated using emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data in the study were obtained from published sources and from specialized surveys of gas distribution system companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. In the year 2000, the Gas Research Institute (GRI) reviewed and revised the 1997 CGA study, with more accurate and better-substantiated data for station vents (GRI 2000). General emission factors were developed for the distribution system using the study data (CGA 1997; GRI 2000) and the gas distribution pipeline distances by province provided by StatCan.

For the year 2000 onwards, emissions are based on data from the UOG study (EC 2014), following an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. Emissions data for the natural gas distribution industry were compiled by ORTECH Consulting Inc. (2013) for CEPEI. CEPEI provided emissions data for the years 2000–2004, 2006–2010 and 2012–2014 following an IPCC Tier 3 approach. Emissions for 2015–2019 are estimated using length of natural gas distribution pipeline. Annex 3.2 presents more details on the methodology used to estimate fugitive emissions from natural gas distribution systems.

3.3.2.3. Uncertainties and Time-Series Consistency

Upstream Oil and Gas

The overall uncertainty for the 2019 upstream oil and gas fugitive emissions is -9.0% to +10.5%. Table 3–13 lists the uncertainties for specific UOG categories. Note that the gas transportation industry includes natural gas transmission, storage and distribution. Accidents and equipment failures, and abandoned oil and gas wells, have the highest uncertainty, while oil production and transport have the lowest uncertainty.

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC Good Practice Guidance (IPCC 2000). According to the IPCC (2000), there are three sources of uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity. The analysis considered only the last two sources of uncertainty; uncertainties from the definitions were assumed negligible, as they were adequately controlled through QA/QC procedures.

Oil Sands/Bitumen

The overall uncertainty for the 2019 oil sands/bitumen fugitive emissions is -19.1% to +20.0%. An IPCC Good Practice Guidance Tier 1 uncertainty assessment was conducted for each oil sands mining and upgrading facility, with full details of the assessment contained in both the bitumen study (CAPP 2006) and the oil sands study (ECCC 2017). Table 3–14 shows the aggregation of facility-level uncertainties by emission source.

Table 3–14 **Uncertainty in Oil Sands/Bitumen Fugitive Emissions**

GHG Source Category	Uncertainty (%)
	Oil Sands/Bitumen
Flaring	±21.4
Fugitive	-30.0 to +35.5
Venting	-30.1 to +30.6
Overall	-19.1 to +20.0

Table 3–13 **Uncertainty in Upstream Oil and Gas Fugitive Emissions**

GHG Source Category	Uncertainty (%)					
	Oil Production and Transport	Gas Production / Processing	Gas Transportation	Accidents and Equipment Failures	Well Drilling, Servicing and Testing	Abandoned Oil and Gas Wells
Flaring	-8.0 to +7.9	± 4.7	-15.6 to +20.3	—	-19.9 to +17.4	—
Fugitive	-11.1 to +11.2	± 12.0	-26.2 to +27.5	± 49.7	-23.0 to +25.6	-48.0 to +71.4
Venting	-8.2 to +8.5	-9.7 to +24.2	-20.1 to +22.6	—	-17.6 to +35.1	—
Total	**-5.8 to +6.0**	**-7.4 to +17.7**	**-19.3 to +20.4**	**± 49.7**	**-16.4 to +15.1**	**-48.0 to +71.4**

Table 3–15 Uncertainty in Oil Refining Fugitive Emissions

	Uncertainty (%)			
	Overall	Excluding Refinery Fuel Gas	Excluding Flare Gas	Excluding Refinery Fuel and Flare Gas
Tier 1	± 8.3	± 4.3	± 8.3	± 8.3
Tier 2	± 14	± 5	± 14	± 14

Downstream Oil and Gas

The CPPI (2004) study provides the data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002. There is greater uncertainty for the 1991–1993 and 2003–2012 periods because of the available level of disaggregation of the activity data. For comparison purposes, a Tier 1 and Tier 2 uncertainty analysis provided overall CO_2 uncertainty values for the 2002 emission factors and activity data (CPPI 2004).

For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±14%. The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. Table 3–15 presents these uncertainty results.

3.3.2.4. QA/QC and Verification

To ensure that the results were correct, the CAPP and UOG studies (CAPP 2005; EC 2014) were subject to the following QA/QC procedures. First, all results were reviewed internally by senior personnel to ensure that there were no errors, omissions or double counting. In addition, individual companies reviewed and commented on the report. The project steering committee and nominated experts performed a second level of review. Where possible, results were compared with previous baseline data and other corporate, industrial and national inventories. Any anomalies were verified through examination of activity levels, changes in regulations, and voluntary industry initiatives.

3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2018 period because of changes to activity data and methodology. See Table 3–2 for a summary of recalculations.

The following improvements caused recalculations in oil and natural gas fugitive emission estimates.

- **Flaring** – the following text describes a number of changes to flaring emission estimates. Flaring emissions increased in the years 1992–2003, 2010, and 2014–2018. There was no change in the years 1990–1991, 2004–2009 and emissions decreased in 2011–2013.
  - **Alberta** – the methodology for estimating flaring emissions from Alberta was updated to incorporate new data sources, as described in section A3.2.2.1.2 of Annex 3. This change resulted in recalculations for oil and natural gas flaring in 2010-2018, with decreases in 2011-2013 and increases in 2010, and 2014-2018. Changes range from -73.4 kt CO_2-eq in 2012 to +63.5 kt CO_2-eq in 2017.
  - **Saskatchewan** – corrections to N_2O emissions from oil sands upgrading from 1992-2003 resulted in increases of +0.5 kt to +1.1 kt CO_2-eq.
  - **Manitoba** – revisions to light/medium crude oil production data resulted in an increase of +0.6 kt CO_2-eq in 2018.
  - **Petroleum refining** – revisions to national refined petroleum products production data resulted in decreases to flaring emission estimates of -0.2 kt CO_2-eq in 2017 and -4.2 kt CO_2-eq in 2018.
- **Abandoned Oil and Gas Wells** – updated provincial datasets from Saskatchewan, Alberta, British Columbia, and New Brunswick resulted in changes to abandoned well counts from 1990 to 2018. This resulted in increases in emissions from abandoned oil wells in 1998-2018 ranging from +0.3 kt to +4.3 CO_2-eq, and decreases ranging from -0.7 kt CO_2-eq in 1990 to -0.2 kt CO_2-eq in 1997.
- **Petroleum Refining** – Related to the emission factor updates for still gas and petroleum coke described in section 3.2.4.5, updates were made to the higher heating values for still gas and petroleum coke for the entire time series. This resulted in changes ranging from -5.9 kt CO_2-eq in 2014 to +3.7 kt CO_2-eq in 2018.
- **Accidents and Equipment Failures** – activity data changes to the number of operating wells in Alberta and Manitoba resulted in recalculations of emissions from surface casing vent flow/gas migration. From 2014 to 2018, these changes resulted in increases ranging from +0.1 kt CO_2-eq in 2014 to +145.0 kt CO_2-eq in 2017.
- **Natural Gas Production** – non-associated gas production data for Alberta is now derived from the Petrinex reporting system. This resulted in changes to emissions estimates for natural gas production from 2012 to 2018, ranging from -70.3 kt CO_2-eq in 2015 to +27.9 kt CO_2-eq in 2014. Revisions to non-associated gas production data in British Columbia also resulted in decreases of -4.0 kt CO_2-eq in 2017 and -0.3 kt CO_2-eq in 2018.
- **Natural Gas Transmission, Distribution and Storage** – minor revisions to pipeline lengths resulted in an increase of -27.6 kt CO_2-eq in 2018.
- **Venting** – the methodology for estimating venting emissions in Alberta was updated to incorporate new data sources, as described in section A3.2.2.1.2 of Annex 3. This change resulted in recalculations for oil and natural gas venting from 2010 to 2018, with

increases occurring from 2010 to 2012 and decreases from 2013 to 2018. Changes in Alberta range from an increase of +371.8 kt CO_2-eq in 2010 to a decrease of -760.9 kt CO_2-eq in 2016. Activity data updates also occurred for venting emissions in 2017 and 2018, including:

- **Non-associated gas production** – revisions to non-associated gas production volumes resulted in recalculations of unreported venting emissions in British Columbia for the years 2017 and 2018. This resulted in changes of -7.9 kt and -0.6 kt CO_2-eq in 2017 and 2018, respectively.
- **Natural gas distribution, transmission and storage** – revisions to pipeline lengths and volumes of natural gas delivered and received from storage resulted in recalculations in 2017 and 2018. These changes resulted in an increase of +0.4 kt CO_2-eq in 2017 and a decrease of -2.6 kt CO_2-eq in 2018.
- **Petroleum Refining** – revisions to refined petroleum product production data resulted in decreases of -1.0 kt CO_2-eq in 2017 and -17.4 kt CO_2-eq in 2018.

3.3.2.6. Planned Improvements

Upstream Oil and Gas

As described above, emission estimates for the UOG industry are based on detailed studies conducted approximately every 5 to 10 years, with emissions for intervening years extrapolated from the latest dataset. This approach does not facilitate the adoption of new scientific data (i.e. emission factors) as they become available, nor does it properly capture the emissions impact of technological improvements or regulations in a timely manner. Work is underway to develop a robust method of estimating emissions that is more adaptable. Additionally, the Alberta Energy Regulator (AER) has supplied new data on accidental venting from well surface casing vents, which currently account for 13% of all oil and gas fugitive emissions. The new data are being reviewed and a method for incorporating them is being developed.

3.4. CO_2 Transport and Storage (CRF 1.C)

Carbon dioxide transport and storage involves the capture of anthropogenic CO_2 and its transport to a storage facility or enhanced oil recovery (EOR) operation. Table 3–16 shows the two sources of CO_2 transported in Canada: CO_2 imported from the Dakota Gasification Company in North Dakota (in the United States) and domestically captured CO_2 from SaskPower's Boundary Dam power station, in Saskatchewan, and Shell's Scotford bitumen upgrader, in Alberta. In 2019, CO_2 emissions from these pipelines were approximately 0.3 kt, an increase of about 0.21 kt since 2000, as shown in Table 3–17.

Three CO_2 pipelines exist in Canada, two of which are associated with the use of carbon dioxide in an enhanced oil recovery (EOR) process. There are no estimates for emissions from storage since the EOR process recovers all CO_2 for reuse. Any net emissions from these operations are included in Canada's inventory as part of the Energy Industries (1.A.1) and Oil and Natural Gas and Other Emissions from Energy Production (1.B.2) categories.

Captured CO_2 Usage for Enhanced Oil Recovery

In Canada, CO_2 captured during coal gasification in the United States and from a coal-fired power station in Saskatchewan acts as a flooding agent in EOR operations to increase crude oil production volume at two depleting oil reservoirs. Carbon dioxide used as a flooding agent in EOR acts as a solvent while also increasing reservoir pressure, resulting in the release of trapped hydrocarbons to production wells. The high-pressure flooding process also results in CO_2 being trapped in the voids previously

Table 3–16 **CO_2 Import and Capture Quantities**

CO_2 Capture Source	CO_2 Quantity (kt)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Imported	NO	NO	1 800	2 000	2 000	2 000	2 000	2 000	2 400	2 000	1 700	1 800	1 500	1 700
Domestic Capture	NO	NO	NO	NO	NO	NO	NO	NO	100	800	1 900	1 600	1 700	1 700

Note:

NO = Not occurring

Table 3–17 **Emissions from CO_2 Transport and Storage Systems**

GHG Source Category	GHG Emissions (kt CO_2)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 Transport and Storage (1.C)	NO	NO	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.22	0.27	0.27	0.28	0.28

Note:

NO = Not occurring

occupied by hydrocarbon molecules. In the future, the fully depleted reservoir will provide long-term geological storage of CO_2.

CO_2 flooding started in 2000 at the Weyburn site and in 2005 at the Apache Midale site in order to extend the life of these mature reservoirs by another 30 years. Carbon dioxide, purchased from the Dakota Gasification Company located in North Dakota and SaskPower's Boundary Dam coal-fired power station, arrives via pipeline. As of January 1, 2019, the Boundary Dam facility had captured approximately 3.0 Mt of CO_2 for shipment to the Weyburn site (SaskPower 2020). Injections at this reservoir include this fresh supply of CO_2 and the recovered CO_2 from previous flooding cycles. Currently, the CO_2 injection rate at the Weyburn-Midale operations is about 2.3 Mt per year.[8] From 2000 to 2017, the Weyburn site injected over 30 Mt of new CO_2 purchased from the Dakota gasification plant, with an injection rate of 7 kt of CO_2 per day (PTRC 2011). Since 2005, the Midale site has injected more than 3 Mt of CO_2, with an injection rate of 1800 t of CO_2 per day (PTRC 2004).

In addition to being a CO_2 EOR operation, Weyburn is also the site of a full-scale geological CO_2 storage research program led by the International Energy Agency's (IEA) Greenhouse Gas Research and Development Programme (IEAGHG) with the support of various industries, research organizations and governments. Modelling and simulation results from the first phase (2000 to 2004) of the IEAGHG's CO_2 monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicate that after EOR operations are completed, over 98% of CO_2 will remain trapped in the Weyburn reservoir after 5000 years, with only 0.14% of the remainder released to the atmosphere (Mourits 2008). Additional details on the findings of the research project are available on the PTRC website.

The IEA Weyburn-Midale research project, outlined on the PTRC website, focused on developing a best practice manual for future projects on the geological storage of CO_2. This research used technical and non-technical components such as site characterization, selection, well bore integrity, monitoring and verification, risk assessment, regulatory issues, public communication and outreach, and business environment policy.

The net impact of GHG emissions from all of these operations is included in Canada's inventory as part of the Energy Industries (1.A.1) and Oil and Natural Gas (1.B.2) categories.

8 CO_2 Injected Data for Weyburn and Midale. Operational information provided in a presentation by F. Mourits, IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project, Natural Resources Canada. January 2010.

3.4.1. Transport of CO_2 – Pipelines (1.C.1.a)

Pipelines transport carbon dioxide captured at Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota and SaskPower's Boundary Dam Power Station near Estevan (which started CO_2 capture in November 2014) to the EOR facility at Weyburn, Saskatchewan.

A pipeline, part of Shell Canada's Quest carbon capture and storage project, transports captured CO_2 north from the Scotford upgrader, near Edmonton, Alberta, to a long-term geological storage site.

3.4.1.1. Source Category Description

The source is fugitive emissions from pipeline systems used to transport CO_2 to injection sites.

3.4.1.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO_2. Pipeline length from both the Canada/United States border to the Cenovus EOR facility at Weyburn and from Boundary Dam to Weyburn are approximately 60 km. The pipeline length between the Scotford refinery and the associated long-term geological storage site is about 80 km. Emission calculations use the IPCC default medium emission factor of 0.0014 kt CO_2/km pipeline length/year.

3.4.1.3. Uncertainties and Time-Series Consistency

Uncertainty estimates are 2006 IPCC defaults for Tier 1 methodologies of +200% to -50% (+/- a factor of 2).

3.4.1.4. QA/QC and Verification

Estimates underwent QC checks in a manner consistent with the 2006 IPCC Guidelines.

3.4.1.5. Recalculations

No recalculations were undertaken.

3.4.1.6. Planned Improvements

Future emissions estimates will include additional CO_2 pipelines, currently under construction in Alberta, as they come on-line and report their data to Canada's Greenhouse Gas Reporting Program. The facility-reported data will be assessed by inventory experts for compliance with quality (such as completeness, transparency, etc.) and methodology standards, as prescribed in Canada's Greenhouse Gas Quantification Requirements (ECCC 2021), in order to determine possible integration into national inventory estimation models.

3.5. Other Issues

3.5.1. CO_2 Emissions from Biofuels: Biodiesel and Ethanol

As per UNFCCC reporting guidelines, a memo item reports CO_2 from sustainably produced biomass fuels combusted to produce energy, and the energy sector totals do not include these emissions. The Land Use, Land-use Change and Forestry (LULUCF) sector tracks the CO_2 as a loss of biomass (forest) stocks. The energy sector reports the CH_4 and N_2O emissions from biomass fuels in the appropriate categories.

3.5.1.1. Fuel Ethanol

Table 3–18 presents the quantities of fuel ethanol used in transportation. Analysis of the chemical properties of ethanol resulted in a higher heating value (HHV)[9] of 29.67 kJ/g, a carbon content of 52.14% and a density of 789.3 kg/m^3 (ECCC 2017b).

According to feedback from StatCan, ethanol is included in RESD gasoline fuel consumption data. Fuel ethanol is therefore introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel ethanol available per province was allocated to each mode (on-road, by vehicle technology class, and off-road as a whole) as per the percentage of total gasoline. In lieu of developing specific emission factors for CH_4 and N_2O from ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO_2 emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

3.5.1.2. Fuel Biodiesel

Table 3–19 presents the quantities of biodiesel used in transportation. A study conducted between 2004 and 2005 (BioMer 2005) provided the properties used for biodiesel. Those properties include an HHV of 35.18 TJ/ML, with a carbon content of 76.5% and a density of 882 kg/m^3.

A portion of the total biodiesel is included in diesel fuel statistics provided by StatCan, but the extent of that coverage is uncertain. Therefore, the volumes of biodiesel consumed are in addition to the volumes of diesel fuel reported in the RESD to ensure that we have full coverage. To address the uncertainty around the coverage of biodiesel, StatCan has introduced a Monthly Renewable Fuels Survey (refer to section 3.2.4.6 for more information). Biodiesel was introduced and modelled as if it were mixed into the total fossil fuel-based diesel for the region(s). Total fuel available per province was allocated to each mode (on-road, by vehicle technology class, and off-road, railways and domestic marine as a whole) as per the percentage of total fossil fuel-based diesel fuel. In lieu of developing specific emission factors for CH_4 and N_2O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO_2 emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

9 *Higher heating value* and *lower heating value* are technical terms identifying the energy content of a specific fuel and differ depending on whether the water in the combustion products is in the liquid or gaseous phase respectively. Synonyms for *higher heating value* include *gross heating value* or *gross calorific value* while synonyms for *lower heating value* include *net heating value* or *net calorific value*.

Table 3–18 **Ethanol Used for Transport in Canada**

Year	1990	2005	2012	2013	2014	2015	2016	2017	2018	2019
Ethanol Consumed (ML)	7	253	2 341	2 441	2 392	2 432	2 516	2 517	2 561	2 594

Table 3–19 **Biodiesel Used for Transport in Canada**

Year	1990	2005	2012	2013	2014	2015	2016	2017	2018	2019
Biodiesel Consumed (ML)	NO	NO	713	782	771	778	749	810	861	861

Note:
NO = Not occurring

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CHAPTER 4

INDUSTRIAL PROCESSES AND PRODUCT USE (CRF SECTOR 2)

4.1. Overview

This chapter covers greenhouse gas (GHG) emissions produced by various industrial processes that chemically or physically transform materials. These processes include the production and use of mineral products, metal production, chemical production, consumption of sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), halocarbon production and use as alternatives to ozone-depleting substances (ODS), and non-energy products from fuels and solvent use.

GHG emissions from fuel combustion supplying energy to industrial activities are reported in the Energy sector (Chapter 3). In some cases, it is difficult to differentiate between emissions associated with energy and those produced by industrial process use of fuel. In such cases, and where industrial process use of fuel is predominant, the emissions are allocated to the Industrial Processes and Product Use (IPPU) sector. Emissions from the use of natural gas for hydrogen production in the upstream and downstream oil industries are accounted for in the Energy sector.

Greenhouse gas emissions from the IPPU sector contributed 54.3 Mt to the 2019 national GHG inventory (Table 4–1), compared with 56.6 Mt in 2005. The 2019 IPPU emissions represented 7.4% of total Canadian GHG emissions in 2019. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2.

In line with the principle of continuous improvement and in response to comments made by the expert review teams (ERTs) on previous submissions, this submission has incorporated improvements/revisions to activity data, emission factors, and/or methods. Detailed explanations for the changes in estimates as a result of these improvements/revisions are described in the "Category-Specific Recalculations" sections of this chapter and are summarized in Table 4–2.

4.2. Cement Production (CRF Category 2.A.1)

4.2.1. Category Description

Portland cement accounts for more than 90% of all cement produced in Canada, while the rest is masonry and other cement (Statistics Canada, n.d.[b]). The Cement Production category considers emissions associated with the production of clinker, the precursor of Portland cement, and excludes other cement production (IPCC, 2006). There are 15 separate facilities that produce clinker in Canada, all of which use dry kilns. These facilities are located in Nova Scotia, Quebec, Ontario, Alberta and British Columbia.[1] Total clinker production capacity in Canada is approximately 18 Mt/year.

1 Natural Resources Canada, Personal communication on Canada's Minerals subsector.

Table 4–1 **GHG Emissions from the Industrial Processes and Product Use Sector, Selected Years**

Greenhouse Gas Category	GHG Emissions (kt CO_2 eq)												
	1990	1995	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
INDUSTRIAL PROCESSES AND PRODUCT USE	**57 000**	**58 400**	**56 600**	**50 700**	**54 300**	**58 500**	**56 200**	**53 900**	**53 500**	**54 500**	**53 000**	**54 300**	**54 300**
Mineral Products	**8 500**	**9 200**	**10 290**	**7 830**	**7 950**	**8 470**	**7 770**	**7 810**	**8 050**	**7 920**	**8 600**	**8 690**	**8 830**
Cement Production	5 820	6 530	7 610	6 010	6 020	6 530	5 970	5 910	6 220	6 150	6 850	6 980	7 180
Lime Production	1 810	1 910	1 760	1 420	1 480	1 500	1 410	1 520	1 420	1 380	1 420	1 390	1 340
Mineral Product Use	860	750	910	410	450	440	380	380	410	390	330	320	320
Chemical Industry	**17 600**	**18 550**	**10 440**	**5 850**	**6 490**	**6 780**	**6 680**	**6 430**	**6 740**	**6 960**	**6 350**	**6 850**	**6 810**
Ammonia Production	2 800	2 960	2 740	2 520	2 910	3 030	2 980	2 560	2 880	2 820	2 580	2 460	2 550
Nitric Acid Production	970	960	1 200	480	480	360	310	210	230	260	250	270	260
Adipic Acid Production	10 300	10 310	2 550	-	-	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 520	4 310	3 960	2 850	3 110	3 390	3 400	3 650	3 630	3 880	3 520	4 110	4 000
Metal Production	**23 770**	**23 490**	**20 230**	**16 030**	**16 870**	**16 690**	**14 800**	**14 970**	**14 430**	**15 350**	**14 600**	**14 530**	**13 850**
Iron and Steel Production	10 480	11 470	10 310	8 980	9 880	9 980	8 050	8 890	8 470	9 220	8 450	8 870	8 260
Aluminium Production	10 330	10 010	8 680	6 870	6 810	6 470	6 530	5 830	5 720	5 990	6 010	5 510	5 290
SF_6 Used in Magnesium Smelters and Casters	2 960	2 010	1 230	190	180	250	210	250	240	140	140	150	290
Production and Consumption of Halocarbons, SF_6 and NF_3	**980**	**500**	**5 120**	**7 740**	**8 610**	**9 120**	**10 120**	**10 980**	**11 080**	**11 330**	**11 550**	**12 560**	**12 440**
Non-Energy Products from Fuels and Solvent Use	**5 800**	**6 320**	**9 990**	**12 800**	**14 000**	**16 940**	**16 290**	**13 260**	**12 640**	**12 290**	**11 270**	**10 990**	**11 630**
Other Product Manufacture and Use	**370**	**390**	**540**	**430**	**390**	**500**	**560**	**480**	**570**	**620**	**660**	**730**	**750**

Note: Totals may not add up due to rounding.

Table 4–2 **Impact of Recalculations from Revisions and Improvements**

Greenhouse Gas Categories	GHG Emissions or Change in Emissions (Mt CO_2 eq), Selected Years												
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
INDUSTRIAL PROCESSES AND PRODUCT USE													
Current (2021) submission	57.0	58.4	54.1	56.6	50.7	54.3	58.5	56.2	53.9	53.5	54.5	53.0	54.3
Previous (2020) submission	56.9	58.3	54.0	56.6	51.4	55.1	59.3	56.8	54.7	54.3	55.2	54.0	56.3
Net change in emissions	+0.1	+0.1	+0.1	+0.0	-0.7	-0.8	-0.8	-0.6	-0.8	-0.8	-0.8	-1.0	-2.0
Mineral Products													
Current (2021) submission	8.5	9.2	10.1	10.3	7.8	8.0	8.5	7.8	7.8	8.0	7.9	8.6	8.7
Previous (2020) submission	8.4	9.1	10.0	10.3	7.8	8.0	8.5	7.8	7.8	8.1	7.9	8.5	8.9
Net change in emissions	+0.1	+0.1	+0.1	+0.0	-0.0	-0.0	-0.0	+0.0	-0.0	-0.0	-0.0	+0.1	-0.2
Chemical Industry													
Current (2021) submission	17.6	18.5	8.8	10.4	5.9	6.5	6.8	6.7	6.4	6.7	7.0	6.4	6.8
Previous (2020) submission	17.6	18.5	8.8	10.4	6.4	7.1	7.5	7.3	7.2	7.6	7.7	6.9	7.7
Net change in emissions	+0.0	+0.0	+0.0	+0.0	-0.6	-0.6	-0.7	-0.7	-0.8	-0.9	-0.7	-0.6	-0.8
Metal Production													
Current (2021) submission	23.8	23.5	23.4	20.2	16.0	16.9	16.7	14.8	15.0	14.4	15.3	14.6	14.5
Previous (2020) submission	23.8	23.5	23.4	20.2	16.2	17.1	16.9	14.8	15.0	14.5	15.4	15.1	15.0
Net change in emissions	+0.0	+0.0	+0.0	-0.0	-0.2	-0.2	-0.2	+0.0	-0.0	-0.0	-0.0	-0.5	-0.4
Production and Consumption of Halocarbons, SF_6 and NF_3													
Current (2021) submission	1.0	0.5	2.8	5.1	7.7	8.6	9.1	10.1	11.0	11.1	11.3	11.5	12.6
Previous (2020) submission	1.0	0.5	2.8	5.1	7.7	8.6	9.1	10.1	11.0	11.0	11.3	11.5	12.6
Net change in emissions	+0.0	-0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
Non-Energy Products from Fuels and Solvent Use													
Current (2021) submission	5.8	6.3	8.5	10.0	12.8	14.0	16.9	16.3	13.3	12.6	12.3	11.3	11.0
Previous (2020) submission	5.8	6.3	8.5	10.0	12.8	14.0	16.8	16.3	13.3	12.6	12.2	11.3	11.5
Net change in emissions	-0.0	-0.0	-0.0	+0.0	+0.0	+0.0	+0.1	-0.0	+0.0	+0.0	+0.1	-0.0	-0.6
Other Product Manufacture and Use													
Current (2021) submission	0.4	0.4	0.6	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.7	0.7
Previous (2020) submission	0.4	0.4	0.6	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.7	0.7
Net change in emissions	+0.0	+0.0	+0.0	+0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0

Note: Totals may not add up due to rounding.

The Cement Production category accounted for 7180 kt (or 1.0%) of Canada's total emissions in 2019, a 6% decrease from 2005.

Emissions resulting from the combustion of fossil fuels to generate heat to drive the reaction in the kiln fall under the Energy sector and are not considered in this category.

4.2.2. Methodological Issues

Carbon dioxide (CO_2) emissions from Cement Production were estimated for 1990–2016 using a modified Tier 2 method (Equation 4–1) that incorporates country-specific emission factors and emissions from carbon-bearing non-fuel materials (IPCC, 2006). For 2017–2019, CO_2 emission estimates came directly from the CO_2 emissions reported by Canadian cement production facilities to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2020). The CO_2 emissions reported by cement production facilities to the GHGRP were calculated using a modified Tier 3 method (IPCC, 2006).

Equation 4–1

$$CO_2\ emissions = EF_{cl} \times M_{cl} \times CF_{ckd} + EF_{toc} \times M_{cl}$$

EF_{cl} = annual calcination emission factor based on clinker production, kt CO_2/kt clinker

M_{cl} = clinker production data, kt of clinker

CF_{ckd} = correction factor for the loss of cement kiln dust and by-pass dust, fraction

EF_{toc} = annual emission factor for CO_2 emissions from total organic carbon in the raw feed, kt CO_2/kt clinker

Disaggregated data on the composition of raw materials and clinker, the calcination degree of cement kiln dust (CKD), and the amount of bypass dust and CKD are not publicly available for 1990–2016. However, national aggregated data expressed as an annual calcination emission factor (EF_{cl}) and annual amounts of bypass dust and CKD are available from the Cement Association of Canada (CAC) for 1990, 2000 and 2002–2014 (CAC, 2014) and from the GHGRP for 2017–2019 (ECCC, 2020). These same quantities have been estimated for the remaining reporting years (1991–1999, 2001, 2015–2016). The CAC receives plant-based data from its member companies in accordance with the quantification method published under the umbrella of the Cement Sustainability Initiative of the World Business Council for Sustainable Development (WBCSD), CO_2 Emissions Inventory Protocol, Version 3.0. The protocol provides for two pathways for estimating process-related CO_2 emissions from the calcination of raw materials. The first is based on the amount and chemical composition of the products (clinker plus dust leaving the kiln system). The second is based on the amount and composition of the raw materials entering the kiln. Canadian cement production facilities report plant-based data to the GHGRP in accordance with section 4 of Canada's Greenhouse Gas Quantification Requirements.[2]

The CO_2 calcination emission factor, organic carbon emission factor, and CKD/bypass dust correction factor vary from year to year and is based on the available data from the CAC for 1990, 2000 and 2002–2014 and from the GHGRP for 2017–2019. For the unknown data years (1991–1999, 2001, 2015–2016), an average is taken from the years before and after the unknown data point.

Clinker production data for 1990–1996 was obtained from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC, 2010). Clinker production data for 1997–2016 was obtained from Statistics Canada (Statistics Canada, 1990–2004, n.d.[a]).

Provincial/territorial emission estimates are apportioned from national emission estimates on the basis of the clinker production capacity of each province/territory for 1990–2016. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[3] For 2014–2016, the Mining and Processing Division of ECCC provided clinker production capacity via personal communication.[4] For 2017–2019, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by cement production facilities in each province/territory.

4.2.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The error associated with the non-response rate of the Statistics Canada survey for clinker production data has also been considered in the uncertainty estimate. The Tier 1 uncertainty associated with the CO_2 emission estimates for clinker production has been calculated to be ±13.8% for 1990–2016 and ±8.5% for 2017–2019. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series. The activity data sources have changed over the time series from CIEEDAC publications to data collected by Statistics Canada, as described in section 4.2.2.

2 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2020. [accessed 2021 Feb 24]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html

3 Panagapko D. 2008–2014. Personal communications (emails to EC, last email September 16, 2014).

4 Sunstrum J. 2020. Personal communications (emails to ECCC, last email July 9, 2020).

4.2.4. Category-Specific Quality Assurance/Quality Control and Verification

This key category in the IPPU sector has undergone checks as outlined in Canada's General Quality Control (QC) (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with quality assurance (QA)/QC requirements as promoted by Volume 1, Chapter 6 (IPCC, 2006).

4.2.5. Category-Specific Recalculations

Recalculations for this category include use of facility reported data from the GHGRP for 2017–2018 and updates to the CO_2 calcination emission factor, organic carbon emission factor and CKD/bypass dust correction factor for 1990–2016. The magnitude of the 1990–2018 recalculations ranged from -190 kt CO_2 eq to +100 kt CO_2.

4.2.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.3. Lime Production (CRF Category 2.A.2)

4.3.1. Category Description

Dolomitic lime and high-calcium lime are both produced in Canada, and emissions from their production are accounted for in this inventory submission. Table 4–3 indicates the proportion of dolomitic and high-calcium lime in Canada. Information on hydraulic lime production in Canada is unavailable, and as a result its proportion of total lime production is assumed to be zero. There are 11 separate lime production facilities in Canada. These facilities are located in New Brunswick, Quebec, Ontario, Manitoba, Alberta and British Columbia. Total lime calcining capacity in Canada is approximately 3.1 Mt/year.

Table 4–3 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2016)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	14%	86%
1993–1999	16%	84%
2000–2002	8%	92%
2003–2008	9%	91%
2009-2010	7%	93%
2011–2016	8%	92%

The Lime Production category contributed 1340 kt (0.2%) to Canada's total emissions in 2019, a 24% decrease from 2005.

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the IPPU sector. CO_2 emissions associated with the use of natural limestone for lime production in the pulp and paper industry are accounted for in the Other Limestone and Dolomite Use category (section 4.4).

4.3.2. Methodological Issues

A Tier 2 methodology (Equation 4–2) is used to estimate the CO_2 emissions from Lime Production for 1990–2016, where country-specific emission factors were applied to national activity data (IPCC, 2006). The country-specific emission factors for dolomitic lime and high-calcium lime were developed using information on Canadian lime compositions collected from the Canadian Lime Institute[5] and from annual averages of all lime production facilities in Canada that reported to the GHGRP for 2017–2019, which are provided in Annex 6. Data on total national lime production, hydrated lime production and lime plant calcining capacities were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2006)[6] for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[7] For 2017–2019, CO_2 emissions came directly from the CO_2 emissions reported by lime production facilities in Canada to the GHGRP (ECCC, 2020). The CO_2 emissions reported by lime production facilities to the GHGRP were calculated using a modified Tier 3 method (IPCC, 2006) in accordance with section 3 of Canada's Greenhouse Gas Quantification Requirements.[8]

Equation 4–2

$$E_{CO2} = \sum_i (Q_i \times EF_i) \times CF_{LKD} \times CF_{hydrated}$$

Q_i = production data of lime i, kt of lime i

EF_i = emission factor for lime type i produced in Canada, kt of lime i/kt CO_2

CF_{LKD} = correction factor that corrects for the loss of lime kiln dust, fraction

$CF_{hydrated}$ = correction factor that corrects for hydrated lime, fraction

5 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute.

6 [NRCan] Natural Resources Canada. 1990–2006. *Canadian Minerals Yearbook*. Minerals and Metals Sector (Annual). Natural Resources Canada (discontinued).

7 [NRCan] Natural Resources Canada. 2007–2018. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division

8 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2020. [accessed 2021 Feb 24]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both high-calcium and dolomitic lime. In the absence of disaggregated data on the breakdown of lime types for 1990–2016, a 15/85 value for dolomitic lime/high-calcium lime was assumed for lime plants that produced both high-calcium and dolomitic lime. Table 4–3 provides the breakdown between Dolomitic and High-Calcium Lime Production in Canada. National CO_2 emissions for 1990–2016 were calculated by applying the Canadian emission factors to the estimated annual national lime production data, by lime type.

The water content of Canadian hydrated lime is estimated to be 28.25%.[9] The water content of hydrated lime is deducted from national lime production to calculate the amount of "dry" lime production, which is broken down into dolomitic lime and high-calcium lime. Corresponding emission factors are subsequently applied.

The lime kiln dust (LKD) correction factor was developed from annual averages of all lime production facilities in Canada as reported to the GHGRP for 2017–2019 and is applied for 1990–2016.

Provincial CO_2 emission estimates are apportioned from national emission estimates on the basis of the calcining capacity of each province/territory for 1990–2016. The *Canadian Minerals Yearbook* (NRCan, 1990–2006) provided data on calcining capacity for 1990–2006. For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[10] For 2014–2016, the Mining and Processing Division of ECCC provided calcining capacity via personal communication.[11] For 2017–2019, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by lime production facilities in each province/territory.

The decline in the share of dolomitic lime between 1999 and 2000 is the result of operational changes at two Ontario plants in that period. First, Guelph DoLime Limited, which produced only dolomitic lime up to 1999, ceased operations in 2000. Second, the Lafarge Canada quarry in Dundas switched from producing only dolomitic lime to both high-calcium and dolomitic lime in 1999–2000.[12] The slight decrease in the share of dolomitic lime in 2008–2009 is attributed to the closure of an Ontario plant that produced only dolomitic lime.

9 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 22, 2008). Canadian Lime Institute.

10 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment Canada, dated November 6, 2013).

11 Sunstrum J. 2020. Personal communications (emails to ECCC, last email July 9, 2020).

12 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment Canada, dated November 6, 2013).

4.3.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The Tier 1 uncertainty associated with the CO_2 emission estimates for Lime Production has been calculated to be ±33.2% for 1990–2016 and ±6.6% for 2017–2019. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series.

The emission factors and estimation method are consistent for 1990–2016. The source of activity data has changed over the time series from the Canadian Lime Institute to Natural Resources Canada, as described in section 4.3.2.

4.3.4. Category-Specific Quality Assurance/Quality Control and Verification

The Lime Production category has undergone informal quality control checks throughout the emission estimation process.

4.3.5. Category-Specific Recalculations

Recalculations for this category include use of facility reported data from the GHGRP for 2017–2018 and updates to the high-calcium lime emission factor for 2009–2016, dolomitic lime emission factor for 2009–2016 and LKD correction factor for 1990–2016. The magnitude of the recalculations ranged from +16 to +34 kt CO_2 eq for 1990–2018.

4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.4. Mineral Product Use (CRF Categories 2.A.3 and 2.A.4)

4.4.1. Category Description

The categories discussed in this section, under the aggregate title of "Mineral Product Use", include Glass Production (CRF category 2.A.3), Ceramics Production (CRF category 2.A.4.a), Other Uses of Soda Ash (CRF category 2.A.4.b), Non-Metallurgical Magnesia Production (i.e., magnesite use) (CRF category 2.A.4.c) and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

In 2019, the aggregate category accounted for 320 kt (or 0.04%) of Canada's total GHG emissions, with a decrease of approximately 65% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 37% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 32%, 16% and 15% of emissions, respectively.

Glass Production (CRF Category 2.A.3)

CO_2 emissions associated with soda ash and limestone consumed in Canadian glass production are included in this category. Soda ash has been the predominant source of CO_2 emissions from Glass Production throughout the entire time series.

Ceramics Production (CRF Category 2.A.4.a)

The production of bricks, roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware, sanitary ware, technical ceramics, and inorganic bonded abrasives are included in the Ceramics Production category. Calcination of carbonates in the clay results in process emissions of CO_2.

To assess the significance of CO_2 emissions from Ceramics Production, emissions were estimated for 2005 to 2007 and for 2011 to 2018. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2008). A Tier 1 method as per 2006 IPCC Guidelines (i.e., Equation 2.14 in Volume 3 of the Guidelines) was used for these years (IPCC, 2006). A default carbon content of 10% was applied to the annual amount of clay used to determine the mass of carbonate consumed (Mc). The Mc for each year from 2005 to 2007 was then multiplied by 85% of the default emission factor for limestone calcination and by 15% of the default emission factor for dolomite calcination to estimate the CO_2 emissions per year. For 2011 to 2018, process emission estimates were obtained from major Canadian manufacturers of structural clay products via the Greenhouse Gas Reporting Program. The emission assessment performed showed that the CO_2 emissions were below 0.05% of Canada's national total GHG emissions and did not exceed 500 kt CO_2 eq. For that reason, CO_2 emissions from Ceramic Production are considered "insignificant" under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. As of the 2020 inventory submission, they are reported in the CRF Reporter as "NE" ("not estimated") with an explanation provided, in accordance with the ERT's recommendation.

Other Uses of Soda Ash (CRF Category 2.A.4.b)

Soda ash is used in the production of chemicals, soaps and detergents, pulp and paper, flue gas desulphurization (FGD), and water treatment.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRF Category 2.A.4.c)

Three magnesia production facilities in Canada reported magnesite consumption in their processes at various times over the years 1990–2007. Two of the three facilities have closed, one in 1991 and the other in 2007; one facility remains in production.

Other Limestone and Dolomite Use (CRF Category 2.A.4.d)

Limestone and dolomite are used in a number of industrial applications in Canada, including the production of cement, lime, glass, and iron and steel. The emissions associated with these industrial applications are reported within their respective categories.

The emissions included in the Other Limestone and Dolomite Use category are associated with other applications, such as its use in pulp and paper mills as makeup lime, and other chemical uses, including FGD and wastewater treatment.

4.4.2. Methodological Issues

Glass Production (CRF Category 2.A.3)

National CO_2 emissions from Glass Production are calculated using a Tier 1 method that applies the stoichiometric carbon emission factors to the estimated quantities of soda ash and limestone consumed in the production of glass.

The fraction of total soda ash use that goes to glass production in the United States is applied to the total Canadian soda ash consumption to obtain the quantity of soda ash used for glass production in Canada. The quantity of limestone consumed in glass production is based on limestone production statistics collected by Natural Resources Canada.[13]

Ceramics Production (CRF Category 2.A.4.a)

CO_2 process emissions from Ceramics Production are considered as "insignificant.", as described in section 4.4.1.

Other Uses of Soda Ash (CRF Category 2.A.4.b)

National CO_2 emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO_2/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data has been estimated on the basis of soda ash production, import and export data.

13 Data for 1990–2006 is available in the *Canadian Minerals Yearbook* (NRCan, 1990–2006). Subsequent data has been provided by Natural Resources Canada via personal communication.

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Import and export data has been obtained from Global Trade Information Services (GTIS, 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada, 2010–2019). The trade data for the years 1990–1994 was assumed to be the average of the 1995–2000 trade data, as GTIS commenced reporting trade data in 1995. The total quantities of soda ash used have been distributed by application type, on the basis of the U.S. pattern of soda ash consumption: glass, chemical, soaps and detergents, pulp and paper, FGD and other. Likewise, provincial emissions have been estimated by apportioning the national emissions according to the respective provincial gross output values of the same sectors.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRF Category 2.A.4.c)

A Tier 1 method is used to estimate CO_2 process emissions from the use of magnesite in magnesia production. The method applies an emission factor of 522 g CO_2/kg magnesite, on the basis of the stoichiometric quantity of carbon available in the magnesite and assumes the purity of magnesite to be 97% (AMEC, 2006). The emission factor is multiplied by facility-specific activity data to estimate CO_2 emissions at provincial and national levels.

Magnesite use activity data was obtained or derived from various sources. One of the three plants operated between 1990 and 1991 and did not have publicly available data on magnesite use. The activity data has been back-calculated from the amount of magnesia produced, which has been assumed to be half of the 1990 capacity reported in the *Minerals and Metals Foundation Paper, 1999* (AMEC, 2006).

A second plant operated between 1990 and 2007. Its production data for 1990–2005 was sourced from Environment Canada, Quebec Region, Environmental Protection Branch.[14] The activity data for 2006 and 2007 has been estimated from the average ratio of magnesite consumed to magnesia produced between 1990 and 2005.

The third plant has been operational for the full reporting period (1990–2019) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2019).

Other Limestone and Dolomite Use (CRF Category 2.A.4.d)

A Tier 2 method is used to estimate CO_2 emissions from limestone and dolomite separately, using respective consumption data (Table 4–4) and emission factors.

The emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2 per kilogram of pure limestone used, and is adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl and Ontario Geological Survey, 1989). The Canadian emission factor is therefore 418 g CO_2/kg of limestone used (AMEC, 2006).

An overall emission factor of 468 g CO_2/kg of dolomite used was derived on the basis of the emission factors for pure limestone (440 kg CO_2/tonne) and magnesite (522 kg CO_2/tonne) and on the assumption that dolomite is composed of approximately 58% $CaCO_3$ and 41% $MgCO_3$ (AMEC, 2006).

For the years 1990 through 2006, data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For subsequent years, information has been provided directly by Natural Resources Canada via personal communication. Moreover, data for stone used as flux in iron and steel furnaces for all years is disaggregated into limestone and dolomite on the basis of a 70/30 split (AMEC, 2006). Table 4–4 exhibits the split between consumption of high-calcium limestone and dolomite in the iron and steel sector, glass production, and other process uses of carbonates. National CO_2 emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRF category 2.A.3), Iron and Steel Production (CRF category 2.C.1, refer to section 4.10), and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

The source of activity data does not provide a comprehensive breakdown of "other chemical uses." Therefore, this subcategory has been assumed to be 100% emissive and 100% composed of limestone and has been duly accounted for. Dolomite is usually less appropriate than limestone for most industrial applications, and most dolomite that is mined is crushed and sieved to be utilized as aggregate in concrete or asphalt (Bliss et al., 2008). Other markets of dolomite, such as glassmaking and agricultural use, are excluded from Canada's "other chemical uses" subcategory.

According to Canadian information,[15] only limestone is used for FGD processes in Canadian coal power plants.

Provincial emission estimates have been obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and dolomite have been used (i.e., pulp and paper, non-ferrous metal, glass, and chemical sectors).

14 Banville J. 2006. Personal communication (email from Banville J to Zaremba R, Environment Canada, dated March 3, 2006). Environment Canada, Environmental Protection Branch, Quebec Region.

15 Cook S. 2013. Personal communication to Edalatmanesh M, Environment Canada, November 18, 2013. Canadian Electricity Association.

Table 4–4 **High Calcium and Dolomite Consumption in Canada**

Year	2.C.1 Iron and Steel		2.A.3 Glass Production	2.A.4.d Other Process Uses of Carbonates		
	High-Calcium Limestone (kt)	Dolomite (kt)	High-Calcium Limestone (kt)	High-Calcium Limestone (kt)		
				Pulp and Paper Mills	Non-Ferrous Smelters	Other Chemical Uses
1990	459	197	171	214	16	846
1991	344	147	169	220	162	964
1992	393	169	154	231	167	264
1993	139	59	161	224	176	244
1994	133	57	146	234	154	587
1995	215	92	146	130	181	436
1996	208	89	146	134	164	711
1997	232	100	181	117	158	915
1998	274	118	158	89	129	857
1999	274	118	137	96	101	522
2000	476	204	51	118	39	928
2001	334	143	44	69	94	680
2002	181	77	46	57	55	927
2003	197	85	18	62	46	939
2004	146	63	18	75	51	1 109
2005	151	65	18	80	47	1 175
2006	140	60	18	173	57	1 057
2007	69	30	32	41	64	1 178
2008	223	95	12	15	65	1 182
2009	182	78	0	36	74	923
2010	219	94	0	41	65	423
2011	350	150	0	40	52	508
2012	532	228	0	31	34	521
2013	438	188	0	30	46	342
2014	709	304	0	40	32	364
2015	866	371	0	37	32	356
2016	791	339	0	36	28	350
2017	85	37	0	45	28	196
2018	0	0	0	30	0	229
2019	0	0	0	28	0	213

4.4.3. Uncertainties and Time-Series Consistency

Glass Production (CRF Category 2.A.3)

The Tier 1 uncertainty assessment of the Glass Production category considers uncertainties associated with the consumption data, emission factors, and assumptions for soda ash and limestone used in glass production. The overall uncertainty associated with the 2019 estimate is ±10.2%.

The same emission factors have been consistently applied over the time series, and the activity data sources are described in section 4.4.2.

Ceramics Production (CRF Category 2.A.4.a)

No uncertainty assessment was performed for this category because this category was determined to be insignificant under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, as described in section 4.4.1.

Other Uses of Soda Ash (CRF Category 2.A.4.b)

A Tier 1 uncertainty assessment was performed for the category of Other Uses of Soda Ash. It took into account the uncertainties associated with the production data (for years before 2001), and import and export data. The uncertainty associated with the category as a whole for the time series ranged from ±7.5% to ±5.9%.

The same emission factor has been consistently applied over the time series. The activity data source is provided in section 4.4.2.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRF Category 2.A.4.c)

A Tier 1 uncertainty assessment was performed for the category of Non-metallurgical Magnesia Production. It took into account the uncertainties associated with the activity data and emission factor. The uncertainty associated with the category as a whole for the time series ranged from ±4.3% to ±8.1%, with data on the use of magnesite being the largest contributor.

The same emission factor has been consistently applied over the entire time series. The activity data source varied across the time series, as described in section 4.4.2.

Other Limestone and Dolomite Use (CRF Category 2.A.4.d)

The Tier 1 uncertainty assessment for the category of Other Limestone and Dolomite Use considers the uncertainty associated with the activity data and emission factors. The uncertainty for the whole time series ranged from ±15.4% to ±38.0%, with activity data on chemical uses being the largest contributor to the uncertainty estimate.

The same emission factors have been consistently applied over the time series. The activity data source is provided in section 4.4.2.

4.4.4. Category-Specific Quality Assurance/Quality Control and Verification

Categories under Mineral Product Use have undergone informal quality control checks throughout the emission estimation process.

4.4.5. Category-Specific Recalculations

For the Other Limestone and Dolomite Use category, updates to the activity data for 2018 resulted in a decrease of less than 1 kt CO_2 eq.

4.4.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.5. Ammonia Production (CRF Category 2.B.1)

4.5.1. Category Description

The Ammonia Production category accounted for 2600 kt (0.3%) of Canada's emissions in 2019, and its level of emissions has remained relatively constant since 1990.

There are currently nine ammonia production plants[16] operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario. Eight of these plants use steam-methane reformers to produce ammonia; they also recover CO_2 emissions to produce urea. The ninth plant uses by-product hydrogen (purchased from a neighbouring chemical plant) to feed into the Haber-Bosch reaction and is therefore assumed to have negligible process-related CO_2 emissions.

Urea production is a downstream process associated with ammonia production plants. The process recovers and uses the by-product CO_2 stream from the ammonia synthesis process. To avoid over-estimation of CO_2 emissions, the use of recovered CO_2 in urea production is accounted for as part of estimations for this category (see Equation 4–2). The use of urea as a fertilizer and its associated emissions are reported in the AFOLU sector, as per 2006 IPCC Guidelines (box 3.2 on page 3.16). Emissions from use of urea-based additives in catalytic converters are discussed in section 4.13 and reported in CRF category 2.D.3. Other uses of urea (e.g., its use as an ingredient in manufacturing of resins, plastics or coatings) were determined to be a significant source of emissions and are reported in CRF category 2.B.10.

4.5.2. Methodological Issues

The Ammonia Production category includes CO_2 emissions resulting from the feedstock use of natural gas and takes into account emissions that are recovered for use in urea production. A Tier 2 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006). Emissions resulting from the energy use of natural gas are accounted for in the Energy sector.

The feedstock use of natural gas is determined by multiplying the annual ammonia production by the calculated ammonia-to-feed fuel conversion factor that is specific to each facility. The annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); that for 2005–2009 was collected by Environment Canada through a voluntary data submission process with the fertilizer industry; and that for 2008–2019 was obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (Statistics Canada, n.d.[c]). The ammonia-to-feed fuel conversion factors were developed from the data collected between 2005 and 2009 as part of the voluntary data submission. For the 2005–2009 period, there were nine plants in operation (two others stopped operating in 2005). Seven of the nine plants (two of which have 2 units each) provided ammonia-to-feed fuel factors. Two of the nine plants did not provide such factors. Also to note is that one of the two plants did not use steam methane reforming and for the remaining facility with SMR, an average of the reported ammonia-to-feed fuel conversion factors was applied. At the plant level, the variability of the ammonia-to-feed fuel conversion factor is very steady, varying by less than 0.001% from year to year over the five years. Similarly, the average value varied by less than 0.001% from year to year over the five years.

The amount of natural gas used as feed is multiplied by the respective province's natural gas carbon content factor (CC_j) to determine the resulting CO_2 emissions generated. The amount of CO_2 recovered for urea

16 Brown, T. Canada. 2018. [accessed 2021 Feb 24]. Available online at https://ammoniaindustry.com/tag/canada/

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production is then subtracted from the process-related emissions (Equation 4–3). Using the 2006 IPCC Guidelines, it is assumed that the urea production process consumes a stoichiometric quantity of CO_2 (i.e., 0.733 kg CO_2/kg urea) and that 5 kg of CO_2 are emitted per tonne of urea produced. The resulting recovery factor (RF_{CO2}) is therefore 0.728 kg CO_2/kg urea.

Equation 4–3 **CO_2 Emissions from Ammonia Production**

$$E_{CO2} = \sum_i AP_i \times FF_i \times CC_j - RF_{CO2} \times UP_i$$

E_{CO2}	=	emissions of CO_2, kt
AP_i	=	ammonia production of facility i, kt
FF_i	=	ammonia-to-feed fuel conversion factor of facility i, m^3 natural gas/t NH_3
CC_j	=	carbon content factor of the fuel in province j, kt CO_2/m^3 of natural gas
RF_{CO2}	=	factor for CO_2 recovered for urea production, 0.728 kg CO_2/kg urea
UP_i	=	urea production of facility i, kt

Urea production data for 2008–2019 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia to urea production for each plant.

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Non-Energy Products from Fuels and Solvent Use category.

Further details with respect to the calculation method used are provided in Annex 3.3.

4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment took into account the uncertainties associated with the ammonia and urea production data, ammonia-to-feed fuel conversion factor and carbon content of natural gas. The uncertainty values associated with CO_2 emissions from the category as a whole vary over time from 6.7% to 9.2% in accordance with changes in natural gas volumes consumed for ammonia production and with changes in urea production.

4.5.4. Category-Specific Quality Assurance/Quality Control and Verification

This category has undergone informal quality control checks throughout the emission estimation process.

4.5.5. Category-Specific Recalculations

The application of updated CO_2 emissions factors for natural gas (Table A6.1-1) resulted in minor recalculations (from + 22 to +31 kt) of the entire time series of this category.

4.5.6. Category-Specific Planned Improvements

There are currently no improvements planned for estimating CO_2 emissions from Ammonia Production.

4.6. Nitric Acid Production (CRF Category 2.B.2)

4.6.1. Category Description

The Nitric Acid Production category accounted for 258 kt (0.035%) of Canada's emissions in 2019, a 79% decrease from 2005.

There are two basic types of nitric acid production technology: high pressure and dual pressure. Both technologies can be found in Canadian nitric acid plants. The high-pressure design, commonly used in North America, applies a single pressure throughout the reaction and absorption stages. High-pressure process plants can function with a non-selective catalytic reduction (NSCR) or selective catalytic reduction (SCR) system. The emission abatement systems are classified as "non-selective" when natural gas is used as a reductant to reduce all nitrogen oxides (NO_x) as well as nitrous oxide (N_2O). In contrast, a selective catalytic reduction (SCR) system uses ammonia, which selectively reacts only with nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases, and not with N_2O, hence a higher N_2O emission factor. Most Canadian plants (as of 2019, seven out of eight) operate with a high-pressure design and six of those seven have NSCR abatement technology installed. The plant with a SCR system had a process-gas catalytic decomposition system installed in 2012–2013, which substantially reduced N_2O emissions. This system catalyzes the N_2O formed during the reaction stage, where ammonia is oxidized to NO_2.

The second type of nitric acid production technology design, i.e., dual pressure, uses low pressure for the reaction stage and higher pressure for the absorption stage. To increase the efficiency of the absorption stage, dual-pressure plants can "extend" the absorption tower by adding more trays. This is referred to in Table A6.2–3 as "Extended Absorption Type 1." One "Type 1" dual-pressure plant is currently operational in Canada. A process-gas catalytic decomposition N_2O abatement system was installed at this plant in 2008.

Alternatively, plants can have a second tower in place to allow "double absorption." This is referred to in Table A6.2–3 as "Extended Absorption Type 2" (Cheminfo Services, 2006). The only "Type 2" dual-pressure plant to operate during the time series closed in 1994.

4.6.2. Methodological Issues

A mix of Tier 1, Tier 2 and Tier 3 methods were used in the estimation of N_2O from Nitric Acid Production, the pre-dominance being with Tier 2, where plant-level production values were applied to technology-level EFs:

- Tier 3 method: use of plant-specific production data and plant-specific emission factors or continuous emissions monitoring system (CEMS) data when these were available from companies; or
- Tier 2 method: use of facility-specific (combined from multiple nitric acid plants at the same facility) or plant-specific production data and production technology-specific emission factors that are provided by plant technology vendors or national technology-specific average values when plant-specific emission factors were not available; or
- Tier 1 method: use of estimated production data and national average technology-specific emission factors when limited or no plant-specific data was available (only one plant).

The Tier 2 method was applied to all six high-pressure plants with NSCR abatement technologies currently in operation in Canada for almost all years.

Tier 3 plant-specific emission factors were also applied to five plants for certain years: two high-pressure plants with NSCR abatement from 1990–2004, one high-pressure plant with NSCR abatement for 2004, one dual-pressure "Type 1" plant from 2008 onwards and one high-pressure SCR plant from 2012 onwards. It should be noted that in order to ensure that confidential plant- or facility-specific production data is fully protected, it is not possible for Canada to specifically associate EFs with the plants. For years where the Tier 3 method could not be applied, a Tier 2 method was used.

The applicability of the emission factors indicated in Table A6.2–3 was assessed in the 2006 Cheminfo study. During this study, companies were asked to provide plant-specific emission factors if available. One of the facilities, which accounted for over 80% of the emissions, provided Tier 2 emission factors for its dual-pressure plant with extended absorption "Type 1" and their high-pressure plant with SCR abatement that were given by their equipment vendor. These technology-vendor emission factors are not considered to be Tier 3 because they are not plant-specific, but are considered confidential and it is not possible for Canada to specifically associate the EFs with the plants. Other facilities were able to provide plant-specific emission factors for some years but not others. The national average technology-specific emission factors applied for the remaining facilities are presented in Table A6.2–3.

When plant or facility-specific production data is unavailable, production is estimated on the basis of the overall capacity utilization of other known plants. The estimated production is multiplied by the most appropriate industry-typical or technology-specific emission factor.

For 1990–2004, the raw activity data and plant-specific emission factors (when available) were obtained through the 2006 Cheminfo study (Cheminfo Services, 2006). For 2005–2011, the data was reported by companies to Environment and Climate Change Canada on a voluntary basis in conjunction with Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For 2012–2019, production data was obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. Updated production data for the two plants with continuous emissions monitoring systems (CEMS) for 2010–2019 was received during a company data request in 2020.

4.6.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Nitric Acid Production. It takes into account the uncertainties associated with the national, facility, and plant-specific nitric acid production data and emission factors. The uncertainty values associated with N_2O emissions from the category as a whole vary from 2.0% to 2.5% between 1990–2007, and drops to 0.8% to 1.0% from 2012–2019. This is due to the replacement of Tier 2 equipment vendor emission factors with Tier 3 continuous emissions monitoring system (CEMS) data from the dual-pressure extended absoption "Type 1" plant and the high-pressure SCR plant after process-gas catalytic decomposition systems were installed. The emission factors are the largest contributors to the uncertainty for this category.

The same emission factors are consistently applied over the time series unless an abatement technology change occurred. The activity data source is provided in section 4.6.2.

4.6.4. Category-Specific Quality Assurance/Quality Control and Verification

The Nitric Acid Production category has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with quality assurance/ quality control (QA/QC) requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.6.5. Category-Specific Recalculations

2008–2018 emissions have been recalculated based on a correction accounting for abatement installations at two plants occurring in 2008 and 2012–2013, and the use of CEMS emission factor data and revised activity data for estimating post-abatement emissions.

4.6.6. Category-Specific Planned Improvements

There are no planned improvements for this category.

4.7. Adipic Acid Production (CRF Category 2.B.3)

4.7.1. Category Description

Invista Canada, formerly Dupont Canada, located in Maitland, Ontario, operated the only adipic acid production facility in Canada. A catalytic N_2O abatement system with an emission monitoring system was started up in 1997. However, the plant has not produced adipic acid since the spring of 2009; hence for years after 2009, both N_2O and CO_2 are indicated as "NO" in the CRF.

4.7.2. Methodological Issues

Emission estimates for adipic acid production were provided by the facility. For the 1990–1996 period, when no emission controls were in place, the reported emission estimates were calculated by multiplying the annual adipic acid production by the IPCC default generation factor of 0.3 kg N_2O/kg adipic acid.

Since 1997, the estimation method calculated emissions that occur when the abator is operating (Equation 4–5) separately from emissions that occur when the abator is not operating (Equation 4–6) due to maintenance or technical problems. The total emissions for the category are the sum of both operational modes, as shown in Equation 4–4.

Equation 4–4

$$\textit{Total Emissions (t)} = N_2O\ \textit{Emissions (t) with abator} + N_2O\ \textit{Emissions (t) without abator}$$

N_2O Emissions with Abator:

Equation 4–5

$$N_2O\ \textit{Emissions}\ (t)\ \textit{with Abator} = (\textit{Production}(t)) \times \left(\frac{0.3t\ N_2O}{t\ \textit{adipic acid}}\right) \times (1 - \textit{Destruction Efficiency}) \times (\textit{Abatement Utilization Ratio})$$

Destruction Efficiency = determined on the basis of the difference between the amount of N_2O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97%.

Abatement Utilization Ratio = number of hours during which N_2O goes through the abator divided by the total operating time.

N_2O Emissions without Abator:

Equation 4–6

$$N_2O\ \textit{Emissions}\ (t)\ \textit{without Abator} = (\textit{Production}(t)) \times \left(\frac{0.3t\ N_2O}{t\ \textit{adipic acid}}\right) \times (1 - \textit{Abatement Utilization Ratio})$$

Abatement Utilization Ratio = number of hours during which N_2O goes through the abator divided by the total operating time.

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N_2O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N_2O only when the reactor is online and abating N_2O gas. The analyzer is not capable of measuring the full range of N_2O concentrations that could potentially exist in the stack. The N_2O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35% to 39% N_2O in the unabated stream. When the abatement reactor is bypassed, there is no N_2O abatement occurring and the analyzer will not record N_2O stack emissions (Cheminfo Services, 2006).

The calculation technique used to estimate emissions for the 1990–1997 period is in accordance with the Tier 1 method of the 2006 IPCC Guidelines (IPCC, 2006).

For the period between 1998 and 2009, the estimation methods used for emissions with and without the abator align with Tier 3 and Tier 2 methods (IPCC, 2006).

4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Adipic Acid Production. It takes into account the uncertainties associated with the adipic acid production data, the emission factor, the destruction efficiency and the abatement utilization factor. The uncertainty associated with the category as a whole is evaluated at ±11%, with the emission factor being the largest contributor. The uncertainty value is applicable to all years of the time series.

As explained in section 4.7.2, two methods are applied in the time series: one for the period during which the plant operated **with** the emission abatement system and another for the period during which the plant operated **without** the emission abatement system.

4.7.4. Category-Specific Quality Assurance/Quality Control and Verification

Adipic Acid Production is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.7.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.7.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

4.8. Soda Ash Production (CRF Category 2.B.7)

4.8.1. Category Description

Soda ash can be produced in the Solvay process in which sodium chloride brine, limestone, metallurgical coke and ammonia are used as the raw materials in a series of reactions. Although CO_2 is generated as a by-product during some of these reactions, it is recovered and recycled for use in the carbonation stage, i.e., CO_2 generation equals uptake (IPCC, 2006). Canada had a single operational Solvay soda ash production facility between 1990 and 2001. There has been no production in Canada since 2001.

4.8.2. Methodological Issues

A Tier 1 method has been applied to estimate the CO_2 emissions potentially generated from the ash production process for the applicable reporting years (1990–2001). However, the net CO_2 emissions are considered negligible because the CO_2 resulting from the Solvay process was recovered for re-use and has been recorded as such in CRF Reporter category 2.B.7 (AMEC, 2006).

4.8.3. Uncertainties and Time Series Consistency

The method, emission factor and activity data are consistent across the time series. The Tier 1 uncertainty associated with the recovered emissions is 14%.

4.8.4. Category-Specific Quality Assurance/Quality Control and Verification

The Soda Ash Production category has undergone informal quality control checks throughout the emission estimation process.

4.8.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.8.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

4.9. Carbide Production, Titanium Dioxide Production, Petrochemical and Carbon Black Production, Fluorochemical Production and Other Uses of Urea (CRF Categories 2.B.5, 2.B.6, 2.B.8, 2.B.9.a, and 2.B.10)

4.9.1. Category Description

Carbide Production (CRF Category 2.B.5)

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC_2). SiC and CaC_2 are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC_2 plant closed in 1992.

Titanium Dioxide Production (CRF Category 2.B.6)

Titanium dioxide (TiO_2) is one of the most commonly used white pigments. Its main use is in paint manufacture followed by paper, plastics, rubber production and other miscellaneous uses. There are two processes for producing TiO_2: the chloride process and the sulphate process. The sulphate process is known to not produce any significant process emissions (IPCC 2006).

According to the 2010 Cheminfo study, there is one TiO_2 producer in Canada. It has been using both the chloride and sulphate processes. During the study, production capacity data for both processes was provided, allowing for the assessment of the significance of emissions from this industry in Canada. Applying the default emission factor of 1.34 tonnes CO_2/tonne of TiO_2 to the 2009 production capacity data (latest available) gave a result that showed that CO_2 emissions from this facility's chloride process represented less than 0.01% of the national level and therefore were considered insignificant (i.e., level for insignificance is below 0.05% of national total and below 500 kt CO_2 eq). In accordance with the ERT's recommendation, as of the 2018 NIR submission, CO_2 emissions from this category are reported in the CRF Reporter as "NE" ("not estimated") and an explanation is provided.

Methanol Production (CRF Category 2.B.8.a)

There were three methanol production facilities operating in Canada between 1990 and 2006. One was closed in 2001, another in 2005 and the last in 2006. Methanol production in Canada ceased in 2006 but resumed in 2011 at one location.

Process GHG (CO_2, methane [CH_4] and N_2O) emissions result from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO, CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases containing CH_4 from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010). N_2O emissions are reported in CRF category 2.B.10 Other (Methanol Production – N_2O Emissions).

Ethylene Production (CRF Category 2.B.8.b)

There were five ethylene facilities in operation in Canada between 1990 and 2019, one of which began operating in 1994 and another of which shut down in 2008. The facilities consume fuels such as ethane and propane in the production of ethylene through steam cracking. Process CO_2 and CH_4 emissions are reported in CRF category 2.B.8.b and N_2O emissions are reported in CRF category 2.B.10 Other (Ethylene Production – N_2O Emission).

Ethylene Dichloride Production (CRF Category 2.B.8.c)

Three ethylene dichloride production (EDC) facilities operated in Canada for different periods between 1990 and 2006; all plants are currently closed, with the last one closing in 2006.

Two processes had been used for the production of EDC in Canada. The first is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst. The second process is called oxychlorination.

In terms of emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO_2. The process CO_2 emissions from EDC production come from the side reaction of feedstock oxidation. The process CH_4 emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services, 2010).

Ethylene Oxide Production (CRF Category 2.B.8.d)

Ethylene Oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. There were five Ethylene Oxide plants operating in Canada between 1990 and 2018, four of which are currently operational. CO_2 emissions are a by-product of the direct oxidation of the ethylene feedstock and are dependent on the selectivity of the process. CH_4 is used to carry all reaction gases through the process. It can be emitted through the ethylene oxide process vent, the purification process exhaust gas stream, and as fugitive.

4

Carbon Black Production (CRF Category 2.B.8.f)

Four facilities produced carbon black in Canada between 1990 and 2019, three of which are currently operating. CO_2, CH_4 and N_2O emissions can arise from carbon black production. It should be noted that N_2O emissions are reported in CRF category 2.B.10 Other (Carbon Black Production – N_2O Emissions), whereas CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use). Because CRF category 2.D cannot be disaggregated, CO_2 emissions from carbon black production are reported as "IE" ("included elsewhere") in the CRF Reporter.

Styrene Production (CRF Category 2.B.8.g)

Three styrene facilities produced styrene in Canada between 1990 and 2019, one of which closed in 1998. CO_2 and CH_4 emissions can arise from styrene production. It should be noted that CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use) and CRF category 2.D cannot be disaggregated. Therefore, CO_2 emissions from styrene production are reported as "IE" in the CRF Reporter.

Fluorochemical Production (By-product Emissions, CRF Category 2.B.9.a)

During the manufacture of chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23 or CHF_3) is generated as a by-product (IPCC, 2000). Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada in the 1980s and early 1990s, but production ended in 1992. In Canada, there has been no manufacturing or import of equipment containing HCFC-22 as of January 1, 2010 (HRAI, 2008). HFC-23 releases as a by-product of HCFC-22 production were 971 kt, 1057 kt and 830 kt (in 1990, 1991 and 1992, respectively). There has been no known production of sulphur hexafluoride (SF_6) or perfluorocarbons (PFCs) in Canada throughout the time series.

Other Uses of Urea (CRF Category 2.B.10 Other [Other uses of Urea – CO_2 Emissions])

The Other Uses of Urea category takes into account potential emissions from urea used as an ingredient in the manufacturing of resins, plastics, and coatings products. To determine the amount of Other Uses of Urea, the total quantity of urea produced at ammonia plants is balanced with the urea that is imported to and exported from Canada, the quantity used for agriculture, and the estimated amount of urea-based additives required in catalytic converters for vehicles.

4.9.2. Methodological Issues

Carbide Production (CRF Category 2.B.5)

Tier 1 IPCC default emission factors were applied to estimate CH_4 emissions from carbide production. A study was commissioned to identify and establish the production capacities of the three carbide production facilities in Canada. A time series of process CH_4 emissions was estimated for the two silicon carbide facilities from 1990 to 2001 and for one calcium carbide facility from 1990 to 1991 on the basis of assumed capacity utilization and CH_4 emission factors. Only production capacity data (SiC and CaC_2) over the time series was identified in the study. The following equation was used to estimate total CH_4 emissions from carbide production:

Equation 4–7

$$\text{Total } CH_4 \text{ emissions (t)} = \sum^{y} [(\textit{SiC capacity} \times \textit{capacity utilization} \times \textit{Emission Factor\_SiC}) + (\textit{CaC}_2\ \textit{capacity} \times \textit{capacity Emission Factor\_CaC}_2)]$$

y	=	companies
SiC or CaC_2 capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission Factor_SiC	=	see Annex 6
Emission Factor_CaC_2	=	see Annex 6

Titanium Dioxide Production (CRF Category 2.B.6)

To assess the emission significance of this category as per the ERT's recommendation, the 2009 (latest available) production capacity data for the chloride process was multiplied by the 2006 IPCC default emission factor of 1.34 tonnes CO_2/TiO_2 produced.

Methanol Production (CRF Category 2.B.8.a)

When available, facility-reported CO_2, CH_4 and N_2O emissions data was included in this submission. The remaining emissions were estimated using a Tier 2 approach where reported facility production data and emissions were used to derive a country-specific emission factor for CO_2, CH_4 and N_2O. National methanol production values are taken from Camford's CPI Product Profile for 1990–1999 and estimated on the basis of assumed capacity utilization for 2000–2006 (Cheminfo Services 2010).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The same country-specific emission factors were applied to the facility's publicly reported production data for 2011

(Cheminfo Services 2015). For 2012–2019, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

Ethylene Production (CRF Category 2.B.8.b)

Two consulting studies were commissioned to evaluate CO_2, CH_4 and N_2O emission sources in Canadian petrochemical production as well as the quantity of fuels consumed as feedstocks. The latter was required to differentiate the emissions associated with petrochemical production (CRF category 2.B.8) from the emissions associated with non-energy uses of fuels (CRF category 2.D).

As part of the first study (Cheminfo Services 2010), a questionnaire was sent on behalf of Environment Canada to the four companies that have had ethylene production operations in Canada. Three of the four operating plants responded to the voluntary questionnaire request, representing 90% of Canadian ethylene production capacity in 2009. The data provided included emissions and production values for the years 2007 to 2009 and was used to develop the facility-level N_2O emission factors. The second study (Cheminfo Services 2015) examined the fuels consumed by Canadian ethylene producers over the 1990–2014 period and derived facility-level emission factors for CO_2 and CH_4 on a year-by-year basis. The two emission factors change over time in step with changes to the feedstocks consumed in Canadian ethylene production.

National ethylene production data is taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2019, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. The facility-specific emission factors applied are treated as confidential since they are derived from business-sensitive data. However, average industry-wide emission factors are recorded in Annex 6.

When process GHGs were reported directly by a facility, the reported data was used in the inventory. When reported emission data is not available, estimated emissions are calculated using the estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding emission factors.

Ethylene Dichloride Production (CRF Category 2.B.8.c)

CH_4 emissions from ethylene dichloride (EDC) production for 1990–2006 were developed through a consulting study. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e., annual production multiplied by the Tier 1 IPCC default emission factor) was taken to develop 1990–2006 process CH_4 emission estimates. The annual EDC production data comes from the Canadian C_2+ Petrochemical Report, which was prepared and published by an independent consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. The default process CH_4 emission factor for EDC as applied comes from Table 2–10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name dichloroethylene. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant on the basis of the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study).

Ethylene Oxide (CRF Category 2.B.8.d)

CO_2 and CH_4 emissions from the production of Ethylene Oxide were estimated using a 2006 IPCC Tier 1 method, which involved multiplication of annual production quantity by the default emission factors. The appropriate Tier 1 CO_2 and CH_4 emission factors used were selected from Tables 3.20 and 3.21 of the 2006 IPCC Guidelines based on consultant knowledge of the industry (Cheminfo, 2010). Because all Ethylene Oxide plants in Canada use pure oxygen as a reactant, the CO_2 emission factor used for all plants were chosen from the list of emission factors for the oxygen process configuration. Within the set of emission factors for this process configuration, emission factors were selected based on plant-specific catalyst selectivities. When there was no emission factor matching the exact plant-specific catalyst selectivity, an emission factor was generated by interpolating between the two closest catalyst selectivity-specific emission factors. All plants used the "No Thermal Treatment" process configuration default CH_4 emission factor. The sector-wide average CO_2 emission factor and the default CH_4 emission factor are displayed in Table A6.2-4. Production data for the years 1990 to 2009 were obtained through the Canadian C_2+ Petrochemical Report, as part of the 2010 Cheminfo Study. For years 2016 onwards, the activity data source was Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. Production data from 2010 to 2015 were linearly interpolated to complete the time series.

Carbon Black Production (CRF Category 2.B.8.f)

CH_4 and N_2O emissions from carbon black production were estimated in 2010 through a consulting study. A survey requesting 1990–2009 data on carbon black capacity and production and on process GHG emissions was sent to the three operating carbon black facilities. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process emissions.

From the received responses, two facility-level Tier 3 emission factors for CH_4 were derived as weighted averages of the reported 2007–2009 data. Two sector-wide process emission factors, one for each CH_4 and N_2O, were also calculated as weighted averages using the same set of data reported by the two facilities (1.3 kg CH_4/t product and 0.032 kg N_2O/t product).

The sector-wide CH_4 EF value is lower than the IPCC default value of 11 kg CH_4/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH_4 from the combustion of fuel as well. The Canadian EF only includes the CH_4 that originates directly from the feed.

Sector-wide emission factors are applied when facility-level emission factors cannot be used. When process emissions are reported directly by a facility, the reported data is used in the inventory. However, when reported emission data is not available, emissions were estimated by multiplying (reported or estimated) carbon black production by facility-level or sector-wide emission factor. The estimated carbon black production is calculated from total national carbon black production less the sum of all reported carbon black production; it is then distributed to each non-reporting facility based on its share of production capacity. National carbon black production data is taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. Interpolations were made for years in between (i.e., 1996–2006) on the basis of a sector average growth rate for 1990–1994. The total sector production for each year from 1996 to 2006 is calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Production data for years 2010–2019 is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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Styrene Production (CRF Category 2.B.8.g)

Process CO_2 emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. CH_4 could be present along with the process reactants ethylene and benzene and would be emitted if there is any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services, 2010).

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH_4 emission estimates. Annual styrene production data was retrieved from the Canadian C_2+ Petrochemical Report. For the purpose of emission estimation at the provincial level, the annual styrene production is allocated to each plant on the basis of capacity share for years 1990–2009. Due to the unavailability of 2010 and 2011 production data, these data years are assumed to be equal to 2009 production. For years 2012–2019, production data is retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

The default process CH_4 emission factor for styrene (4 kg/t) comes from Table 2–10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor cannot be found.

Fluorochemical Production (By-product Emissions, CRF Category 2.B.9.a)

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23/t HCFC-22 produced (IPCC, 2006). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practised in Canada. The 1990–1992 production data was collected by Environment Canada from HCFC producers.[17]

Other Uses of Urea (CRF Category 2.B.10 Other [Other uses of Urea – CO_2 Emissions])

There is no available methodology in the IPCC 2006 Guidelines for the estimation of emissions coming from other uses of urea. Because it is believed that the Canadian context would be similar to that of the United States for this category, the Canadian methodology (see Equation 4–8) was derived from that described in the U.S. National GHG Inventory.[18]

Equation 4–8

Total CO_2 emissions (t) =

$$[U_{production} - U_{fertilizer} + U_{imports} - U_{exports} - (U_{UAN\ fertilizer} - U_{UAN\ imports}) - U_{UAN\ exports} - U_{SCR}] \times EF$$

$U_{production}$	=	Urea produced in Canada (t)
$U_{fertilizer}$, $U_{UAN\ fertilizer}$	=	Urea applied as fertilizer (t) from urea and urea-ammonium-nitrate (UAN)
$U_{imports}$, $U_{UAN\ imports}$	=	Urea imported to Canada (t) as urea or urea-ammonium-nitrate (UAN)
$U_{exports}$, $U_{UAN\ exports}$	=	Urea exported from Canada (t) as urea or urea-ammonium-nitrate (UAN)
U_{SCR}	=	Urea used as an additive in catalytic converters (t)
EF	=	0.733 t CO_2 emitted per t urea

Urea production data for 2008–2019 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia to urea production for each plant. Emissions from the production of urea have been accounted for in CRF category 2.B.1, Ammonia Production.

17 Bovet Y and Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Environment and Climate Change Canada, during the years 2004–2006). UPCIS.

18 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016 (2018 release). Available online at: https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf, pg.4-28.

Import and export data for urea and urea-ammonium-nitrate from 1990–2019 were obtained from Statistics Canada's Canadian International Merchandise Trade Database.[19]

The data for quantities of urea and urea-ammonium-nitrate used as a fertilizer were obtained from the AFOLU sector. Lastly, urea used as an additive in catalytic converters was calculated based on the estimated emissions, which are discussed in section 4.14 and reported in CRF category 2.D.3.

It is assumed that any urea that is not used as a fertilizer, as an additive for selective catalytic converters, or that is not exported in the same year is used as an ingredient in manufacturing of resins, plastics or coatings. It is also assumed that all the carbon contained in the urea used for other uses is released in the same year as its production or import.

To estimate the CO_2 emitted from Other Uses of Urea, an emission factor of 0.733 kg CO_2 emitted/kg of urea used is applied. This factor is the stoichiometric quantity of CO_2 required to produce urea, assuming the complete conversion of ammonia and CO_2 to urea (IPCC, 2006). The same factor is used as the emission factor based on the assumption that all CO_2 used to manufacture urea gets emitted upon the use of that urea.

4.9.3. Uncertainties and Time-Series Consistency

Carbide Production (CRF Category 2.B.5)

A Tier 1 uncertainty assessment was performed for the Carbide Production category (Cheminfo Services 2010) using expert knowledge following the 2006 IPCC Guidelines.

Regarding the carbide capacity data, an uncertainty of ±5% is applied when survey uncertainties are not provided. The uncertainty associated with the category as a whole for the time series where emissions occurred (1990–2001) ranges from ±16% to ±27% (Cheminfo Services, 2010).

Titanium Dioxide Production (CRF Category 2.B.6)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Titanium Dioxide Production category following the 2006 IPCC Guidelines. The uncertainty estimate for the 2009 estimate was ±15%. However, the uncertainty estimate associated with this category is not taken into account in the overall uncertainty assessment in Annex 2, because this category was determined to be insignificant.

Methanol Production (CRF Category 2.B.8.a)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Methanol Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected (Cheminfo Services, 2010), uncertainties based on expert knowledge were used in the analysis.

The uncertainty associated with the category as a whole for the time series ranged from 7% to 20% for CH_4 emissions, from 11% to 30% for N_2O emissions and from 4% to 11% for CO_2 emissions.

Ethylene Production (CRF Category 2.B.8.b)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010, 2015) for the Ethylene Production subcategory following the 2006 IPCC Guidelines.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided any uncertainty estimates for their data. Uncertainties based on expert knowledge of the industry were therefore used in the analysis.

The uncertainties for the time series range from ±7% to ±12% for CH_4 emission estimates, from ±12% to ±21% for N_2O emission estimates and from ±4% to ±7% for CO_2 emission estimates.

Ethylene Dichloride Production (CRF Category 2.B.8.c)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Ethylene Dichloride Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), uncertainties based on expert knowledge of the industry were used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at ±21% (Cheminfo Services, 2010).

Ethylene Oxide (CRF Category 2.B.8.d)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Ethylene Oxide Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), uncertainties based on expert knowledge of the industry were used in the analysis. The uncertainty associated with the category range from ±30.5% to ±38.8% for CH_4 emission estimates, and from ±7.5% to ±9.8% for CO_2 emission estimates.

19 Statistics Canada, Canadian International Merchandise Trade Database. Available online at: http://www5.statcan.gc.ca/cimt-cicm/home-accueil?lang=eng.

Carbon Black Production (CRF Category 2.B.8.f)

A Tier 1 uncertainty assessment was performed by Cheminfo Services for the Carbon Black Production subcategory following the 2006 IPCC Guidelines. In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, uncertainties based on expert knowledge of the industry were used in the analysis.

Uncertainties associated with this category range from ±6% to ±11% for CH_4 emissions, from ±11% to ±13% for N_2O emissions and from ±2% to ±7% for CO_2 emissions.

Styrene Production (CRF Category 2.B.8.g)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Styrene Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services, uncertainties based on expert knowledge of the industry were used in the analysis. The Tier 1 uncertainty associated with CH_4 emissions from styrene production ranges from ±20% to ±22%.

Fluorochemical Production (By-product Emissions, CRF Category 2.B.9.a)

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it is believed that the production data reported by HCFC-22 producers was reasonably accurate. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC, 2000). The IPCC 2006 Guidelines state that a 50% uncertainty factor for a Tier 1 HFC production estimate may be appropriate.

Other Uses of Urea (CRF Category 2.B.10 Other [Other Uses of Urea – CO_2 Emissions])

A Tier 1 uncertainty assessment was completed for the Other Uses of Urea category following the 2006 IPCC Guidelines.

The assessment took into account the uncertainties associated with urea production data, import and export data, urea used in agriculture data, urea used in catalytic converters, and the urea-to-CO_2 conversion factor. In addition, it was assumed that the uncertainty associated with the calculated value of urea available in one year for other uses was high due to the assumption that all the urea is converted to CO_2, regardless of the type of final product. The overall uncertainty associated with CO_2 emission estimates from other uses of urea ranged from ±6.5% to ±10.0%.

4.9.4. Category-Specific Quality Assurance/Quality Control and Verification

CO_2 emission estimates for categories under Petrochemical and Carbon Black Production and the Fluorochemical Production category have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Emission estimates of the other two GHGs (i.e., CH_4 and N_2O) for the same categories and CO_2 emission estimates for the Titanium Dioxide Production category have undergone informal quality control checks.

4.9.5. Category-Specific Recalculations

Recalculations were performed for 2013 and 2016 to 2018 Other Uses of Urea emissions. The 2013 recalculation was a result of fixing a data transcription error and increased emissions by +0.22 kt CO_2 eq (+0.09%). Recalculations for 2016–2018 were due to updates in import and export quantities of urea and urea-ammonium-nitrate fertilizers and ranged from -7.2 kt CO_2 eq (-1.2%) to 75.6 kt CO_2 eq (21%).

4.9.6. Category-Specific Planned Improvements

There are no improvements planned for CRF category 2.B, Chemical Industry.

4.10. Iron and Steel Production (CRF Category 2.C.1)

4.10.1. Category Description

The Iron and Steel Production category contributed 8263 kt (1.1%) to Canada's total emissions in 2019, a 20% decrease from 2005.

There are four integrated iron and steel mills in Canada, all located in Ontario. One of the mills uses the electric arc furnace (EAF) process to produce a portion of its steel. Annex 3.3 provides additional detail on the technologies employed in Canada to produce iron and steel.

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy sector.

Total emissions in the Iron and Steel Production category is the sum of emissions from the following sources:

- CO_2 emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron
- CO_2 emissions during steel production, which occur to a much lesser extent (these come from the oxidation of carbon in crude iron and electrode consumption)
- CO_2 emissions given off by limestone flux in the blast furnace
- CH_4 emissions from metallurgical coke use (as a reductant)

4.10.2. Methodological Issues

An IPCC Tier 2 methodology is used to estimate emissions from Iron and Steel Production (IPCC, 2006). The method reflects the operation of Canadian facilities with country-specific emission factors for coke (EF_{met_coke}) and carbon content of pig iron. For more specific information on the Canadian Iron and Steel sector, refer to Annex 3.3.

CO_2 emissions from pig iron production were estimated using the following equation:

Equation 4–9

$$E_{CO2\_PI} = (EF_{met\_coke} \times M_{met\_coke}) - (P_{PI} \times CC_{PI}) \times (44/12)$$

E_{CO2_PI}	=	process emissions from pig iron production, kt
EF_{met_coke}	=	year-specific emission factors (t CO_2/ t metallurgical coke used)
M_i	=	mass of i used or produced, kt; where i is metallurgical coke, ore
CC_i	=	carbon content of i, %, where i is metallurgical coke, pig iron
P_{PI}	=	production of pig iron, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon

For the purposes of calculating emission estimates for this category, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke (Cheminfo Services, 2010). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated under the appropriate industrial category in the Energy sector.

The data source for the use of metallurgical coke was the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, 1990–2019). Data on total pig iron production in Canada came from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from the Canadian Steel Producers Association (CSPA) for 2013–2016, and the Greenhouse Gas Reporting Program (GHGRP) for 2017–2019 (ECCC, 2020). The emission factors for coke use (EF_{met_coke}) from 1990–2009 are year-specific and come from the Cheminfo Services (2010) study. In that study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and emission estimates for the years 1990 to 2009. The emission factors were calculated as ratios of CO_2 emissions to coke consumption. The Canada-specific coke (EF_{met_coke}) emission factors for 2010–2016 was estimated as an average of the 2009 value from Cheminfo Services (2010), and the yearly national average of GHGRP data for the years 2017–2019 (ECCC, 2020). The emissions factor of coke for 2017–2019 was the year-specific national average of facility provided data, as reported to the GHGRP (ECCC, 2020). The coke carbon content was then applied to the coke use data provided by Statistics Canada. With respect to the carbon content of pig iron, CSPA[20] provided an industry-average content value that was used for 1990–2016. The national annual weighted average of facility reported carbon content of pig iron was used for 2017–2019, as per GHGRP (ECCC, 2020).

CO_2 emissions from steel production were estimated using the following equation:

Equation 4–10

$$E_{CO2\_steel} = [CC_{iron} \times M_{iron} + CC_{scrap\ steel} \times M_{scrap\ steel} - CC_{BOF} \times M_{BOF} - CC_{EAF} \times M_{EAF}] \times 44/12 + EF_{EAF} \times P_{EAF} + EF_{BOF} \times P_{BOF}$$

E_{CO2_steel}	=	process emissions from steel production, kt
CC_j	=	carbon content of i, %, where j is the pig iron charged, or scrap steel charged in either the electric arc furnace (EAF) or basic oxygen furnace (BOF)
M_j	=	mass of j used, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon
EF_k	=	emission factors (t CO_2/ t steel produced)
P_k	=	steel production by either EAF or BOF, kt

According to Equation 4–10, part of the CO_2 emitted from the steel production process is estimated on the basis of the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in basic oxygen furnaces (BOFs) and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–10) is not equal to the amount of total pig iron production (used in Equation 4–9). As part of the steel production process, emissions are also generated by the consumption of electrodes in EAFs and in secondary ladle metallurgy. These are accounted for in the last two terms of the equation.

20 Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

Data on the total pig iron and scrap steel charged to steel furnaces, and on the amount of steel produced in EAFs and BOFs was obtained from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from CSPA for 2013–2017 and from GHGRP for 2018–2019. The facility-specific emission factors from the GHGRP are treated as confidential, since they are derived from business-sensitive data. However, a range of national emission factors and carbon contents are available in Annex 6, based in part, on the CSPA,[21] and in part on the annual averages for all facilities in Canada as reported to the GHGRP from 2017–2019 (ECCC, 2020).

The methodology used to estimate CO_2 emissions from limestone used as a flux in iron and steel furnaces is described in section 4.4.2.

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990–2019) multiplied by an emission factor. The emission factor value for CH_4 emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

Data on provincial-level metallurgical coke use from RESD (Statistics Canada, 1990–2019) was used to distribute national-level emissions to the applicable provinces.

It should be noted that RESD data published for any given year is preliminary and subject to revision in subsequent publications. The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO_2 emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO_2 generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in estimating emissions of each source in this category, such as data on metallurgical coke use, the emission factor of coke, data on pig iron and steel production, the carbon content of pig iron and steel, limestone data and associated emission factors. The assessment also considered the error associated with the non-response rate of the Statistics Canada surveys. The uncertainties for CO_2 and CH_4 emission estimates associated with this category are ±5.58% and ±405%, respectively.

4.10.4. Category-Specific Quality Assurance/Quality Control and Verification

Iron and Steel Production (CO_2) is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.10.5. Category-Specific Recalculations

CO_2 emissions for this category were recalculated to integrate facility reported data from the GHGRP and to include a correction by the CSPA to the 2013–2017 quantities of pig iron charged to furnaces for steel production. The method change included updates to the emission factor for metallurgical coke use from 2010–2018, as well as the emission factors and carbon contents for steel production for the years of 2013 to 2018. The magnitude of the recalculations ranged from -525 to +14 kt CO_2 eq and impacted the time series from 2010–2018.

4.10.6. Category-Specific Planned Improvements

As noted earlier, a smaller part of the process CO_2 emissions associated with iron and steel production originates from the use of reductants other than metallurgical coke, namely natural gas and coal. This fuel data is from the RESD, and owing to its aggregated format, it is currently not possible to allocate the appropriate portion to CRF category 2.C.1, Iron and Steel Production.

Natural gas used as a reductant in the production of direct-reduced iron (DRI) and coal used in pulverized coal injection (PCI) in blast furnaces are currently reported in the Energy sector (as combustion emission sources in Iron and Steel Production). Also, a fraction of coal (aggregated with non-energy fuels in RESD) used in iron and steel making is currently reported under the Non-Energy Products from Fuels and Solvent Use category (section 4.14).

As supporting information (to disaggregate RESD fuel data) becomes available, it is planned to allocate the aforementioned emissions to CRF category 2.C.1, Iron and Steel Production.

21 Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

4.11. Aluminium Production (CRF Category 2.C.3)

4.11.1. Category Description

The Aluminium Production category accounted for 5293 kt (0.7%) of Canada's emissions in 2019, representing an overall decrease in emissions of 39% since 2005.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the combustion of baking furnace packing material are accounted for under the Aluminium Production category (IPCC 2006).

In addition to CO_2 emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), both of which are included in this submission. This submission also includes a small amount of SF_6 that is emitted from its use as cover gas as well as a degassing (purifying) agent at some aluminium plants that produce high magnesium-aluminium alloys.[22] The consumption of SF_6 is highly variable depending on whether one or both of these operations (SF_6 use as a cover gas and/or purifying agent) occur within a given year causing significant changes in the trend of SF_6 in this source category.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants using Søderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The last Søderberg aluminium smelter in Canada was closed in 2015,[23] and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency.

4.11.2. Methodological Issues

As of 2013, Canada's aluminium companies, which operate in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative, which are consistent with the methods presented in the 2006 IPCC Guidelines. Under a memorandum of understanding signed in 2006 between Environment Canada and the Aluminium Association of Canada (AAC), Environment Canada receives the same data sets as those provided by AAC member companies in the provinces. As of the data year 2018, aluminium companies have been reporting their emissions directly to ECCC's GHGRP (ECCC 2020), methods of which are also consistent with the 2006 IPCC Guidelines.

The process-related emission estimates for aluminium production are directly obtained from AAC. In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO_2, PFC and SF_6 emissions and plant-specific production data for the time series are also obtained from AAC. According to the methodology documents supplied by the AAC, SF_6 emissions are equal to consumption in the aluminium industry.

Depending on data availability for each year in the time series, the estimation techniques applied vary between Tiers 1, 2 and 3. For example, the largest Canadian producer of aluminium reported that its 2008 emissions were developed using plant-specific parameters; for earlier years, and where plant-specific data was not available, companies have used Quebec's Framework Agreement or International Aluminium Institute (IAI) EFs as the default (Alcan 2010). Since 2015, all facility-reported process-related estimates of CO_2, PFCs and SF_6 are Tier 3 plant-level estimates using plant-specific parameters.[24]

4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the Aluminium Production category (i.e., for the CO_2, PFC and SF_6 emission estimates). It takes into account the uncertainties associated with all the parameters used to calculate the emissions. The *Aluminium Sector Greenhouse Gas Protocol* (IAI, 2006) was the main source of uncertainty values for parameters. The uncertainties for the CO_2, PFC and SF_6 estimates are ±7%, ±9% and ±5%, respectively. For the CO_2 and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO_2 and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have higher uncertainties. For the SF_6 estimate, it is assumed that the uncertainty is equivalent to the 2006 IPCC default for a Tier 2 method Magnesium Casting category, since the method used to develop SF_6 emission estimates is the same for both Aluminium Production and Magnesium Casting.

4

22 Chaput P. 2007. Personal communication (email from Chaput P to Au A, Environment Canada, dated Oct 12, 2007). Aluminium Association of Canada.

23 Banville J. 2020. Personal communication (email from Banville J to Au A, Environment and Climate Change Canada, dated June 15, 2020). Environment and Climate Change Canada, Environmental Protection Branch.

24 Banville J-F. 2017. Personal communication (email received from Banville J-F to Au A, Environment Canada, April 7, 2017). Aluminium and Iron Ore Pelletizing Sectors.

4.11.4. Category-Specific Quality Assurance/Quality Control and Verification

CO_2 and PFC emissions from Aluminium Production are key categories that have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.11.5. Category-Specific Recalculations

There were no recalculations for this category.

4.11.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.12. Magnesium Production (CRF Category 2.C.4)

4.12.1. Category Description

SF_6 is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. SF_6 is not manufactured in Canada and is solely imported.

During the 1990–2006 period, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro closed in the first quarter of 2007 and Timminco closed in August 2008. Another magnesium producer, Métallurgie Magnola, operated between 2000 and 2003, but closed in April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects designed to find a substitute for SF_6 and eventually eliminate the use of SF_6 as a cover gas at its plant.[25] This research, as well as the use of substitute gas mixtures, produced significant reductions in SF_6 emissions in the mid- to late 1990s. The significant increase in magnesium production across 1999–2000, noted in an ERT's review comment, was the consequence of a new facility beginning operation in 2000 and the other two facilities increasing their SF_6 use by more than 30% between 1999 and 2000. For 2005–2007, Norsk Hydro's SF_6 emissions were significantly reduced as a result of the gradual reduction in production and the plant's closure in 2007.

There were 11 magnesium casting facilities in operation during the 1990–2004 period (Cheminfo Services, 2005b). Only a few of them had used SF_6 every year during the entire period. Some casters started using SF_6 towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as sulphur dioxide (SO_2). Two facilities have ceased their casting operations over the last few years. During the 2005–2008 period, only seven facilities were in operation and had used SF_6. Two companies shut down their magnesium casting operations at different times in 2009 (one in June and one in December). In 2010, another facility moved its operations to the United States.

It is estimated that the remaining five magnesium casting facilities in operation released about 290 kt CO_2 eq (< 0.1% of Canada's emissions in 2019).

Following comments received from the ERT in 2017, emissions from magnesium casting previously reported in CRF category 2.C.7 are reported altogether with SF_6 emissions coming from primary magnesium production in CRF category 2.C.4 since the 2018 inventory submission.

4.12.2. Methodological Issues

SF_6 emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (Environment Canada, 1990–2007). For previous years (i.e., 1990–1998), the data was provided voluntarily by the producers to Environment Canada through personal communication. Since there was no reported 2008 data for Timminco, its 2008 SF_6 value was estimated on the basis of its 2007 data and the number of months of operation in 2008 (i.e., seven months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

Norsk Hydro and Timminco were contacted in 2006 regarding the methodology they had applied to estimate SF_6 emissions. Both companies reported that they had estimated emissions based on the assumption that SF_6 emissions are equivalent to SF_6 consumption. However, they used different methods for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method,[26] which involves measuring the weight of gas cylinders used at the facility at the time of purchase and at the time they are returned to suppliers at the end of their usage. Timminco reported using the accounting method for estimating its SF_6 use.[27] In this method, accounting of delivered purchases and inventory changes of SF_6 used are recorded. The purchases must

25 Laperrière J. 2004. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 27, 2004). Norsk Hydro.

26 Laperrière J. 2006. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 4, 2006). Norsk Hydro.

27 Katan R. 2006. Personal communication (emails from Katan R to Au A, Environment and Climate Change Canada, dated March 16–22, 2006). Timminco.

be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 2 type method, as it is based on the reporting of facility-specific emission data.

The approach for estimating SF_6 emissions from casting facilities assumes all SF_6 used as a cover gas is emitted to the atmosphere. SF_6 use data for the time series came from a combination of data sources, including: results of the Cheminfo Services study (2002) with data received from the Cheminfo Services (2005b) study for 1990 to 2004 data and facility reported values received through voluntary data submission initiatives for 2005 to 2019 data. When data were not available for a facility for certain years, alternative methods and assumptions were applied.

For 2005–2007, SF_6 consumption data was provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data was made available by six of the seven casting facilities through the voluntary data submission process. For the remaining facility, it was assumed that its 2008 SF_6 use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations had shut down in 2009, were not able to report their 2009 SF_6 use data, but provided reasonable assumptions that could be used to estimate the 2009 SF_6 use. SF_6 use data for 2009 was provided by the other five facilities. For 2014 to 2019, SF_6 use data was provided by four out of five operating magnesium casting facilities through a voluntary data collection. In the case where SF_6 use data was not available for a facility during the years 2010 to 2019, SF_6 emissions were estimated based on provincial gross output data. More specifically, a ratio of “provincial gross output for a year with no facility-specific SF_6 use data” to “provincial gross output for the most recent year for which the facility provided SF_6 use data” was calculated. SF_6 emissions (for the years with no SF_6 use data) were then estimated by multiplying the ratio by the most recent facility-specific SF_6 emission value.

The technique applied to estimate emissions from magnesium casting for 1990–2004, 2008–2009 and 2010–2019 (for certain facilities) is considered to be of Tier 2 type (IPCC, 2006). For 2005–2007 and 2010–2019 (for certain facilities) for which facility reported data was available, the emission estimation method is of Tier 3 type.

4.12.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for Magnesium Casting. It took into account the uncertainty associated with the SF_6 data reported by each facility. The uncertainty varied from ±1.0% to 20.9% from 1990 to 2019.

The uncertainty for Magnesium Production was also estimated using a Tier 1. For the time period which magnesium production was active (1990–2008), the uncertainty varied from 2.9% to 30%. The data source remains consistent over the time series.

The methodology, which equates consumption of SF_6 as a cover gas to emissions of SF_6, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

4.12.4. Category-Specific Quality Assurance/Quality Control and Verification

The Magnesium Production category has undergone checks as outlined in Canada’s General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as outlined in Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. There is a step (step 4.4) in Canada’s current QC process for detecting large fluctuations (e.g., in production or in implied emission factors).

The Magnesium Casting category has undergone informal quality control checks.

4.12.5. Category-Specific Recalculations

Emission estimates for 2010 to 2018 were recalculated for Magnesium Casting due to updates in gross output data and inclusion of updated SF_6 use data provided by the operating magnesium casting facilities. The changes were between -0.29 kt to +13 kt.

4.12.6. Category-Specific Planned Improvements

There are no planned improvements for magnesium production.

4.13. Lead and Zinc Production (CRF Category 2.C.5 and 2.C.6)

4.13.1. Category Description

Emissions from lead and zinc production occur in Canada due to the use of reductants in the sintering or smelting processes. Currently, CO_2 emissions are reported under category 2.D.3, Non-Energy Products from Fuels and Solvent Use, since disaggregation is not possible at this time. Future improvements include identifying the type of production processes in Canada and disaggregating emissions, if possible, based on the type of reductant used in lead and zinc production.

4.14. Non-Energy Products from Fuels and Solvent Use and Use of Urea in Selective Catalytic Reduction Vehicles (CRF Category 2.D.3)

4.14.1. Category Description

Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3)

The Non-Energy Products from Fuels and Solvent Use category includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other categories of the IPPU sector. The following are examples of fuels in non-energy applications: the use of natural gas liquids (NGLs) and refinery output as feedstocks in the chemical industry and the use of lubricants such as engine oil and grease in transportation and industrial applications, with “use” defined as “close-to-production” consumption of fuel, e.g., burning of motor oil in the engine’s combustion chamber (excludes waste oil incineration, which is allocated to the Waste sector). All of these activities result in varying degrees of oxidation of the fuel, producing CO_2 emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting as well as petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock or for other non-energy purposes is reported in an aggregated manner by Statistics Canada as “non-energy use” for each individual fuel. In the event that CO_2 emissions resulting from non-energy fuel use are allocated to another category of the IPPU sector (as is the case for Ammonia Production, Petrochemical Production, Iron and Steel Production, and Aluminium Production), those emissions are subtracted from the total emissions from this category to avoid double counting. Additional details on the method used to calculate emissions from this category can be found in Annex 3, section A3.3.3.

The Non-Energy Products from Fuels and Solvent Use category contributed 11 600 kt (1.6%) to Canada’s total emissions in 2019, a 16% increase from 2005.

Efforts have been made to examine the possibility of disaggregating lubricating oils and greases from the Non-Energy Products from Fuels and Solvent Use category and reporting the associated CO_2 emissions under CRF category 2.D.1, instead of CRF category 2.D.3. However, results of the examination show that reporting CO_2 emissions coming from use of lubricating oil and greases as a separate CRF category can lead to disclosure of confidential activity data. Hence, these emissions are kept in CRF category 2.D.3.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRF Category 2.D.3)

Selective catalytic reduction (SCR) is an emission reduction technology that can use urea as a liquid-reducing agent to help reduce NO_x emissions from vehicle exhaust. CO_2 emissions from the use of urea-based additives in the catalytic converters are considered non-combustive emissions.

4.14.2. Methodological Issues

Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3)

Emission factors for non-energy use of fuels were developed on the basis of the total potential CO_2 emission rates and percentages of carbon stored in products. The total potential CO_2 emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides energy unit-based EFs. The fractions or percentages of carbon stored used are IPCC default values (IPCC/OECD/IEA, 1997; IPCC, 2006), which are used to determine the “oxidized during use” (ODU) factor (1 minus the percentage of carbon stored).

The types of non-energy fuels that are included in the estimation model for the Non-Energy Products from Fuels and Solvent Use category are outlined in Table 4–5.

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada, 1990–2019). It should be noted that RESD data for any given year is preliminary and subject to revisions in subsequent publications. This data was multiplied by the emission factors shown in Annex 6 to estimate CO_2 emissions for this category. For example, to estimate emissions coming from non-energy use or oxidation of petroleum products, such as petroleum used for other products, RESD data was multiplied by the potential CO_2 emission factor and by

Table 4–5 **Non-Energy Fuel Types Used in the Canadian GHG Inventory**		
Gaseous Fuels	Solid Fuels	Liquid Fuels
Natural gas	Canadian bituminous coal	Propane
	Sub-bituminous coal	Butane
	Foreign bituminous coal	Ethane
	Lignite	Petrochemical feedstocks
	Anthracite	Naphthas
	Metallurgical coke	Lubricating oils and greases
	Petroleum coke	Petroleum used for other products[a]

Note:

a. Other products include waxes, paraffin and unfinished products (items that cannot be identified in end-product terms).

the ODU factor (which is 1 minus percentage of carbon stored). The percentage of carbon stored in petroleum used as other products, which includes waxes, paraffin and unfinished products, was determined to be equivalent to the default factor from the revised 1996 IPCC Guidelines and not that for paraffin wax as per the 2006 IPCC guidelines, because the disaggregation of paraffin wax use is not possible.

This technique is consistent with the method described in the 2006 IPCC Guidelines and is considered to be a Tier 1 type method as it is based on the use of national consumption data and average national emission factors. Emissions of CH_4 and N_2O for CRF category 2.D.3 are included under category 2.B.8, Petrochemical and Carbon Black Production, and emissions of N_2O from the production of methanol, carbon black and ethylene production are included in 2.B.10, Other (Chemical Industry). Emission factors for CH_4 and N_2O are presented in Table A6.2-4 in Annex 6.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRF Category 2.D.3)

The 2006 IPCC Guidelines recommends that Equation 3.2.2 (Volume 2) be used for the estimation of emissions from the use of urea-based additives in catalytic converters.

For estimating emissions from this source, road transportation activity data must be considered. More specifically, vehicle population, fuel consumption ratios and kilometre accumulation rates are used to determine the amount of diesel consumed by these vehicles and consequently the volume of urea-based diesel exhaust fluid (DEF) additive consumed by their SCR catalyst. For more information on the sources of this information, refer to Annex 3.1.

To determine the portion of the fleet employing this technology (technology penetration ratio), vehicle certification and regulatory data is used to identify the vehicles equipped with SCR. The Canadian Vehicles in Operation Census and R.L. Polk & Co.'s database for light-duty and heavy-duty vehicles, respectively, were consulted to calculate the annual technology penetration ratios.

A dosing rate representing 2% of the diesel consumption has been employed as it is the midpoint of the range suggested in the 2006 IPCC Guidelines. Additionally, the default DEF purity of 32.5% was corroborated at Environment Canada's national vehicle emission testing facility, where concentration measurements were taken with a refractometer as part of its testing program.[28]

4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Non-Energy Products from Fuels and Solvent Use. The assessment took into account the uncertainties associated with the activity data and emission factors (ICF Consulting, 2004). The uncertainty for the category as a whole was estimated at ±20%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

A Tier 1 uncertainty assessment was performed for the category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. The overall uncertainty was found to be ±50%.

4.14.4. Category-Specific Quality Assurance/Quality Control and Verification

Non-Energy Products from Fuels and Solvent Use is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

The category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles has undergone informal quality control checks throughout the emission estimation process.

4.14.5. Category-Specific Recalculations

For the Non-Energy Products from Fuels and Solvent Use category, CO_2 emissions were recalculated due to the update of the emission factor for petroleum coke, which contributed to minor recalculations for the whole time series. There were also recalculations between 2011 and 2018 due to revisions of activity data. The overall impact of all revisions ranges from 1 kt to 560 kt.

28 Rideout G. 2014. Personal communication (email to McKibbon S. November 4, 2014). Pollution Inventories and Reporting Division, Environment and Climate Change Canada.

Revised activity data caused a minor upward recalculation of 0.06 kt in 2018, for the category of use of urea in SCR vehicles.

4.14.6. Category-Specific Planned Improvements

Emission factors for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. There is a plan to evaluate whether these emission factors are still valid and to update them if necessary. In addition, as supporting information becomes available (i.e., information that would allow disaggregation of fuel data and allocation to the appropriate source category) for other (more specific) categories (e.g., iron and steel production), emissions in the Non-Energy Products from Fuels and Solvent Use category will be revised to avoid double counting of emissions and to improve transparency in the inventory.

There is no planned improvement for estimating CO_2 from use of urea in SCR vehicles.

4.15. Electronics Industry (CRF Categories 2.E.1 and 2.E.5)

4.15.1. Category Description

Industrial processes related to the electronics industry in Canada include the use of Perfluorocarbons (PFCs), SF_6 and NF_3 in semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing. This subsector does not include emissions of SF_6 used in electrical equipment or PFCs used as electrical insulation, as a dielectric coolant, and as a heat transfer medium as these are included under Other Product Manufacture and Use (CRF subsector 2.G).

It is estimated that emissions from the electronics industry in Canada accounted for about 29 kt CO_2 eq in 2019.

4.15.2. Methodological Issues

PFC Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

The activity data for PFC usage in the semiconductor industry was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17). The largest known user of PFCs for semiconductor manufacturing from the 2014–2019 gas distributor surveys was independently surveyed and provided revised annual purchase quantities. There are two main uses of PFCs in the semiconductor manufacturing industry in Canada: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition chambers.

The IPCC Tier 2 methodology, as shown in Equation 4–11, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–11

$$E_{SC,PFC} = E_{FC} + E_{CF_4} + E_{C_2F_6}$$

$E_{SC,PFC}$ = total PFC emissions from PFC use in semiconductor manufacturing

E_{FC} = emissions resulting from the use of PFCs (see IPCC 2006 Volume 3, Equation 6.2)

E_{CF_4} = CF_4 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.3)

$E_{C_2F_6}$ = C_2F_6 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.4)

Process-specific Tier 2b emission factors were used when information on process use was available from semiconductor manufacturing facilities or gas distributors. When the process use of the gas was unknown, Tier 2a emission factors were used. Default Tier 2a and Tier 2b emission factors used in IPCC 2006 equations 6.2, 6.3, and 6.4 are found in Table 6.3 of the 2006 IPCC Guidelines. The subset of emission factors used for estimating Canadian emissions are presented in Table A6.2-10.

The heel (h) value was assumed to equal 0.1, as suggested in the 2006 IPCC Guidelines. As no information on emission control technologies for these processes in Canada was available for 1990–2013 data years, it was assumed that no emission control technologies were used. One facility provided annual gas-specific and process-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively a_i and d_i in the IPCC Guidelines) for 2014–2019 data years. These fractions were used to estimate emissions from this facility and these years only. For all other 2014–2019 users, since no information on emission control technologies was available, it was assumed that no emission control technologies were used.

NF_3 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

In 2013, Environment Canada commissioned a study to determine the extent of NF_3 usage in Canada, including a survey of all potential NF_3 gas suppliers as well as seven identified potential users (Cheminfo Services, 2014). In the survey, only one semiconductor manufacturing facility indicated usage of NF_3 in 2013, and a gas distributor identified an additional unidentified purchaser between 2010 and 2013. The results of the study are considered to be complete, as both Canadian fabrication plants in the SEMI World Fab Watch database responded to the survey (Cheminfo Services, 2014). Additionally, previous research conducted by

Environment Canada using the Domestic Substances List (Environment Canada, 1986) indicated that between 33 and 199 kg of NF_3 were used in 1986. All NF_3 usage in Canada is believed to occur in the semiconductor manufacturing industry.

The use of NF_3 in the plasma cleaning of chemical vapour deposition (CVD) chambers can produce by-product emissions of CF_4 (a PFC). The IPCC Tier 2 methodology, as shown in Equation 4–12, was used to estimate NF_3 and by-product CF_4 emissions from the semiconductor manufacturing industry:

Equation 4–12

$$E_{SC,NF_3} = E_{NF_3} + E_{CF_4}$$

E_{SC,NF_3} = total emissions from NF_3 use in semiconductor manufacturing

E_{NF_3} = NF_3 emissions resulting from the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.2)

E_{CF_4} = CF_4 emitted as a by-product during the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.3)

To determine NF_3 use and emissions throughout the time series, various assumptions needed to be made. For the unidentified 2010-2013 purchaser, the use of the purchased quantity of NF_3 was assumed to be evenly distributed amongst the years since no information on annual use was available. Emissions for this purchaser were estimated using Tier 2a emission factors and the default heel value of 10%. It was assumed that no emission control technologies were employed. The identified 2013 user stated that the NF_3 was used in an etching process and provided a purchase quantity and an amount fed into the process, effectively providing an annual facility-specific heel value. Emissions for this facility were estimated using Tier 2b emission factors representative of the etching process. The company indicated that no emission control technologies were employed. It was assumed that 2010–2012 use levels for this company were at 2013 levels, and emissions were calculated using the same method.

To estimate emissions for years 1990–2009, emissions for 1986 were first calculated using the midpoint value of the range from the Domestic Substances List using Tier 2a emission factors and the default heel value, and it was assumed that no emission control technologies were used. Then, the 1990–2009 emissions were calculated by linearly interpolating the 1986 and 2010 NF_3 and by-product CF_4 emissions values. The emissions were interpolated, rather than interpolating the use of NF_3 and calculating emissions independently, because this latter approach would have induced a discontinuity with the by-product emissions of CF_4 from the application of different sets of emission factors (Tier 2a EFs were used for 1986, and a combination of Tier 2a and 2b EFs were used for 2010).

Voluntary surveys were collected from major gas distributors and the identified 2013 user for data years 2014–2019. Other than the identified 2013 user, gas distributors did not export any NF_3 to the semiconductor industry, so the unidentified 2010–2013 user is assumed to have stopped using NF_3 after 2013. Emissions for 2014–2019 are therefore estimated using annual purchase data from the sole facility, the default heel value of 10%, and Tier 2b emission factors for etching process use. The facility states that they have emission control technology on-site capable of abating NF_3 and CF_4 emissions, but that the process gases from this part of production are not fed into the abatement technology (a_i is equal to 0 for 2014–2019). In all cases, NF_3 usage was assumed, as opposed to NF_3 remote usage, based on the definitions stated in the 2006 IPCC Guidelines.

SF_6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

The method applied to estimate SF_6 Emissions from Semiconductor Manufacturing was similar to what was used to estimate PFC and NF_3 emissions. However, use of SF_6 as a process gas in etching and chemical vapour deposition (CVD) processes does not produce any fluorocarbon by-product emissions. A Tier 2a estimate was conducted using IPCC 2006 Volume 3, Equation 6.2.

Quantities of SF_6 sold to semiconductor manufacturers for 1995–2003 were obtained from major Canadian gas suppliers. Since 1990–1994 sales data is unavailable, it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level.

From 2004 onwards, the total amount of SF_6 used in the semiconductor manufacturing industry was estimated by multiplying the total SF_6 imported (from Statistics Canada) by the proportion of gas distributor SF_6 sales data attributed to semiconductor manufacturing (in %) (Cheminfo Services, 2005a and several ECCC surveys). No SF_6 sales data was collected for the years 2010–2013, so the proportions of gas distributor SF_6 sales data attributed to semiconductor manufacturing were linearly interpolated between 2009 and 2014. As of inventory compilation, 2019 survey data from gas distributors was incomplete. To calculate the 2019 proportion of gas distributor SF_6 sales data attributed to semiconductor manufacturing, each missing distributor's 2014–2018 average sales pattern was used. SF_6 import data was available until 2011 from Statistics Canada. For 2012–2018 data years, the gross output (GO) economic data for NAICS 334 (Computer and Electronic Products Manufacturing) was used as a proxy variable to estimate the annual imports of SF_6.

Due to the two different sources of SF_6 data (i.e., Canadian gas suppliers for 1995–2003 and Statistics Canada for 2004–2009), there was a significant difference among these periods. To ensure a consistent trend over the entire time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied for 1990–2003 (both data sources had SF_6 import data for years 1998–2000).

Emissions were calculated using the heel value (h) of 12% provided and confirmed by two major SF_6 gas distributors, Air Liquide and Praxair.[29] The IPCC 2006 default emission factor (1-U) of 0.2 was used. From 1990 to 2013, it was that assumed no emissions control technologies were used by the industry. For 2014 to 2019, the largest known SF_6 user in the semiconductor manufacturing industry provided annual facility-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively, a_i and d_i in the IPCC Guidelines). It was assumed that all other facilities had no emissions control technologies operating from 2014 to 2019. The annual proportion of each facility's share of the sum of all gas distributor SF_6 sales data attributed to semiconductor manufacturing (s_f) was used in Equation 4–13 to calculate the total emissions from SF_6 use in semiconductor manufacturing. Equation 4–13 is an expanded country-specific version of IPCC 2006 Volume 3, Equation 6.2:

Equation 4–13

$$E_{SC,SF_6} = (1-h) \times [FC \times (1-U) \times \left(1 - \sum_{f=1}^{n} (s_f \times a_f \times d_f)\right)]$$

E_{SC,SF_6}	=	total emissions from SF_6 use in semiconductor manufacturing
h	=	heel value of 12%, as provided by gas distributors Air Liquide and Praxair
FC	=	total amount of SF_6 used in the semiconductor manufacturing industry (SF_6 imported multiplied by the proportion of gas distributor sales data attributed to semiconductor manufacturing)
U	=	U is the fractional use rate of SF_6 (fraction destroyed or transformed in process), equal to 0.8 (see IPCC 2006 Volume 3, Table 6.3)
s_f	=	facility-specific share of the gas distributor sales data attributed to semiconductor manufacturing
a_f	=	facility-specific fraction of SF_6 volume fed into process types with emission control technology
d_f	=	facility-specific fraction of SF_6 destroyed by the emission control technology

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

The activity data for PFC (Perfluorocarbon) usage in Other Emissive Applications was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17). PFC usage was last reported in a voluntary data collection survey for 2008 data, identifying a minor amount of PFCs used for emissive applications in the electronics industry. In 2009 and 2014–2019 data surveys, major gas distributors did not report any PFC use in emissive applications. As such, emissions were assumed to be zero for years 2010–2019 after the remaining 2008 charges were released in 2009. Emissive sources in Canada include electrical environmental testing, gross leak testing and thermal shock testing. The IPCC Tier 1a methodology was used to estimate emissions at the application level. Since no emission factors for Other Emissive Applications were available in the 2006 IPCC Guidelines, default emission factors from the IPCC 2000 Good Practice Guidance document were applied, where 50% of the initial charge is emitted during the first year and the remaining in the following year.

4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for PFC consumption as a whole. Uncertainties related to activity data (IPCC 2006) and emission factors (Japan Ministry of the Environment, 2009) were taken into account in the assessment for PFC consumption. The uncertainty associated with the category as a whole for the time series ranges from ±10% to ±24%.

The 2006 IPCC Guidelines show the relative error for Tier 2b etching with NF_3 to be a factor of three (300%), as per IPCC 2006, Volume 3, Table 6.9.

A Tier 1 uncertainty assessment was performed for the category of SF_6 Emissions from Semiconductor Manufacturing (±45%).

4.15.4. Category-Specific Quality Assurance/Quality Control and Verification

Categories under the Electronics Industry subsector have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

The facility-provided gas-specific emission control technology destruction efficiencies were cross-checked against the Tier 2a and 2b default efficiency parameters in IPCC 2006, Volume 3, Table 6.6 as a quality control check before being used to estimate 2014–2019 emissions.

29 Rahal H and Tardif A. 2006. Personal communications (emails from Rahal H and Tardif A to Au A, Environment and Climate Change Canada, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

4.15.5. Category-Specific Recalculations

There has been recalculations of emissions of all gases in the category of Semiconductor Manufacturing due to receiving 2014–2019 data surveys from major gas distributors and one user.

PFC Emissions from Semiconductor Manufacturing was recalculated for years 2009–2018 due to the introduction of the calculation of by-product C_2F_6 emissions to meet the requirements of the 2006 IPCC Guidelines, and from the usage of received 2014–2019 data surveys. Previous years were not affected by the introduction of C_2F_6 because no use of PFCs that produce by-product C_2F_6 emissions were reported until 2009. 2010–2013 PFC distribution values were interpolated from the prior survey (2009 data) to the newly received survey data. The effects of these recalculations range from +0.066 kt CO_2 eq (+4%) in 2009 to +12 kt in 2018 (+550%).

NF_3 Emissions from Semiconductor Manufacturing was recalculated for years 2014–2018 with the received user survey data, with changes ranging from -0.058 kt (-48%) to +0.37 kt (+312%).

SF_6 Emissions from Semiconductor Manufacturing was recalculated for years 2010–2018 from the usage of received 2014–2018 data surveys and from an update in gross output data. 2010–2013 proportions of gas distributor sales data attributed to semiconductor manufacturing (in %) were interpolated from the 2009 survey data to the newly received survey data. The update in gross output data only affects the 2012–2018 years where gross output data is used to extrapolate the 2011 SF_6 import data.

4.15.6. Category-Specific Planned Improvements

Voluntary data surveys for 2019 were not collected from all major gas distributors. For missing gas distributors, 2019 distribution rates were calculated using each distributor's average 2014–2018 survey data. A voluntary data collection of 2019 data will be continued in 2021 to obtain up-to-date PFC, SF_6 and NF_3 use and sales data. In addition, more Canadian semiconductor manufacturers will be contacted to verify gas distributor purchase data and obtain information on implemented emission control technologies. The data obtained from facilities will be assessed for quality for eventual implementation in future inventory submissions.

4.16. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, HFCs)

4.16.1. Category Description

In order to provide a clear representation of the Canadian category of Product Uses as Substitutes for Ozone-Depleting Substances, explanations on hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have been divided into two separate sections in this report (sections 4.16 and 4.17, respectively).

Before the Montreal Protocol ban on the production and use of chlorofluorocarbons (CFCs) came into effect in 1996, very few HFCs were produced and used globally. In Canada, HFC-23 was produced until 1992 as a by-product of HCFC-22 production, which ended in 1992. There has been no other production of HFCs in Canada. Also, Canadian emissions from HFC consumption were considered negligible for the 1990–1994 period (IPCC/OECD/IEA, 1997). HFC consumption in Canada began in 1995. HFCs are used in a variety of applications, including refrigeration, air conditioning, fire suppression, aerosols, solvent cleaning, and foam blowing agents. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g., refrigerators).

HFC releases contributed 12 410 kt CO_2 eq (1.7%) to Canada's total emissions in 2019, a 143% increase from 2005.

4.16.2. Methodological Issues

For this submission, Canada has implemented the IPCC Tier 2a approach to estimating HFC emissions by type of sub-application (IPCC, 2006).

Activity Data

Canadian HFC use data is derived from bulk imports, and imports and exports of manufactured items (MIs). Canada occasionally exports small quantities of HFCs in bulk. Up to the year 2005, activity data was gathered via periodic, mandatory surveys for the data years 1995 through 2004; additional mandatory activity data collection took place in 2014 and 2016, covering activity data of years 2008 through 2015. Activity data for 2017, 2018 and 2019 was collected in 2018, 2019 and 2020, respectively, from the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* (ODS Regulations). Note that the 1996 survey did not include information on imports and exports of manufactured items for the 1995 data year, and the activity data was therefore estimated on the basis of the 1996–1998 survey data.

Voluntary surveys for bulk sales and imports and exports of MIs data by market segment were collected from 2006 to 2011 covering activity data of years 2005 through 2010. The surveys were collected by Environment Canada and

Table 4–6 **HFCs Used in Canada and Years for which Activity Data is Available**

HFC Type	Years	HFC Type	Years
HFC-125	1995–2015, 2017–2019	HFC-23	1995–2004, 2008–2015, 2017–2019
HFC-134	2008, 2009, 2015, 2017–2019	HFC-236fa	1996–1998, 2000–2004, 2008, 2010, 2012 and 2013
HFC-134a	1995–2015, 2017–2019	HFC-245fa	2001–2015, 2017–2019
HFC-143	2013	HFC-32	1995–2015, 2017–2019
HFC-143a	1995–2015, 2017–2019	HFC-365mfc	2008–2015, 2017–2019
HFC-152a	1995–2015, 2017–2019	HFC-41	1999, 2000 and 2010
HFC-227ea	1995–2015, 2017–2019	HFC-4310mee	1998–2015, 2018 and 2019

others (additional information is provided in Annex 3.3) and had varying response rates and aggregation levels of sub-applications.

The 2014, 2016, and 2018–2020 mandatory surveys of HFC bulk imports, exports and sales by HFC type and market segment forms the foundation for the 2008 through 2015 and 2017 through 2019 portion of the HFC inventory. When there were overlaps between the voluntary and the mandatory surveys, the mandatory surveys took precedence. Some additional imports and exports of MIs activity data was reported to the 2014 and 2016 surveys and are included in the inventory. Reporting of HFCs to the 2014 and 2016 mandatory surveys were done on the basis of applications and sub-applications so that the quantities for manufacture and servicing could be broken out.

The full list of HFCs and the years activity data was collected is shown in Table 4–6. No data was collected for 2016.

There are two facilities in Canada that can destroy HFCs and other substances, but no data is publically available on the amount of HFC destroyed.

Emission Factors

Surveys were performed in 2012 to document practices in HFC use and disposal and to support the development of country-specific emission factors that are representative of Canada’s circumstances (Environmental Health Strategies Inc. [EHS], 2013; Environment Canada, 2015). The country-specific emission factors were applied to the refrigeration and air conditioning sub-applications for the entire time period.

For the aerosols, foam blowing, fire extinguishing, solvents, and miscellaneous sub-applications, default emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. All emission factors are presented with references in Annex 6.

Estimation Methodology

Because the actual numbers of the various types of equipment are not available for Canada, the IPCC Tier 2a approach (IPCC, 2006) was used with the annual quantities of HFC consumed by application and sub-application, as discussed in Volume 3, Chapter 7, section 7.1.2.1 (IPCC, 2006). For the calculation of the net consumption of a HFC in a specific sub-application, Equation 7.1 from Volume 3, Chapter 7 (IPCC, 2006) has been adapted to the Canadian context and used. Refer to Annex 3.3 for additional details on methodology.

The lifecycle of each HFC is tracked by sub-application and year, then annual emissions are estimated for each applicable lifecycle stage (assembly of the product, in-service operation of the product and end-of-life decommissioning). The annual quantity of each HFC that remains in products (in stock) after assembly, in-service and end-of-life losses are also calculated. In this way, the mathematically expanded version of the method discussed in Volume 3, Chapter 7, section 7.1.2.2 (IPCC, 2006) and subsequent sections are applied. Emissions for each lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. The HFC emission estimation equations applied for each unique sub-application are explained in more detail in Annex 3.3.

4.16.3. Uncertainties and Time-Series Consistency

A Monte Carlo uncertainty assessment was performed for the consumption of HFCs. It took into account the uncertainties associated with all sub-applications, such as residential/commercial refrigeration, stationary/mobile air conditioning, etc. To determine the uncertainty for a sub-application, the uncertainties related to activity data (Cheminfo Services, 2005c) and emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. It should be noted that the overall category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the sub-application emission estimates, which changes from year to year. The uncertainty associated with the category as a whole for 2019 was ±11%.

4.16.4. Category-Specific Quality Assurance/Quality Control and Verification

Consumption of halocarbons resulting in HFC emissions is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Volume 1, Chapter 6 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

4.16.5. Category-Specific Recalculations

Application of updated proxy variables for all sub-applications resulted in recalculations for 2011–2018 HFC emission estimates, with the largest increase being less than 1 kt CO_2 eq in 2012 and the largest decrease being 26 kt CO_2 eq in 2018.

4.16.6. Category-Specific Planned Improvements

Research into the commercial and industrial refrigeration emission factors, market share and other characteristics in Canada will be examined for application in future inventories. A data gap exists with the in-item data that is available up to 2010. To fill this gap, sources of statistics and import/export data will be searched and examined. Another planned improvement is to obtain more information on HFC destruction activities in Canada to further improve end-of-life emission factors.

4.17. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, PFCs)

4.17.1. Category Description

PFC consumption in Canada began in 1995. Like HFCs, PFCs are also used as substitutes for ODS being phased out under the Montreal Protocol (IPCC, 2006). However, the uses of PFCs are very limited compared to HFCs in Canada. Canadian applications that have used PFCs as Substitutes for ODS over the time series include Refrigeration and Air Conditioning, Foam Blowing Agents, and Solvents.

PFC releases contributed to about 2.4 kt CO_2 eq in 2019, a 74% decrease from 1995.

4.17.2. Methodological Issues

The 2006 IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 to 2018. Details of the methods are found in the following subsections. The 1995–2000 activity data was obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001 and 2002 data was unavailable, emission estimates were developed on the basis of the assumption that the use quantities in various applications stayed constant after 2000. Environment Canada conducted a collection of 2003–2007 PFC use data from major distributors of PFCs in 2008 and 2009. The data from the major distributors was then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors was collected in 2009 and 2010. 2014–2019 PFC data was collected from gas distributors in 2019 and 2020 voluntary surveys. To estimate PFC use for the 2010–2013 period, sub-application use quantities were interpolated between the 2009 and 2014 data surveys.

Since no uses of PFCs as Substitutes for ODS was recorded in 2014–2019 surveys, emissions for 2014–2019 are estimated from the in-service and end-of-life leakage rates for applications with products still in service. Emission factors applied for the use of PFCs as ODS Substitutes are presented in Table A6.2-12.

Refrigeration and Air Conditioning
(CRF Category 2.F.1, PFCs)

IPCC Tier 2a methodology, i.e., equations 12, 13 and 14 from Volume 3, Chapter 7, section 7.5 of the 2006 IPCC Guidelines, was used to estimate the emissions from the assembly, operation and disposal of the following sub-applications: industrial refrigeration, commercial refrigeration, stationary air conditioning systems and mobile air conditioning systems.

The assembly losses (k values) and annual operating leakage rates (x values) used were chosen from a range of values that were provided for each sub-application in the 2006 IPCC Guidelines. Loss and leakage rates by sub-application can be seen in Table A6.2-12.

The refrigerant "bank" used for this calculation includes the amount of PFCs contained in imported or manufactured equipment in Canada and excludes the amount of PFCs exported and lost during assembly.

PFC use in Canada began in 1995. It is assumed that there were no PFC emissions from the disposal of refrigeration and stationary air conditioning systems between 1995 and 2009 and from the disposal of mobile air conditioning systems between 1995 and 2006 since these systems have an average lifespan of 15 and 12 years, respectively (IPCC 2006). An additional assumption is that there are no recovery or recycling technologies in place and therefore 100% of the quantities remaining in systems are released once the end of the lifespan is reached, i.e., any remaining refrigerant in a refrigeration system built in 1995 would be emitted in the year 2010. Fluctuations in annual emissions are to be expected during years where the lifespans have been reached and the remaining PFCs in the systems are disposed of. Emissions from the refrigeration and air conditioning sub-applications are likely to be over-estimated since various regulatory requirements currently existing in Canada would prohibit the release of PFCs.

No uses of PFCs in the assembly of refrigeration and air conditioner units have been recorded in data surveys after 2008. A small amount of estimated in-service and end-of-life emissions continue to contribute a total of 2.4 kt CO_2 eq in 2019.

Foam Blowing Agents (CRF Category 2.F.2, PFCs)

IPCC Tier 1a methodology was applied using IPCC 2006 default emission factors since activity data at the sub-application level was not available. Equation 7.7 from Volume 3, Chapter 7, section 7.4, of the 2006 IPCC Guidelines was used to estimate the emissions from closed-cell foam sub-applications. During the production of closed-cell foam, approximately 10% of the PFCs used in manufacturing are emitted. The remaining quantity of PFCs is trapped in the foam and is slowly emitted at a rate of 4.5% of the original charge per year over a period of approximately 20 years (IPCC, 2006).

The last reported use of PFCs in closed-cell foam was in 1997, and the estimated in-service emissions from this use expired in 2017.

Aerosols (CRF Category 2.F.4, PFCs)

PFC emissions from this source are expected to be negligible since major gas distributors did not report any PFC use in aerosols in voluntary data submissions conducted in 2009 and 2019.

Solvents (CRF Category 2.F.5, PFCs)

The IPCC Tier 1a methodology presented in the 2006 IPCC Guidelines was used to estimate PFC emissions from solvents. A product lifetime of two years was assumed and a default IPCC emission factor of 50 percent of the initial charge/year was used (IPCC, 2006). Equation 7.5 from Volume 3, Chapter 7, section 7.2, of the 2006 IPCC Guidelines was used to estimate emissions for each year and is calculated to be half of the PFCs used as solvents in the estimated year plus half of the PFCs used as solvents in the previous year. The amount of PFCs used each year is equal to the amount of PFCs produced and imported as solvents and excludes the amount of PFCs exported as solvents. Main sub-applications include electronics cleaning, laboratory solvents, and carrier solvents for various products (e.g., protective coating, mould release agents, lubricants).

A marginal amount of PFC use in solvents was indicated by gas distributors in a 2009 survey, and none was indicated in 2014–2019 surveys. Since no data is available for 2010–2013, use quantities are interpolated between the 2009 amount and the 2014 amount (zero). Since all emissions from the use of solvents are estimated take place in production year and the next year, no emissions are estimated after 2014.

4.17.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for PFC consumption. As in the case of HFC consumption, uncertainties related to activity data (IPCC, 2006) and emission factors (Japan Ministry of the Environment, 2009) were taken into account in the assessment for PFC consumption. The uncertainty associated with the category as a whole for the time series ranged from ±10% to ±24%.

4.17.4. Category-Specific Quality Assurance/Quality Control and Verification

The category of PFC consumption has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.17.5. Category-Specific Recalculations

There have been minor recalculations ranging from -0.57 kt CO_2 eq (-31%) in 2014 to +0.0016 kt CO_2 eq (+0.09%) in 2004 across the time series due to fixing of calculation errors within the refrigeration and foam blowing agent emission estimates and updating of solvents estimates for 2010–2018 with the results of the completed 2014–2019 gas distributor surveys.

4.17.6. Category-Specific Planned Improvements

Voluntary data surveys for 2019 were not collected from all major gas distributors. For missing gas distributors, 2019 distribution quantities were calculated using each distributor's average 2014–2018 survey data, which were negligible for all PFC Substitutes for ODS applications. A voluntary data collection of 2019 data will be continued in 2021 to obtain up-to-date PFC distribution data.

4.18. Other Product Manufacture and Use (CRF Category 2.G)

4.18.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of SF_6 in electrical equipment (CRF category 2.G.1), N_2O emissions from medical applications (CRF category 2.G.3.a), N_2O emissions from use as a propellant (CRF category 2.G.3.b) and PFC Emissions from Other Contained Product Uses (CRF category 2.G.4) such as uses within power transformers as an electronic insulator, as a dielectric coolant, or as a heat transfer medium, which are not ODS substitutes or electronics industry-related.

In electric utilities, SF_6 is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations. In Canada, SF_6 is primarily used in high-voltage circuit breakers and related equipment.

Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N_2O for commercial sales in Canada. It supplies N_2O to two of the three primary N_2O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N_2O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N_2O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services, 2006).

N_2O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. Other areas where N_2O can be used include production of sodium azide (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors surveyed during the 2006 study, approximately 82% of their N_2O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services, 2006).

Of all applications in which N_2O can be used, only the two major types are emissive. When N_2O is used as an anaesthetic, it is assumed that none of the N_2O is metabolized (IPCC 2006). In other words, the used N_2O quickly leaves the body in exhaled breath (i.e., is emitted) as a result of the poor solubility of N_2O in blood and tissues. When N_2O is used as a propellant, only emissions coming from N_2O used in whipped cream are estimated, because the amounts of N_2O employed in other food products and in non-food products are considered negligible, according to the food industry and the gas producer and distributors. When the cream escapes from the can, the N_2O gas expands and whips the cream into foam. As none of the N_2O is reacted during the process, it is all emitted to the atmosphere (Cheminfo Services, 2006).

Note that emissions from use of solvents in dry cleaning, printing, metal degreasing and a variety of industrial applications, as well as household use, are not estimated.

The Other Product Manufacture and Use category contributed about 718 kt (<0.1%) to Canada's total emissions in 2019, an 92% increase from 1990.

4.18.2. Methodological Issues

Sulphur Hexafluoride Emissions from Electrical Equipment (CRF Category 2.G.1)

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for certain years (i.e., 2006–2019) of the time series, in place of the previous top-down approach (which assumed that all SF_6 purchased from gas distributors replaces SF_6 lost through leakage). The SF_6 emission estimates by province for 2006–2019 are typically provided by the Canadian Electricity Association (CEA), and BC Hydro, which collectively represent electricity companies across Canada. BC Hydro was a member of CEA, prior to 2017, and Hydro- Québec joined CEA in 2017. The CEA was unable to provide 2019 data in time for the publication since it had extended reporting deadlines from their members due to the pandemic in 2020. As such, data from 2018 was maintained constant for 2019 for all provinces that report through the CEA. However, BC Hydro provided updated data for 2019. CEA and BC Hydro data was prepared following the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* ("the Protocol") (Environment Canada and Canadian Electricity Association). Note that CEA and BC Hydro do not provide corresponding activity data. However, the quantification of emissions in the methodologies used is based on the mass of SF_6 injected into the equipment or contained in the cylinders. The national SF_6 estimate for each year during the 2006–2019 period was the sum of all provincial estimates. The *Protocol* is the result of a collaborative effort between Environment Canada, CEA and Hydro-Québec.

In summary, the *Protocol* explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life-cycle methodology. It also explains the different options available for estimating the equipment life-cycle emissions. These are equal to the sum of SF_6 used to top up the equipment and the equipment disposal and failure emissions (which are equal to either nameplate capacity less recovered quantity for disposal emissions or simply to nameplate capacity for failure emissions). A more detailed description of the methodology is provided in Annex 3.3.

Estimates were not available from CEA or Hydro-Québec for the years 1990 to 2005 because a systematic manner for taking inventory of the quantities of SF_6 from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF_6 distributors were used to obtain usage data prior to the application of the *Protocol*. To resolve this issue of data availability and to ensure a consistent time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied. In this case, the overlap was assessed between four sets of annual estimates (2006–2009) derived from the distributor surveys and obtained under the *Protocol*.

Emissions at provincial/territorial levels were estimated on the basis of the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

N_2O emission estimates for these categories are based on a consumption approach. Since it is virtually impossible to collect consumption data from all end users, it is assumed that domestic sales and imports (obtained directly from NOC) equal domestic consumption. Equation 8.24 of the 2006 IPCC Guidelines was used to estimate N_2O emissions and covers more than one calendar year because both supply and use are assumed to be continuous over the year; for example, N_2O supplied in the middle of a calendar year is not fully used until the middle of the following calendar year.

The producer and distributors were surveyed to obtain sales data by market segment and qualitative information to establish the 2005 Canadian N_2O sales pattern by application (Cheminfo Services, 2006). The sales patterns for 2006–2019 are assumed to be the same as that for 2005. The amounts of N_2O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume and their respective share of sales.

Provincial and territorial estimates were developed by distributing the national-level estimates on the basis of provincial/territorial population data (Statistics Canada, n.d.[d]).

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

The activity data on PFCs used in Other Contained Products was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17). Data on PFC use as a heat transfer medium was collected in 2014–2019 gas distributor data surveys, where one distributor indicated its use. 2010–2013 use quantities are interpolated between the previous 2009 data surveys and the 2014–2019 surveys. As of inventory compilation, not all gas distributors have filled out 2019 PFC data surveys. Therefore, 2019 use patterns for missing distributors are assumed to be the average of each distributor's 2014–2018 surveys.

The IPCC Tier 2 emission factors (IPCC, 2000) used to calculate PFC Emissions for Other Contained Product Uses are a leakage rate of approximately 1% during the manufacturing process and an annual leakage rate of 2% during their lifetime of 15 years (IPCC, 2000). It is assumed is that there are no recovery or recycling technologies in place and therefore 100% of the PFCs remaining in Other Contained Products are released once the end of the lifespan is reached. These emission factors are presented in Table A6.3-2, and are applied to the PFC data in accordance with Equation 3.54 of the IPCC 2000 Good Practice Guidance. No methodology is presented for this category in the 2006 IPCC Guidelines.

4.18.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of SF_6 from Electrical Equipment. It should be noted, however, that the uncertainty assessment was done using 2007 data. It is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category as a whole was estimated at ±30.0%. Depending on the years, the data source and methodology used for SF_6 from electrical equipment could vary, as explained in section 4.17.2 (Methodological Issues).

A Tier 1 uncertainty assessment was performed for the categories of N_2O Emissions from Medical Applications and Propellant Usage. It took into account the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty for these combined categories was evaluated at ±20%. It is expected that the uncertainty for this sector would not vary considerably from year to year as the data sources and methodology applied are the same.

A Tier 1 uncertainty assessment was performed for the category of PFC consumption as a whole. Uncertainties related to activity data (IPCC, 2006) and emission factors (Japan Ministry of the Environment, 2009) were taken into account in the assessment for PFC consumption. The uncertainty associated with the category as a whole for the time series ranged from ±10% to ±24%.

4.18.4. Category-Specific Quality Assurance/Quality Control and Verification

The categories of N_2O Emissions from Medical Applications and Propellant Usage, and PFC Emissions from Other Contained Product Uses have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

The category of SF_6 Consumption in Electrical Equipment has undergone informal quality control checks throughout the emission estimation process.

4.18.5. Category-Specific Recalculations

There were recalculations of less than 1 kt CO_2 eq for SF_6 emissions from electrical equipment for 2016 and 2017 due to updates in activity data.

Recalculations for PFC Emissions from Other Contained Product Uses occurred for years 2010–2018 due to the implementation of 2014–2019 gas distributor data surveys. The impacts of these recalculations ranged from -0.077 kt CO_2 eq (-1%) in 2010 to -5.4 kt CO_2 eq (-21%) in 2018.

4.18.6. Category-Specific Planned Improvements

As mentioned previously, SF_6 is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF_6 gas can be mixed with carbon tetrafluoride (CF_4) gas. Currently, Canada only reports SF_6 from this source category (CRF category 2.G.1). There are plans to collect CF_4 emission data to report in future inventory submissions.

Collected 2014–2019 sales data from gas distributors from voluntary data surveys indicate that SF_6 may be used for some applications within the SF_6 and PFCs from Other Product Use source category (CRF category 2.G.2). Previously, internet searches were conducted and found that the applications for CRF category 2.G.2 seemed to not exist at a detectable level. The possible applications within the source category include use within car tire adiabatic applications, as a leak detector, and in military applications. Disaggregated 2.G.2 categories will be included in 2019–2020 gas distributor data surveys to ensure that major distributors can identify and report these categories as intended uses if they occur. A Tier 1 emission estimation will be performed for these years to assess the significance level of emissions coming this category. If the category is determined to be significant, efforts will be made to develop emission estimates for the whole time series.

There are plans to develop an updated Canadian N_2O sales pattern by application in future inventory submissions in the emissions estimates of the N_2O Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF category 2.G.3.b) categories. The current sales breakdown is assumed to be the same as 2005.

For the PFC Emissions Other Contained Product Uses source category (CRF category 2.G.4), voluntary data surveys for 2019 were not collected from all major gas distributors. For missing gas distributors, 2019 distribution rates were calculated using each distributor's average 2014–2018 survey data. A voluntary data collection of 2019 data will be continued in 2021 to obtain up-to-date PFC distribution data for Other Contained Product Uses applications.

CHAPTER 5

AGRICULTURE (CRF SECTOR 3)

5.1. Overview

The Agriculture sector has contributed 8% of Canada's total greenhouse gas (GHG) emissions annually since 1990, and emissions within the sector increased by 26% between 1990 and 2019. Emission sources from the Agriculture sector include the Enteric Fermentation (methane [CH_4]) and Manure Management (nitrous oxide [N_2O] and CH_4) categories for emissions associated with livestock production and the Agricultural Soils (N_2O) and Field Burning of Agricultural Residues (CH_4 and N_2O) categories for emissions associated with crop production. Carbon dioxide emissions from lime and urea application are reported in the Agriculture sector; however, CO_2 emissions from and removals by agricultural lands are reported in the Land Use, Land-Use Change and Forestry (LULUCF) sector under the Cropland category (see Chapter 6). GHG emissions from on-farm fuel combustion are included in the Energy sector (Chapter 3).

The largest sectors in Canadian agriculture are beef cattle (non-dairy), swine, cereal and oilseed production. There is also a large poultry industry and a large dairy industry. Sheep are raised, but production is highly localized and small compared to the beef, swine, dairy and poultry industries. Other alternative livestock, namely bison,[1] llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, minks, rabbits, and mules and asses, are produced for commercial purposes, but production is small.

Canadian agriculture is highly regionalized as a result of historic and climatic influences. Approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced on the Prairies, a semiarid to subhumid ecozone, while approximately 75% of the dairy cattle herd, 60% of swine and poultry and more than 90% of corn and soybean are produced on the humid mixedwood plains ecozone in eastern Canada.

In 1990, there were 10.5 million beef cattle in Canada, 1.4 million dairy cattle, 10 million swine and 101 million poultry. Beef cattle and swine populations peaked in 2005 at 15 million head each. Since 2005, beef populations have decreased to 11 million head. Swine populations decreased to 12.5 million head in 2010, but have since increased, reaching 14 million head in 2019. Since 1990, poultry populations have increased to 154 million, whereas dairy cattle populations have decreased steadily, totalling less than 1 million head in 2019.

As a result of changes in cropping practices in Canada, canola production increased from 3 Mt in 1990 to 19 Mt in 2019, corn production from 7 Mt to 13 Mt, and soybean production from 1.3 Mt to 6.0 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt. However, production has since increased, reaching 32 Mt in 2019. With the changes in crop production, inorganic nitrogen consumption has more than doubled, from 1.2 Mt N in 1990 to 2.6 Mt N in 2019, the area under summerfallow has decreased by 7.8 million hectares (Mha) and land under conservation tillage has increased by 17 Mha.

As a result of the combined changes in livestock and cropland production, Canada's total greenhouse gas (GHG) emissions from the Agriculture sector rose from 47 Mt CO_2 eq in 1990 to 59 Mt CO_2 eq in 2019 (Table 5–1). This 27% increase, is mainly due to greater use of inorganic nitrogen fertilizers (121%), higher populations of beef cattle and swine (4% and 37% increases, respectively), and changes in feeding and manure handling practices in the dairy and swine industries.

Emissions of CH_4 from livestock accounted for 25 Mt CO_2 eq in 1990 and 28 Mt CO_2 eq in 2019, and mean estimates lie within an uncertainty range of -16% to +20%. Over the 1990 to 2019 time series, mean CH_4 emissions are estimated to have increased by 3.1 Mt CO_2 eq, a 12% increase. The observed increase in emissions falls within an uncertainty range of 10% to 17%. Emissions of N_2O from agricultural soils and livestock accounted for 21 Mt CO_2 eq in 1990 and 29 Mt CO_2 eq in 2019;

1 In the Common Reporting Format (CRF) tables, bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "buffalo" although the species referred to is the North American bison (*Bison bison*) that is raised for meat production using methods similar to beef cattle. In the text of the NIR, this animal category will be discussed as bison.

mean estimates lie within an uncertainty range of -27% to +29%. Over the time series, mean N_2O emissions increased by 7.7 Mt CO_2 eq, an increase of 37%.

Emissions from the Agriculture sector peaked in 2005, and decreased to 55 Mt CO_2 eq in 2011, with reductions in emissions from animal production as livestock populations decreased (see Enteric Fermentation and Manure Management source categories, Table 5–1). Since 2011, livestock populations have stabilized, while emissions associated with fertilizer use have increased. These trends, in combination with high crop production in recent years, have caused emissions to increase from their low point in 2011 to 59 Mt CO_2 eq in 2019.

In this submission, emissions were calculated as being 1 kt CO_2 eq higher in 1990, 32 kt CO_2 eq higher in 2005 and 45 kt CO_2 eq higher in 2018 than in the previous submission, for recalculations of 0.002%, 0.05% and 0.09%, respectively (Table 5–2).

Recalculations were the result of minor revisions to activity data inputs and the spatial redistribution of livestock and crops (Table 5–3 and see Annex 3.4). Activity data updates include a revision to crop yields for minor field crops for the years 2004 to 2018, revision of lime production inputs from 2017, and corrections to the spatial distributions of livestock and crop areas.

Table 5–1 **Short-and Long-Term Changes in GHG Emissions from the Agriculture Sector**

GHG Source Category		GHG Emissions (kt CO_2 eq)									
		1990	2000	2005	2013	2014	2015	2016	2017	2018	2019
Agriculture TOTAL[a]		**47 000**	**57 000**	**60 000**	**59 000**	**58 000**	**58 000**	**59 000**	**58 000**	**59 000**	**59 000**
Enteric Fermentation (CH_4)		**22 000**	**28 000**	**31 000**	**25 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**
Dairy Cattle		4 000	3 400	3 200	3 200	3 200	3 200	3 200	3 300	3 400	3 500
Beef Cattle[b]		18 000	23 000	26 000	20 000	20 000	20 000	20 000	20 000	20 000	19 000
Others[c]		730	1 100	1 300	1 100	1 100	1 100	1 100	1 100	1 100	1 100
Manure Management		**6 100**	**8 000**	**8 800**	**7 800**	**7 700**	**7 800**	**7 900**	**7 900**	**7 900**	**7 900**
Dairy Cattle	CH_4	430	560	680	870	870	870	880	890	920	940
	N_2O	520	460	350	270	270	260	260	260	270	270
Beef Cattle[b]	CH_4	810	1 100	1 200	1 000	1 000	1 000	1 000	1 000	1 000	1 000
	N_2O	1 900	2 700	3 000	2 300	2 300	2 300	2 300	2 300	2 300	2 300
Swine	CH_4	1 000	1 500	1 800	1 500	1 500	1 600	1 700	1 700	1 700	1 700
	N_2O	120	90	80	60	60	60	60	60	60	60
Poultry	CH_4	160	190	190	190	200	200	200	200	200	200
	N_2O	430	530	540	580	590	600	610	610	610	610
Others[d]	CH_4	40	50	60	50	50	50	40	40	40	40
	N_2O	90	150	170	140	140	130	120	120	120	120
Indirect Source of	N_2O	600	770	840	690	690	700	710	710	700	700
Agricultural Soils (N_2O)		**17 000**	**19 000**	**19 000**	**24 000**	**23 000**	**24 000**	**25 000**	**24 000**	**25 000**	**24 000**
Direct Sources		14 000	16 000	15 000	20 000	19 000	20 000	20 000	20 000	20 000	20 000
Synthetic Nitrogen Fertilizers		5 700	7 500	6 900	11 000	11 000	11 000	11 000	10 000	11 000	11 000
Organic Nitrogen Fertilizers		2 100	2 400	2 500	2 300	2 300	2 300	2 400	2 400	2 400	2 400
Crop Residue Decomposition		4 400	4 600	4 900	6 500	5 700	5 900	6 500	6 500	6 400	6 300
Cultivation of Organic Soils		60	60	60	60	60	60	60	60	60	60
Mineralization of Soil Organic Carbon		490	520	490	670	710	760	810	870	930	1 000
Conservation Tillage[e]		-290	-740	-850	-1 500	-1 400	-1 400	-1 400	-1 400	-1 400	-1 500
Summerfallow		1 300	1 000	750	480	380	330	270	190	130	60
Irrigation		280	320	330	400	390	390	410	390	400	410
Manure on Pasture, Range and Paddock		220	250	260	210	210	210	200	200	200	200
Indirect Sources		2 800	3 400	3 400	4 200	4 000	4 100	4 200	4 100	4 200	4 200
Field Burning of Agricultural Residues (CH_4 & N_2O)		**220**	**130**	**40**	**50**	**50**	**60**	**50**	**50**	**50**	**50**
Lime and Urea Application (CO_2)		**1 200**	**1 600**	**1 400**	**2 700**	**2 500**	**2 600**	**2 500**	**2 400**	**2 600**	**2 600**

Notes:

a. Totals may not add up due to rounding.

b. Beef Cattle includes dairy heifers. This category corresponds to “Non-Dairy Cattle” in the CRF tables.

c. Others, Enteric Fermentation, includes buffalo, goats, horses, lambsheep, llamas/alpacas, swine, deer/elk, wild boars.

d. Others, Manure Management, includes bison, goats, horses, sheep, llamas/alpacas, foxes, minks, rabbits, deer/elk, wild boars.

e. The negative values reflect a reduced N_2O emission due to the adoption of conservation tillage.

5

Rice is not produced in Canada and is not a source of CH_4 emissions. Prescribed burning of savannas is not practised in Canada.

For each emission source category, a brief introduction and a brief description of methodological issues, uncertainties and time-series consistency, quality assurance/quality control (QA/QC) and verification, recalculations, and planned improvements are provided in this chapter. The detailed inventory methodologies and sources of activity data are described in Annex 3.4.

5.2. Enteric Fermentation (CRF Category 3.A)

5.2.1. Source Category Description

Methane (CH_4) is produced during the normal digestive process of enteric fermentation by herbivores typically raised in agricultural animal production. Microorganisms break down carbohydrates and proteins into simple molecules for absorption through the gastrointestinal tract, and CH_4 is produced as a by-product. This process results in an accumulation of CH_4 in the rumen that is emitted by eructation and exhalation. Some CH_4 is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Large ruminant animals, such as cattle, generate the most CH_4.

In Canada, animal production varies from region to region. In western Canada, beef cattle production dominates, combining both intensive production systems with high animal densities finished in feedlots and low-density, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities, and production has intensified significantly since 1990, affecting both milk productivity and management approaches. Eastern Canada has also traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH_4 by enteric fermentation, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars and sheep, are raised as livestock, but populations of these animals have traditionally been low. In Canada, over 95% of Enteric Fermentation emissions come from cattle.

5.2.2. Methodological Issues

The diversity of animal production systems and regional differences in production facilities complicate emission estimation. For each animal category/subcategory, CH_4 emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding regionally derived emission factor.

For cattle, CH_4 emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided in the 2006 IPCC Guidelines (IPCC, 2006). A national study

Table 5–2 **Quantitative Summary of Recalculations for the Agriculture Sector in 2021 NIR**

		Recalculations (kt CO_2 eq)							
		1990	2000	2005	2014	2015	2016	2017	2018
Previous submission (2020 NIR), kt CO_2 eq		47 000	57 000	60 000	58 000	58 000	59 000	58 000	59 000
Current submission (2021 NIR), kt CO_2 eq		47 000	57 000	60 000	58 000	58 000	59 000	58 000	59 000
Change due to continuous improvement or refinement:									
Revision of Activity Data									
Manure Management	kt CO_2 eq	-0.05	-0.14	0	0.001	0.001	0	0	0.36
	%	-0.0001	-0.0003	0	0.000001	0.000001	0	0	0.0006
Agricultural Soils	kt CO_2 eq	0.8	-0.1	32	26	25	33	32	52
	%	0.002	-0.0001	0.05	0.04	0.04	0.06	0.06	0.09
Field Burning of Agricultural Residues	kt CO_2 eq	0	0	0	0	0	0	0	0.44
	%	0	0	0	0	0	0	0	0.001
Liming and Application of Urea and Other Carbon-Containing Fertilizers	kt CO_2 eq	0	0	0	0	0	0	-74	-8
	%	0	0	0	0	0	0	-0.13	-0.0136

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2021 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
Revision of activity data (crop production, liming, distribution of crops and livestock)	CH_4 and N_2O emissions from direct and indirect emissions from manure management systems and agricultural soils. CH_4 and N_2O emissions from crop residue burning, lime production.	1990–2018

by Boadi et al. (2004) broke down cattle subcategories, by province, into subannual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to produce annual emission factors for each individual animal subcategory that take into account provincial production practices. The data describing each production stage were obtained by surveying beef and dairy cattle specialists across the country.

For dairy cattle, the basic subcategory classes developed by Boadi et al. (2004) were accurate for the mid-2000s when the Tier 2 model was populated; however, it was recognized that certain dairy production parameters were not static over time and these parameters could impact all aspects of emissions from the dairy sector. Further work was carried out and implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters for dairy and to create a time series that better captures changes in dairy production practices. Increased milk production associated with improved genetics as well as improved feed quality in dairy cattle herds over the 1990–2019 time period are reflected in a 23% increase in CH_4 emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NEl) becomes greater and requires increased food consumption.

In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and, as a consequence, feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased by 7.4% during that period. Since then, non-dairy cattle weights have remained relatively stable, while slaughter animal weights have continued to increase, but at a lower rate. Emission factors have since decreased as a result of a combination of the stabilization of cattle weights and a shift in cattle subcategory populations. Since 2005, beef cow and replacement heifer populations have decreased substantially, while finishing animal populations (slaughter heifers and steers) have remained constant. As a result, the proportion of finishing animals in the national herd has increased from 17% to 20%. Since finishing animals have a lower emission factor, the overall emission factor for the Non-Dairy Cattle category has decreased from its peak in 2005.

For non-cattle animal categories, CH_4 emissions from the process of enteric fermentation continue to be estimated using the IPCC Tier 1 methodology. The poultry, rabbits and fur-bearing animal categories are excluded from the estimates for the Enteric Fermentation category since no emission factors are currently available.

Activity data consist of domestic animal populations for each animal category/subcategory, by province, and are obtained from Statistics Canada (Annex 3.4, Table A3–1). The data are based on the *Census of Agriculture*, conducted every five years and updated annually by semi-annual or quarterly surveys for cattle, swine and sheep.

5.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis was performed on the methodology used to estimate CH_4 emissions from agricultural sources using a Monte Carlo technique. The analysis considered the uncertainty in the parameters defined in Boadi et al. (2004) as they are used within the IPCC Tier 2 methodology equations. Details of this analysis can be found in Annex 3.4, section A3.4.2.4. Uncertainty distributions for parameters were taken from Karimi-Zindashty et al., (2012), although some additional parameters and updates were included in this analysis. For 2019, uncertainty ranges from the 2012 analysis are applied to new emission estimates. An uncertainty analysis of the updated dairy model has not yet been performed and reported uncertainty estimates are based on the methodology of Boadi et al. (2004).

The uncertainty range for CH_4 emissions from the Enteric Fermentation category was similar in 1990 and 2019, and mean estimates in 2019 lie within a range of -1714% to +17% (Table 5–4). Over the time series of 1990 to 2019, mean emissions are estimated to have increased by 1.7 Mt CO_2 eq, a 7% increase. The observed increase falls within an uncertainty range of +4% to +13%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-Dairy Cattle Tier 2 emission factors was the highest (41%). Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (Cfi) (Karimi-Zindashty et al., 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2019), with the exception of milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: (1) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (2) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of milk production for the entire Canadian herd from 1990 to 1998 was calculated on the basis of the average ratio between the publishable and the management data from 1999 to 2007.

Table 5–4 **Uncertainty in Estimates of CH_4 Emissions from Enteric Fermentation**

Animal Category	Uncertainty Source		Mean Value[a,b]	2.5% Prob.	97.5% Prob.
Dairy Cattle	Population (1 000 head)		973	922 (-5.2%)	1 024 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		142	121 (-15%)	170 (+19%)
	Emissions (Mt CO_2 eq)		3.5	2.9 (-16%)	4.2 (+20%)
Non-Dairy Cattle	Population (1 000 head)		10 927	10 718 (-1.9%)	11 149 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		71	60 (-15%)	84 (+18%)
	Emissions (Mt CO_2 eq)		19	16 (-16%)	24 (+21%)
Other Animals	Emissions (Mt CO_2 eq)		1.1	0.87 (-18%)	1.2 (+18%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	22	19 (-16%)	27 (+21%)
		2019	24	21 (-14%)	28 (+17%)
	Trend	1990–2019	1.7 (+7.4%)	0.99 (+4.4%)	2.8 (+13%)

Notes:

a. Mean value reported from database, with the exception of the trend, which is the difference between 1990 and 2019.

b. Values in parentheses represent the uncertain percentage of the mean, with the exception of the trend, where values in parentheses represent the percentage change between 1990 and 2019.

5.2.4. QA/QC and Verification

Enteric Fermentation, as a key category, has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes are documented and archived in electronic form. The IPCC Tier 2 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab, 2004).

Internal Tier 2-level QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology and input data, and a review and compilation of Canadian research on the process of enteric fermentation (MacDonald and Liang, 2011). The literature review suggested that no specific bias can be clearly identified in the enteric emission estimate. Based on the sensitivity analyses carried out in the uncertainty analysis and the literature review, improvements to the cattle model require the development of country-specific parameters that take into account specific regional management influences on emissions, replacing IPCC defaults currently used in the emission model, as has been done for Dairy Cattle. Details of this review can be found in Annex 3.4. A recent top-down quality assurance study was carried out using low-altitude aircraft-based flux technology (Desjardins et al., 2018). Though reconciling the top-down estimates with the bottom-up estimates was challenging due to difficulties in differentiating agricultural CH_4 emissions from wetland emissions, the top down estimates were consistent with the bottom-up estimates in areas where wetland emissions were minimal.

5.2.5. Recalculations

No recalculations to Enteric Fermentation occurred in the 2021 NIR submission (Table 5–5).

5.2.6. Planned Improvements

In general, the enteric fermentation methodology is robust; improvements are mainly dependent on the ability to collect more complete data on the composition of the diet fed to livestock, as that will facilitate the development of parameters specific to animal subcategories within different regions of Canada. Dairy feed information is currently being processed to update the timeline for changes to dairy feed in recent years.

A study with Canadian experts in the beef industry to update and improve the beef production model, intended to characterize variability in animal management strategies in different regions across Canada, was carried out. Work is ongoing to evaluate how, and if, other drivers of change can be integrated into the IPCC Tier 2 calculation structure.

5.3. Manure Management (CRF Category 3.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include (1) liquid storage, (2) solid storage and drylot, and (3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigesters. No manure is burned as fuel.

Both CH_4 and N_2O are emitted during handling and storage of livestock manure. The magnitude of emissions depends on the quantity of manure handled, its characteristics, and the type of manure management system. In general, poorly aerated manure management systems generate high CH_4 emissions but relatively low N_2O emissions, whereas well-aerated systems generate high N_2O emissions but relatively low CH_4 emissions.

Manure management practices vary regionally, by animal category, and over time. Dairy, swine and poultry production occurs in modern high-density production

Table 5–5 **Recalculations of Emission Estimates and Their Impact on Emission Trends and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH_4 and Manure Management N_2O**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Manure Management CH_4	1990	2020	2 453	0.01	0.0005	Long term (1990–2018)	
		2021	2 453			57	57
	2005	2020	3 893	0.0002	0.00001		
		2021	3 893			Short term (2005–2018)	
	2018	2020	3 846	-0.003	-0.00007	-1	-1
		2021	3 846				
Manure Management – Direct N_2O	1990	2020	3 062	-0.05	-0.002	Long term (1990–2018)	
		2021	3 062			10	10
	2005	2020	4 102	-0.001	-0.00001		
		2021	4 102			Short term (2005–2018)	
	2018	2020	3 369	0.31	0.009	-18	-18
		2021	3 369				
Manure Management – Indirect N_2O	1990	2020	613	-0.005	-0.0008	Long term (1990–2018)	
		2021	613			15	15
	2005	2020	838	0.001	0.0001		
		2021	838			Short term (2005–2018)	
	2018	2020	703	0.05	0.007	-16	-16
		2021	703				

facilities. The dairy industry has experienced a shift in manure storage practices since 1990, with larger operations with liquid systems being replaced by smaller operations with solid systems. The swine industry produces large volumes of liquid manure, and there has been an increase in the use of liquid manure systems in swine production since 1990, while poultry manure is predominantly managed in solid form. Both swine and poultry manure are spread on a limited landbase. Feedlot beef production results in large volumes of drylot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars, sheep, and mules and asses, are generally raised in pastured and/or medium-density production facilities producing mainly solid manure. Fur-bearing animals also produce solid manure.

5.3.1. CH_4 Emissions from Manure Management (CRF Category 3.B [a])

5.3.1.1. Source Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO_2. However, if little oxygen is present, carbon is reduced, resulting in the production of CH_4. The quantity of CH_4 produced depends on manure characteristics and on the type of manure management system. Manure characteristics are, in turn, linked to animal category and animal nutrition.

5.3.1.2. Methodological Issues

Methane emissions from Manure Management are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.4 for detailed methodology). The animal population data are the same as those used for the Enteric Fermentation emission estimates (section 5.2.2). Methane emission factors for Manure Management are estimated using the IPCC Tier 2 methodology (IPCC, 2006).

Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005) or from the 2006 IPCC Guidelines. For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE). However, for dairy cattle and swine, some parameters within the model were replaced with updated values in order to better capture trends in feeding practices and/or animal weights, as described in Annex 3.4. In particular, for dairy cattle, the digestibility (DE) of feed is responsive to animal diet, and for swine, volatile solids excreted in manure are adjusted based on trends in body weights and growth rates. Volatile solids (VS) were estimated using Equation 10.23 of the 2006 IPCC Guidelines and manure ash contents from Marinier et al. (2004). For all other livestock, parameters taken from Marinier et al. (2004) were used to calculate VS on the basis of ash content and digestible energy derived from expert consultations. Urinary energy (UE) coefficients were applied according to the 2006 IPCC Guidelines. VS for swine were corrected for animal mass as described in Annex 3.4. For sheep and poultry categories, different parameters were used for animal subcategories based on animal size for lambs and adult sheep and turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH_4 producing potential (B_0), CH_4 conversion factors (MCF) and the proportion of manure handled by AWMS for each animal category. For major livestock categories other than dairy and swine, the MCF was taken from the 2006 IPCC Guidelines and AWMS proportions were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. For swine and dairy cattle, a manure storage system time series was developed in order to track changes in the proportion of manure in AWMS subsystems with and without crust and covers. Values of MCF taken from the 2006 IPCC Guidelines were assigned to AWMS subsystems, and a weighted MCF was calculated for each AWMS based on the proportion of manure in each subsystem. For minor animals (fur-bearing animals, rabbits, deer and elk, and mules and asses), Tier 1 emission factors were used. A more complete description of the derivation of the proportional distribution of manure storage systems is provided in Annex 3.4, section A3.4.3.3.

Increases in cattle emission factors over the 1990–2019 period (see Annex 3.4.3) reflect higher gross energy intake for dairy cattle due to changes in feed, herd characteristics and increased milk productivity. Most importantly, for dairy, emission factors also reflect trends in manure storage practices, primarily, a shift from solid systems to liquid systems. For non-dairy cattle, changes are due to changes in live body weights (see section 5.2.2). Changes in swine emission factors (see Annex A3.4.3.6) for sows is related to the shift in swine production from eastern to western Canada and for growing swine are a result of increases in growth rates and final carcass weights.

5.3.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis of CH_4 emissions from agricultural sources using the Monte Carlo technique included CH_4 emissions from management of manure. The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012) and additional and updated parameters specific to this analysis. Details of this analysis can be found in Annex 3.4, section A3.4.3.8.

The CH_4 emission estimate of 3.9 Mt CO_2 eq from manure management of Canadian livestock in 2019 lies within an uncertainty range of -28% to +23% (Table 5–6). The CH_4 emission estimate from manure management in 1990, 2.5 Mt CO_2 eq, has a slightly larger uncertainty range, -44% to +36%, due to greater uncertainty associated with the type of manure management systems in 1990.

The estimate of a 57% increase in mean emissions between 1990 and 2019 lies within an uncertainty range of +45% to +66%.

As was the case with the Enteric Fermentation category, most uncertainty in the emission estimate was associated with the calculation of the emission factor. The uncertainty range around the mean emission factor was as high as 110% in the case of dairy cattle. The uncertainty in emissions was most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the MCF that was applied to all regions of Canada and all animal types and the maximum methane production capacity (B_0) (Karimi-Zindashty et al., 2012). An uncertainty analysis on the new dairy and swine models has not yet been performed, but because the MCF factor is driving uncertainty for manure management, it is not expected that changes to these models would have a large impact on national manure management uncertainty. The introduction of an AWMS time series for the dairy and swine sectors may, however, play an important role in influencing the trend uncertainty for manure management emissions.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2019), with the exception of milk production for dairy cattle and bull weights. Milk production from 1990 to 1999 in Ontario and the western provinces, and bull carcass weights, were estimated as described in section 5.2.3.

5.3.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in electronic form. The IPCC Tier 2 CH_4 emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins, 2004). These documents have been archived in electronic form.

Internal Tier 2 QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in Annex 3.4, section A3.4.3.7.

Table 5–6 **Uncertainty in Estimates of CH_4 Emissions from Manure Management**

Animal Category	Uncertainty Source		Mean Value[a]	2.5% Prob.[b]	97.5% Prob.
Dairy Cattle	Population (1 000 head)		973	922 (-5.2%)	1 024 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		39	21 (-45%)	53 (+37%)
	Emissions (Mt CO_2 eq)		0.94	0.52 (-45%)	1.29 (+37%)
Non-Dairy Cattle	Population (1 000 head)		10 927	10 718 (-1.9%)	11 149 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		3.7	2.8 (-25%)	5.4 (+45%)
	Emissions (Mt CO_2 eq)		1	0.7 (-27%)	1.52 (+51%)
Swine	Population (1 000 head)		13 978	13 646 (-2.4%)	14 315 (+2.4%)
	Tier 2 Emission Factor (kg/head/year)		4.8	2.2 (-54%)	7.0 (+45%)
	Emissions (Mt CO_2 eq)		1.7	0.9 (-49%)	2.38 (+42%)
Other Animals	Emissions (Mt CO_2 eq)		0.25	0.17 (-31%)	0.28 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	2.5	1.4 (-44%)	3.3 (+36%)
		2019	3.9	2.8 (-28%)	4.8 (+23%)
	Trend	1990–2019	1.4 (+58%)	1.1 (+45%)	1.6 (+66%)

Notes:

a. Mean value reported from database, with the exception of the trend, which is the difference between 1990 and 2018.

b. Values in parentheses represent the uncertain percentage of the mean, with the exception of the trend, where values in parentheses represent the percentage change between 1990 and 2018.

5.3.1.5. Recalculations

Minor recalculations occurred to methane emissions from manure management for all years due to revisions to spatial distribution of populations, which altered the weighting of manure management system fractions for bulls and calves. These changes resulted in an increase in emissions of 0.01 kt CO_2 eq in 1990 and <1 t CO_2 eq in 2005 and a decrease of 0.003 kt CO_2 eq in 2018. The recalculations did not alter the short-term or long-term trend (Table 5–5).

5.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of AWMS based on Statistics Canada's farm environmental management surveys (FEMS). Those data, combined with Canadian publications on livestock management (Sheppard et al., 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman, 2011, 2012), have provided the basis for a new manure management time series for dairy and swine production in Canada, and work is being considered for other major livestock categories. Further refinements to parameters used in the calculation of VS based on changes in animal feed are being considered for implementation in the medium-term.

5.3.2. N_2O Emissions from Manure Management (CRF Category 3.B [b])

5.3.2.1. Source Category Description

The production of nitrous oxides (N_2O) during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH_4+) to nitrate (NO_3-), and denitrification is the reduction of NO_3- to N_2O or N_2. Manure from the Non- Dairy Cattle, Sheep, Goats Horses, Deer and Elk, Mules and Assess, Wild Boar and Fur-bearing Animals categories are mainly handled with a solid and dry lot system, which is the type of manure management system that emits the most N_2O. N_2O emissions from urine and dung deposited by grazing animals are reported separately (see section 5.4.1.4).

5.3.2.2. Methodological Issues

N_2O emissions from Manure Management are estimated for each animal category by multiplying the animal population of a given category by its nitrogen excretion rate and by the emission factor associated with the AWMS.

For dairy cattle, nitrogen excretion is calculated using the mass balance approach provided in the IPCC Tier 2 methodology. Nitrogen intake is calculated based on GE and the percentage crude protein in the animal diet, and nitrogen retention is calculated using milk production and cattle weight statistics. Nitrogen excretion is based on the difference between nitrogen intake and retention. Default IPCC N_2O emission factors are assigned to AWMS subsystems (Annex 3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

For swine, nitrogen excretion is calculated for market and breeding animals using the IPCC Tier 1 methodology, using a country-specific animal mass time series for market swine. Default IPCC N_2O emission factors are assigned to AWMS subsystems (Annex 3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

For all other livestock categories, nitrogen excretion is estimated using the IPCC Tier 1 methodology. The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines.

The animal characterization data are the same as those used for estimates for Enteric Fermentation (section 5.2) and Manure Management (section 5.3.1). The 2006 IPCC default emission factors for a developed country with a cool climate are used to estimate manure nitrogen emitted as N_2O for each type of AWMS.

5.3.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out to estimate emissions of N_2O from agricultural sources (Karimi-Zindashty et al., 2014). For N_2O emissions from Manure Management, the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and all uncertainty in AWMS systems, animal populations and characterizations were identical to those used in the analysis of CH_4 from Enteric Fermentation and Manure Management defined in sections 5.2.3 and 5.3.1.3. Details of this analysis can be found in Annex 3.4, section A3.4.6.

The estimate of direct N_2O emissions of 3.3 Mt CO_2 eq from Manure Management in 2019 lies within an uncertainty range of 1.9 Mt CO_2 eq (-43%) to 5.1 Mt CO_2 eq (+51%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor (+/-100% uncertainty). Due to the size of the N_2O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed due to limitations in software capabilities. An uncertainty analysis of the new dairy and swine models has not yet been performed.

The same methodology, emission factors and data sources are used for the entire time series (1990–2019).

5.3.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodology and changes to methodologies are documented and archived in both paper and electronic form. A complete Tier 2 QC was carried out on all calculation processes and parameters during the rebuilding of the agricultural N_2O emission database.

There are very few published data on N_2O emissions from manure management and storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve on the current methodology.

5.3.2.5. Recalculations

Direct N_2O emissions from manure management were recalculated for all years (Table 5–5) due to changes in the spatial distribution of livestock. The net impact of these changes was a decrease in emissions of 0.05 kt CO_2 eq in 1990 and 0.001 kt CO_2 eq in 2005 and an increase of 0.31 kt CO_2 eq in 2018. The recalculations did not alter the short-term or long-term trend (Table 5–5).

5.3.2.6. Planned Improvements

Data from direct measurements of N_2O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N_2O emissions from point sources. However, it will likely take several years before N_2O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in section 5.3.1.6, implementation of an AWMS time series is the main source of improvement available for this emission source. Improvements to dairy and swine have been implemented based on Statistics Canada farm environmental management surveys, and plans are in place to incorporate this analysis for other livestock categories.

Furthermore, as noted in section 5.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition and country-specific nitrogen excretion rates. These data have been integrated for dairy cattle, but similar analysis is still to be completed for swine. For select other livestock categories, changes will be incorporated over the medium term.

Further uncertainty analyses will be carried out to establish trend uncertainty and consider the changes in the livestock models over the medium term.

5.3.3. Indirect N_2O Emissions from Manure Management (CRF Category 3.B [c])

5.3.3.1. Source Category Description

The production of N_2O from manure management can also occur indirectly through NH_3 volatilization and leaching of N during storage and handling of animal manure. A fraction of the nitrogen in manure that is stored is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching and runoff. The nitrogen that is transported from the manure storage site in this manner is assumed to undergo subsequent nitrification and denitrification elsewhere in the environment and, as a consequence, to produce N_2O.

5.3.3.2. Methodological Issues

Indirect emissions of N_2O from manure management are estimated by applying N loss factors to the quantity of manure N contained in each AWMS, and then multiplying by an N_2O emission factor. The N loss factors are calculated differently for both dairy cattle and swine, compared with other livestock categories.

For dairy cattle and swine, the amount of manure nitrogen subject to loss by leaching and volatilization of NH_3 and NO_x during storage is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2010; Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and manure management system.

For all other livestock categories, the amount of manure nitrogen subject to losses from volatilization of NH_3 during storage is calculated for each animal type and manure management system using default values provided in the 2006 IPCC Guidelines. Leaching losses are not estimated because no country-specific leaching loss factors are available.

Emission factors of N_2O from NH_3 volatilization and leaching of N during manure storage and handling are taken from the 2006 IPCC Guidelines for all livestock categories.

5.3.3.3. Uncertainties and Time-Series Consistency

A full uncertainty analysis using the Monte Carlo technique has not been carried out to estimate indirect emissions of N_2O from manure management. The uncertainty associated with livestock populations, manure N excretion rates, AWMS, fractions of N leaching and NH_3 volatilization along with indirect N_2O emission factors are available but has not been used in a Monte Carlo analysis to date. Uncertainty is assumed to be equivalent to the uncertainty associated with indirect emissions from agricultural soils.

The same methodology, emission factors and data sources are used for the entire time series (1990–2019).

5.3.3.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodology and databases are documented and archived in both paper and electronic form.

5.3.3.5. Recalculations

Indirect N_2O emissions from manure management were recalculated due to changes in the spatial distribution of livestock that resulted in a decrease in emissions of 0.005 kt CO_2 eq in 1990 and in increases of 0.001 kt CO_2 eq in 2005 and 0.05 kt CO_2 eq in 2018. The recalculations did not alter the short-term or long-term emission trends (Table 5–5).

5.3.3.6. Planned Improvements

As noted in section 5.3.1.6, country-specific NH_3 volatilization fractions and N leaching coefficients stratified by livestock subcategory and AWMS have been implemented for dairy and swine, and similar emission factors have been developed for beef cattle. Non-Dairy Cattle Tier 2 parameters may be revised as necessary, based on more recent information.

5.4. N_2O Emissions from Agricultural Soils (CRF Category 3.D)

N_2O emissions from agricultural soils consist of direct and indirect emissions. N_2O emissions from anthropogenic nitrogen inputs occur both directly from the soils to which the nitrogen is added and indirectly. Changes in crop rotations and management practices, such as summerfallow, tillage and irrigation, affect direct N_2O emissions by altering the mineralization rates of organic nitrogen, nitrification and denitrification. Indirect emission occur through two pathways: (1) the volatilization of nitrogen from inorganic fertilizer and manure applied to fields as NH_3 and NO_x and its subsequent deposition off-site; and (2) the leaching and runoff of inorganic fertilizer, manure and crop residue N.

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5.4.1. Direct N_2O Emissions from Managed Soils (CRF Category 3.D.1)

Direct sources of N_2O from soils include the application of organic and inorganic nitrogen fertilizers, crop residue decomposition, losses of soil organic matter through mineralization, and cultivation of organic soils. In addition, Canada also reports three country-specific sources of emissions/removals: tillage practices, summerfallow and irrigation. Emissions/removals from these sources are estimated on the basis of nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

5.4.1.1. Inorganic Nitrogen Fertilizers

5.4.1.1.1. Source Category Description

Inorganic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which can release N_2O. Emission factors associated with fertilizer application depend on many factors, such as soil types, climate, topography, farming practices and environmental conditions (Gregorich et al., 2005; Rochette et al., 2008a).

5.4.1.1.2. Methodological Issues

Canada has developed a country-specific Tier 2 methodology to estimate N_2O emissions from inorganic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes and topographic conditions. Emissions of N_2O are estimated for each ecodistrict and are scaled up to provincial and national scales. The amount of nitrogen applied to the land is estimated from yearly fertilizer sales. All inorganic nitrogen fertilizers sold by retailers are assumed to be applied for crop production purposes in Canada. The quantity of fertilizers applied to forests is deemed negligible. More details on the inventory method can be found in Annex 3.4.

5.4.1.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis, using the Monte Carlo technique on the methodology used to estimate emissions of N_2O from agricultural sources noted in section 5.3.2.3, included all direct and indirect emissions from soils (Table 5–7). For N_2O emissions from fertilizer, the analysis considered the uncertainty in the parameters defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level.

The estimate of N_2O emissions of 11 Mt CO_2 eq from the application of fertilizers on agricultural soils in 2019 lies within an uncertainty range of 7.4 Mt CO_2 eq (-35%) to 16 Mt CO_2 eq (+43%) (Table 5–7). The main source of uncertainty in the calculation is associated with the parameters (slope and intercept) of the regression equation relating emission factors to the ratio of precipitation to potential evapotranspiration (P/PE).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

While Statistics Canada conducts QC checks before the release of inorganic nitrogen fertilizer consumption data, the Pollutant Inventories and Reporting Division of Environment and Climate Change Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N_2O associated with inorganic fertilizer nitrogen applications on agricultural soils in Canada vary on a site-by-site basis, but there is a close agreement

Table 5–7 **Uncertainty Estimates for N_2O Emissions from Manure Management and Agricultural Soils**

Emission Source		Mean Value[a]	2.5% Prob.[b]	97.5% Prob.
		Mt CO_2 eq		
Manure Management				
Direct Emissions		3.3	1.9 (-43%)	5.1 (+51%)
Indirect Emissions		0.7	0.28 (-60%)	1.2 (+70%)
Agricultural Soils (N_2O)		**24**	**16 (-36%)**	**37 (+52%)**
Direct N_2O Emissions from Managed Soils		20	15 (-28%)	27 (+34%)
	Inorganic N Fertilizers	11	7.4 (-35%)	16 (+43%)
	Organic N Fertilizers	2.4	1.6 (-33%)	3.4 (+41%)
	Crop Residues	6.3	4.1 (-35%)	9.1 (+45%)
	Cultivation of Organic Soils	0.061	0.013 (-79%)	0.12 (+96%)
	Mineralization Associated with Loss of Soil Organic Matter	1	0.65 (-35%)	1.4 (+45%)
	Urine and Dung Deposited by Grazing Animals	0.2	0.081 (-60%)	0.36 (+75%)
	Soil N Mineralization/Immobilization	-1	-0.57 (-44%)	-1.6 (+55%)
Indirect N_2O Emissions from Managed Soils		4.2	1.7 (-60%)	7.1 (+70%)
	Atmospheric Deposition	1.2	0.31 (-75%)	2.6 (+110%)
	Leaching and Runoff	3	0.59 (-80%)	5.9 (+100%)

Notes:

a. Mean value reported from database.

b. Values in parentheses represent the uncertain percentage of the mean.

between the IPCC default emission factor of 1% (IPCC, 2006) and the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al., 2005; Desjardins et al., 2010).

5.4.1.1.5. Recalculations

Although no direct recalculations occurred to N_2O emission from inorganic fertilizers, the changes to the distribution of livestock and crop areas resulted in some minor recalculations. The emissions decreased by 0.12, 0.09 and 0.33 kt CO_2 eq in 1990, 2005 and 2018, respectively (Table 5–8). There were no changes in the short- or long-term trends.

5.4.1.1.6. Planned Improvements

A compilation of soil N_2O flux data since 1990 collected mainly through published literature is ongoing to identify key factors, including soil properties, climatic conditions, types of nutrient sources and management practices, explaining N_2O emissions from agricultural soils in Canada and to re-evaluate the empirical relationship between N_2O emission factors, growing season precipitation and potential evapotranspiration.

5.4.1.2. Organic Nitrogen Fertilizers Applied to Soils

5.4.1.2.1. Source Category Description

The application of organic nitrogen sources as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N_2O emissions. Emissions from this category include (1) all manure managed by drylot, liquid and other animal waste management systems, and (2) human biosolids managed by municipal wastewater treatment plants.

5.4.1.2.2. Methodological Issues

Like the methodology used to estimate N_2O emissions from inorganic nitrogen fertilizers, the method used to estimate N_2O emissions from organic manure applied to agricultural soils is a country-specific IPCC Tier 2 method that takes into account moisture regimes (long-term growing season precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of organic nitrogen applied to agricultural soils by an emission factor for each ecodistrict, summed at the provincial and national levels. All manure that is handled by AWMS, except for the urine and dung deposited by

Table 5–8 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Organic and Inorganic Fertilizer Application, Crop Residue Decomposition, and Urine and Dung Deposited by Grazing Animals**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Inorganic N Fertilizers	1990	2020	5 720	-0.12	-0.002	Long term (1990–2018)	
		2021	5 720			100	100
	2005	2020	6 891	-0.09	-0.001		
		2021	6 891			Short term (2005–2018)	
	2018	2020	11 463	-0.33	-0.003	66	66
		2021	11 462				
Organic N Fertilizers	1990	2020	2 061	-0.1	-0.003	Long term (1990–2018)	
		2021	2 061			16	16
	2005	2020	2 548	-0.2	-0.01		
		2021	2 547			Short term (2005–2018)	
	2018	2020	2 383	-0.3	-0.01	-6	-6
		2021	2 383				
Crop Residue Decomposition	1990	2020	4 415	0	0	Long term (1990–2018)	
		2021	4 415			43	44
	2005	2020	4 851	27	0.57		
		2021	4 879			Short term (2005–2018)	
	2018	2020	6 306	51	0.80	30	30
		2021	6 356				
Urine and Dung Deposited by Grazing Animals	1990	2020	224	-0.01	-0.01	Long term (1990–2018)	
		2021	224			-9	-9
	2005	2020	258	0.001	0.0003		
		2021	258			Short term (2005–2018)	
	2018	2020	204	0.01	0.01	-21	-21
		2021	204				

grazing animals, is assumed to be subsequently applied to agricultural soils after accounting for N losses during storage. Based on provincial regulations and crop requirements, biosolids were applied to ecodistricts, and subsequent emissions were calculated using the country-specific Tier 2 emission factors.

5.4.1.2.3. Uncertainties and Time-Series Consistency

In the case of N_2O emissions from organic nitrogen fertilizer application, the uncertainty analysis considered the uncertainty in the parameters used in producing estimates of manure N noted in section 5.3.2.3 and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors, as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 2.4 Mt CO_2 eq from application of Canadian livestock manure in 2019 lies within an uncertainty range of 1.6 Mt CO_2 eq (-33%) to 3.4 Mt CO_2 eq (+41%) (Table 5–7). The main source of uncertainty in the calculation of emissions from organic nitrogen fertilizer includes the slope of the P/PE regression equation for estimating N_2O emission factors, animal N excretion rates, emission factor modifiers for texture ($RF_{TEXTURE}$), tillage (RF_{TILL}) and N content of the biosolids.

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.2.5. Recalculations

Minor recalculations in organic fertilizers (manure and biosolids) occurred due to the changes in distribution of crops and livestock populations, which subsequently altered the spatial distribution of N. The emissions decreased by 0.1, 0.2 and 0.3 kt CO_2 eq in 1990, 2005 and 2018, respectively (Table 5–8). No changes in long- or short-term trend values were observed.

5.4.1.2.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to differentiate N_2O emission factors between organic and inorganic N sources and between application to annual versus perennial crops. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.3. Crop Residues (CRF Category 3.D.1.4)

5.4.1.3.1. Source Category Description

When a crop is harvested, a portion of the crop is left in the field to decompose. The remaining plant matter is a nitrogen source that undergoes nitrification and denitrification and can thus contribute to N_2O production.

5.4.1.3.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in crop residues multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues is estimated using country-specific crop characteristics (Janzen et al., 2003). Emission factors are determined using the same approach as for inorganic fertilizer nitrogen application based on moisture regimes and topographic conditions.

5.4.1.3.3. Uncertainties and Time-Series Consistency

For N_2O emissions from crop residue decomposition, the uncertainty analysis considered the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 6.3 Mt CO_2 eq from crop residue decomposition in 2019 lies within an uncertainty range of 4.1 Mt CO_2 eq (-35%) to 9.1 Mt CO_2 eq (+45%) (Table 5–8). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the P/PE regression equation for estimating N_2O emission factors and emission factor modifiers for texture ($RF_{TEXTURE}$) and tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.3.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.3.5. Recalculations

Recalculations were the result of a minor correction to activity data for crop production from 2004 to 2018. Emissions remained unchanged in 1990, and increased by 27 and 51 kt CO_2 eq in 2005 and 2018, respectively (Table 5–8). As a result of these changes, the long-term emission trend increased from 43% to 44%, and the short-term trend remained unchanged at 30%.

5.4.1.3.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to differentiate N_2O emission factors between nitrogen sources and between application to annual versus perennial crops. Further uncertainty work will be carried out over the medium term to capture the most recent changes in the agricultural soil emission model and to establish trend uncertainty.

5.4.1.4. Urine and Dung Deposited by Grazing Animals (CRF Category 3.D.1.3)

5.4.1.4.1. Source Category Description

When urine and dung are deposited by grazing animals, nitrogen in the manure undergoes various transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N_2O can be emitted.

5.4.1.4.2. Methodological Issues

N_2O emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al., 2014; Lemke et al., 2012). Details of these new emission factors can be found in Annex 3.4, section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N_2O.

5.4.1.4.3. Uncertainties and Time-Series Consistency

The uncertainty of the new estimates of N_2O emissions associated with urine and dung deposited by grazing animals was estimated on the basis of the previous uncertainty analysis using the parameters and uncertainty distributions defined in the Tier 1 methodology of the 2006 IPCC Guidelines with the exception of new emission factors. Animal populations, the proportion of animals on pasture systems and their characterizations were identical to those used in the analysis of CH_4 from the Enteric Fermentation and Manure Management categories defined in sections 5.2.3 and 5.3.1.3.

Under these assumptions, the estimate of N_2O emissions of 0.2 Mt CO_2 eq from pasturing Canadian livestock in 2019 lies within an uncertainty range of 0.082 Mt CO_2 eq (-60%) to 0.36 Mt CO_2 eq (+75%) (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.4.4. QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors.

5.4.1.4.5. Recalculations

Revisions to the distribution of livestock populations resulted in small changes to N_2O emissions from urine and dung deposited by grazing animals. Emissions decreased in 1990 by 0.001 kt CO_2 eq and increased in 2005 and 2018 by 0.001 and 0.01 kt CO_2 eq (Table 5–8), respectively, with no changes in long- or short-term trends.

5.4.1.4.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to take into account changes made to the PRP model and to establish trend uncertainty over the medium term.

5.4.1.5. Mineralization Associated with Loss of Soil Organic Matter (CRF Category 3.D.1.5)

5.4.1.5.1. Source Category Description

Carbon loss in soils as a result of changes to land management practices is accounted for within the Cropland category of the LULUCF sector (Chapter 6). Nonetheless, nitrogen mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This nitrogen, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification. As a result, this nitrogen must be taken into account because of its contribution to soil N_2O emissions.

5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in soil organic matter that is lost as a result of changes in cropland management practices multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels.

The quantity of soil organic carbon loss at an ecodistrict level from 1990 to 2019 is taken from carbon reported for the Cropland Remaining Cropland category of LULUCF, excluding the effect of forest land conversion to cropland (FLCL) within 20 years (i.e., N_2O emissions resulting from disturbance of CLCL, as the FLCL disturbances are already reported under LULUCF), perennial above-ground biomass and cultivation of histosols. A data set containing soil organic carbon and nitrogen for all major soils in Saskatchewan was used to derive an average C:N ratio for cropland soils. Ecodistrict-based soil N_2O emission factors (EF_{BASE}) are the same as those used for the estimation of emissions from inorganic fertilizer application, organic manure applied as fertilizer and crop residue decomposition. Emission factors are based on precipitation and potential evapotranspiration data for the individual ecodistrict in which carbon mineralization occurs.

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5.4.1.5.3. Uncertainties and Time-Series Consistency

Uncertainty parameters are based on the standard deviation of the soil database, uncertainty estimates of carbon loss and the uncertainty around ecodistrict-based emission factors. Impacts to agricultural soil uncertainty will be re-evaluated during the next full round of uncertainty assessments when they are renewed. Due to the small contribution to total emissions, this source would not likely affect overall emission uncertainty. Currently, uncertainty estimates for this category are considered to be the same as uncertainty in emissions from crop residue decomposition.

5.4.1.5.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.5.5. Recalculations

Recalculations to N_2O emissions from the mineralization of soil organic matter occurred in years 1992 to 2018 due to an update to an internal land use source file, as described in Chapter 6.5.1.1. Emissions did not change in 1990 and decreased by 0.006 kt and 0.43 kt CO_2 eq in 2005 and 2018, respectively. The long-term trend remained constant at 58%, and the short-term trend decreased from 115% to 114%.

5.4.1.5.6. Planned Improvements

Through a compilation of soil N_2O flux data from the published literature, Canada aims to differentiate N_2O emission factors between organic and inorganic N sources. The uncertainty for this category will be calculated in the next round of uncertainty analysis.

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5.4.1.6. Cultivation of Organic Soils (CRF Category 3.D.1.6)

5.4.1.6.1. Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhance the decomposition of organic matter and nitrogen mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification and thus in higher N_2O production (Mosier et al., 1998).

5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils. Emissions of N_2O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2019 (Liang et al., 2004a).

5.4.1.6.3. Uncertainties and Time Series Consistency

For N_2O emissions from organic soils, the uncertainty analysis considered the uncertainty in the area of cultivated organic soils and in the default emission factor.

The N_2O emission estimate of 0.061 Mt CO_2 eq from organic soils in 2019 lies within an uncertainty range of 0.01 Mt CO_2 eq (-79%) to 0.12 Mt CO_2 eq (+96%) (Table 5–7). The main source of uncertainty is in the IPCC Tier 1 default emission factor.

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.6.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.6.5. Recalculations

There were no recalculations in this source of emission estimates.

5.4.1.6.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.7. Changes in N_2O Emissions from Adoption of No-Till and Reduced Tillage

5.4.1.7.1. Source Category Description

This category is not derived from additional nitrogen inputs (i.e., fertilizer, manure or crop residue). Rather, it is implemented as a modification to N_2O emission factors to account for the change from conventional to conservation tillage practices—namely, reduced tillage (RT) and no-tillage (NT).

5.4.1.7.2. Methodological Issues

Compared with conventional or intensive tillage, the practice of direct seeding or no-tillage, as well as reduced tillage, results in changes to several factors that influence N_2O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al., 2004b). As a result, compared with conventional tillage, conservation tillage (i.e., RT and NT) generally reduces N_2O emissions for the Prairies (Malhi and Lemke, 2007), but increases N_2O emissions for the non-Prairie regions of Canada (Rochette et al., 2008b). The net result across the country is a small reduction in emissions. This reduction is reported separately as a negative estimate (Table 5–7).

Changes in N_2O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for inorganic fertilizers, manure nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve the transparency in reporting. However, this separation causes negative emissions to be reported. An empirically derived tillage factor (F_{TILL}), defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainties and Time-Series Consistency

For N_2O emissions from the adoption of conservation tillage practices, the uncertainty analysis considered the uncertainty in tillage practice areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emission reductions of -1.5 Mt CO_2 eq from conservation tillage practices in 2019 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–7). Tillage practice calculations are dependent on all soil emission calculations, and uncertainty is therefore influenced by all factors described in previous uncertainty sections, in particular the emission factor modifier for tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.7.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.7.5. Recalculations

Minor revisions to crop and livestock activity data redistributed nitrogen among different ecodistricts on the landscape and modified the areas on which tillage practices were carried out.

The changes increased the impact of tillage adoption on N_2O emissions by 1 kt CO_2 eq in 1990 and decreased it by 2.9 kt CO_2 eq in 2005 and 6 kt CO_2 eq in 2018. These recalculations increased the impact of tillage adoption on the trend from 385% to 389% in the long term, with no changes in the short term (69%) (Table 5–9).

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Table 5–9 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Conservation Tillage Practices, Summerfallow and Irrigation**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Conservation Tillage Practices	1990	2020	-296	1.0	-0.3	Long term (1990–2018)	
		2021	-295			385	389
	2005	2020	-849	-2.9	0.3		
		2021	-852			Short term (2005–2018)	
	2018	2020	-1 436	-6.0	0.4	69	69
		2021	-1 442				
Summerfallow	1990	2020	1 305	-0.1	-0.004	Long term (1990–2018)	
		2021	1 305			-90	-90
	2005	2020	743	3.3	0.5		
		2021	746			Short term (2005–2018)	
	2018	2020	130	0.5	0.4	-82	-82
		2021	131				
Irrigation	1990	2020	281	0.1	0.05	Long term (1990–2018)	
		2021	281			41	41
	2005	2020	332	0.6	0.2		
		2021	332			Short term (2005–2018)	
	2018	2020	396	0.9	0.2	19	20
		2021	397				

5.4.1.7.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to update the method for estimating the impact of tillage practices on soil N_2O emissions. Work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.8. N_2O Emissions Resulting from Summerfallow

5.4.1.8.1. Source Category Description

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N_2O emissions. Summerfallow is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, higher soil temperature, and greater availability of soil carbon and nitrogen (Campbell et al., 1990, 2005).

5.4.1.8.2. Methodological Issues

Experimental studies have shown that N_2O emissions in fallow fields are not statistically different from emissions on continuously cropped fields (Rochette et al., 2008a). Omitting areas under summerfallow in calculations of N_2O emissions because no crops are grown or because no fertilizer is applied could lead to underestimating total N_2O emissions. The emissions from summerfallow land are therefore calculated through a country-specific method by summing emissions from fertilizer nitrogen, manure nitrogen application to annual crops and crop residue nitrogen for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under summerfallow (Rochette et al., 2008a). A more detailed description of the approach is provided in Annex 3.4.

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5.4.1.8.3. Uncertainties and Time-Series Consistency

For N_2O emissions from summerfallow, the uncertainty analysis considered the uncertainty in summerfallow areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, crop residue decomposition defined in section 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 0.06 Mt CO_2 eq from summerfallow land in 2019 lies within an uncertainty range of -44% to +55%, based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–7). Summerfallow emissions were derived from soil emission calculations, and uncertainty is therefore influenced by all factors identified in previous uncertainty sections, in particular the emission factor modifier for tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.8.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.8.5. Recalculations

As in the case of emissions from tillage practices (section 5.4.1.7.5), summerfallow emissions were impacted by minor revisions to the distribution of crops and livestock, resulting in recalculations in this section.

As a result of these changes, emissions associated with summerfallow decreased by 0.01 kt CO_2 eq in 1990 and increased by 3.3 kt CO_2 eq in 2005 and 0.5 kt CO_2 eq in 2018 (Table 5–9). Emission trends in the short (-90%) and long term (-82%) remained unchanged.

5.4.1.8.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.9. N_2O Emissions from Irrigation

5.4.1.9.1. Source Category Description

As in the case of tillage practices and summerfallow, the effect of irrigation on N_2O emissions is not derived from additional nitrogen input but rather reflects changes in soil conditions that affect N_2O emissions. Higher soil water content under irrigation increases the potential for N_2O emissions through increased biological activity, reducing soil aeration (Jambert et al., 1997) and thus enhancing denitrification.

5.4.1.9.2. Methodological Issues

The methodology is country-specific and is based on the assumptions that (1) irrigation water stimulates N_2O production in a way similar to rainfall and (2) irrigation is applied at rates such that the combined amounts of precipitation and irrigation water are equal to potential evapotranspiration at local conditions. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was estimated using an EF_{BASE} estimated at a P/PE = 1 (precipitation/potential evapotranspiration, EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of a given ecodistrict.

To improve transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.9.3. Uncertainties and Time-Series Consistency

For N_2O emissions from irrigation, the uncertainty analysis considered the uncertainty in irrigation areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 0.41 Mt CO_2 eq from irrigated land in 2019 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–7). The irrigated land emission factor for a given ecodistrict is a function of all soil emission factor calculations, and uncertainty is therefore influenced by all factors described in previous uncertainty sections, in particular the slope and intercept of the P/PE regression equation.

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.1.9.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodology are documented and archived in both paper and electronic form.

5.4.1.9.5. Recalculations

Emissions from irrigation are linked to all soil emission calculations. Small changes to the distribution of crops resulted in recalculations to emissions linked to irrigation.

These changes increased emissions slightly by 0.1 kt CO_2 eq in 1990, 0.6 kt CO_2 eq in 2005 and 0.9 kt CO_2 eq in 2018, with a relative change of 0.05%, 0.2% and 0.2%, respectively. These recalculations increased the short-term trend from 19% to 20%, while the long-term trend remained constant at 41% (Table 5–9).

5.4.1.9.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.2. Indirect N_2O Emissions from Managed Soils (CRF Category 3.D.2)

A fraction of the nitrogen from both inorganic fertilizer and manure that are applied to agricultural fields is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent re-deposition or leaching and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N_2O.

5.4.2.1. Atmospheric Deposition of Nitrogen

5.4.2.1.1. Source Category Description

When organic or inorganic fertilizer is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH_3 or NO_x, which can be redeposited elsewhere and undergo further transformation, resulting in N_2O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

5.4.2.1.2. Methodological Issues

There are few published scientific data that actually determine N_2O emissions from atmospheric deposition of NH_3 and NO_x. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Although Indirect Soil N_2O Emissions from Agricultural Soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines.

A country-specific method is used to estimate ammonia emissions from the application of inorganic and dairy and swine manure N to soils. The method for deriving ammonia emission factors from inorganic N closely follows the model used by Sheppard et al. (2010) to derive specific emission factors for various ecoregions in Canada. Ammonia emission factors are derived based on the type of inorganic N fertilizer, degree of incorporation into soil, crop type and soil chemical properties. The default IPCC emission factor, 0.01 kg N_2O-N/kg N, is used to derive the N_2O emission estimate (IPCC, 2006).

For dairy cattle and swine, the amount of manure nitrogen subject to losses from volatilization of NH_3 following application is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and AWMS. For all other animal manure applied to fields, default volatilization fractions provided in the 2006 IPCC Guidelines were used to estimate N loss as NH_3.

5.4.2.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from atmospheric deposition of N considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines, as well as the uncertainty in the estimate of NH_3.

The estimate of N_2O emissions of 1.2 Mt CO_2 eq from volatilization and redeposition in 2019 lies within an uncertainty range of 0.31 Mt CO_2 eq (-75%) to 2.6 Mt CO_2 eq (+110%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor of 1% (uncertainty range, 0.2% to 5%).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.2.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.2.1.5. Recalculations

Recalculations occurred as a result of revisions to activity data, including livestock populations, crop areas, and crop production.

These recalculations increased emissions by 0.03 kt CO_2 eq in 1990, by 0.11 kt CO_2 eq in 2005 and by 0.31 kt CO_2 eq in 2018 (Table 5–10). The short-term and long-term trends remained unchanged at 50% and 11%, respectively.

5.4.2.1.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

5.4.2.2. Nitrogen Leaching and Runoff

5.4.2.2.1. Source Category Description

When inorganic fertilizer, manure and crop residue are added to cropland, a portion of the nitrogen from these sources is lost through leaching and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, and can produce N_2O emissions off-site.

5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from leaching and runoff in Canada. As in the case of N_2O emissions from volatilization and deposition of NH_3 and NO_x, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines.

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching and runoff of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) multiplied by the amount of inorganic fertilizer nitrogen and crop residue nitrogen and by an emission factor of 0.0075 kg N_2O-N/kg N (IPCC, 2006).

The default value for $FRAC_{LEACH}$ in the Revised 1996 Guidelines is 0.3. However, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC, 2006), such as in the Prairies. Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the 2006 IPCC

Table 5–10 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Atmospheric Deposition and Leaching and Runoff**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Atmospheric Deposition	1990	2020	830	0.03	0.003	Long term (1990–2018)	
		2021	830			50	50
	2005	2020	1 121	0.11	0.01		
		2021	1 121			Short term (2005–2018)	
	2018	2020	1 247	0.31	0.02	11	11
		2021	1 247				
Nitrogen Leaching and Runoff	1990	2020	1 960	-0.1	-0.003	Long term (1990–2018)	
		2021	1 960			52	53
	2005	2020	2 286	4	0.2		
		2021	2 290			Short term (2005–2018)	
	2018	2020	2 983	7	0.2	30	31
		2021	2 990				

Guidelines is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points described above.

5.4.2.2.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from nitrogen leaching and runoff considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and the uncertainty in the estimate of total N.

The estimate of N_2O emissions of 2.9 Mt CO_2 eq from nitrogen leaching and runoff in 2019 lies within an uncertainty range of 0.59 Mt CO_2 eq (-80%) to 5.9 Mt CO_2 eq (+100%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor of 0.75% of total N leached (uncertainty range of 0.05% to 2.5%).

The same methodology and emission factors are used for the entire time series (1990–2019).

5.4.2.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.2.2.5. Recalculations

As was the case with volatilization, recalculations occurred as a result of revisions to activity data, including livestock populations, crop areas, and crop production.

The recalculations decreased emissions by 0.1 kt CO_2 eq or 0.003% in 1990 and increased emissions by 4 kt CO_2 eq or 0.2% in 2005 and by 7 kt CO_2 eq or 0.2% in 2018. These recalculations caused an increase in the long-term trend from 52% to 53% and in the short-term trend from 30% to 31%.

5.4.2.2.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

5.5. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (CRF Category 3.F)

5.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for the purpose of disease control through residue removals. However, this practice has declined in recent years because of concerns over soil quality and environmental issues. Field burning of agricultural residues is a net source of CH_4, CO, NO_x and N_2O (IPCC, 2006).

5.5.2. Methodological Issues

There are no published data on emissions of N_2O and CH_4 from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the 2006 IPCC Guidelines were used for estimating emissions.

A complete time series of activity data on the type and percent of each crop residue subject to field burning was developed based on Statistics Canada's *Farm Environmental Management Survey* (FEMS)[2] and on expert consultations (Coote et al., 2008).

Crop-specific parameters required for estimating the amount of crop residue burned, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, were obtained from Janzen et al. (2003) and are consistent with the values used to estimate emissions from crop residue decomposition.

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5.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC, 2006).

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. On the basis of the area of specific seeded crop, the uncertainty in the amount of crop residues burned is estimated to be ±50% (Coote et al., 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The level uncertainties for CH_4 and N_2O emission estimates were estimated to be ±64% and ±69%, respectively.

2 https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044

5.5.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in both paper and electronic form.

5.5.5. Recalculations

There were no recalculations in this category for the years 1990 or 2005. Emissions in 2018 increased by 0.4 kt CO_2 eq due to the revision of crop activity data. The long-term trend remained at -78%, and the short-term trend increased from 15% to 16%.

5.5.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

5.6. CO_2 Emissions from Liming (CRF Category 3.G)

5.6.1. Source Category Description

In Canada, limestone is often used in the production of certain crops, such as alfalfa, to neutralize acidic soils, increase the availability of soil nutrients, particularly phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that occur in the soil. The rate of release will vary with soil conditions and the compounds applied.

5.6.2. Methodological Issues

Emissions associated with the use of lime were calculated from the amount of lime applied annually and the proportion of carbonate in the minerals used for liming soils that breaks down and is released as CO_2. Methods and data sources are outlined in Annex 3.4.

5.6.3. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on annual lime consumption in each province were estimated to be ±30%. This uncertainty was assumed to include the uncertainty in lime sales, uncertainty in when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was considered to be -50% based on the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties were estimated to be 0.21 ± 0.14 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2019).

5.6.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.6.5. Recalculations

Recalculations to emissions from liming occurred as a result of updates to lime production activity data for the years 2017 and 2018. There is no change in emissions for the years 1990 or 2005 and a decrease of 8 kt CO_2 eq in 2018. The short-term trend decreased from -2% to -7%, and the long-term trend decreased from -53% to -55%.

5.6.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

5.7. CO_2 Emissions from Urea Application (CRF Category 3.H)

5.7.1. Source Category Description

When urea ($CO(NH_2)_2$) or urea-based nitrogen fertilizers is applied to a soil to augment crop production, CO_2 is released on hydrolysis of the urea. According to the 2006 IPCC Guidelines, the quantity of CO_2 released to the atmosphere should be accounted for as an emission. In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$.

5.7.2. Methodological Issues

Emissions associated with urea application were calculated from the amount of urea or urea-based fertilizers applied annually, and the quantity of carbon contained in the urea that is released as CO_2 after hydrolysis. Methods and data sources are outlined in Annex 3.4.

5.7.3. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on the annual urea or urea-based fertilizer consumption were estimated to be ±15%. The uncertainty estimate associated with the emissions was based on simple error propagation using survey uncertainty and an uncertainty of -50% associated with the emission factor specified in the 2006 IPCC Guidelines. The overall mean and uncertainties were estimated to be 2.4 ± 1.2 Mt CO_2 eq for the level uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates. Urea consumption in Canada increased significantly from 1990 to 2019 with a relatively high inter-annual variability in a range of up to ±25% annually. Although we cannot identify specific factors that result in interannual variability, urea-based fertilizer shipments in Canada vary due to price fluctuations, climate factors influencing crop production, and other factors.

5.7.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.7.5. Recalculations

There were no recalculations involved in emission estimates for this source category.

5.7.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

CHAPTER 6

LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 4)

6.1. Overview

The Land Use, Land-Use Change and Forestry (LULUCF) sector reports greenhouse gas (GHG) fluxes between the atmosphere and Canada's managed lands as well as those associated with land-use change and emissions from harvested wood products (HWP) derived from these lands. The assessment includes emissions and removals of carbon dioxide (CO_2); additional emissions of methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO)[1] due to controlled biomass burning; CH_4 and N_2O emissions from wetland drainage and rewetting due to peat extraction; and N_2O released following Land Converted to Cropland.

The estimated net GHG flux in the LULUCF sector, calculated as the sum of CO_2[2] and non-CO_2 emissions and CO_2 removals, amounted to a net removal of 57[3] Mt in 1990 and net emissions of 8.2 Mt in 2005 and 9.9 Mt in 2019. When applied to the national totals, the net flux estimates decrease by 9.4% in 1990 and increase by 1.1% in 2005 and by 1.4% in 2019, the total Canadian GHG emissions. Table 6–1 provides the net flux estimates for 1990, 2005 and recent years in the major LULUCF sector categories and subcategories. The full time series of LULUCF sector estimates is available in Table 10 of the common reporting format (CRF) series.

The Forest Land category has the largest influence on sectoral totals. The net fluxes are negative (removals) for all years of the time series. When interannual variations and trends in the net flux from the managed forest associated with wildfires and other natural disturbances are removed from reporting, net removals from Forest Land decrease from 200 Mt in 1990 to 130 Mt in 2007. The decrease in removals reflects the influence of forest harvesting and an interaction with low-mortality insect disturbances. Since 2007, net removals have fluctuated, increasing to 140 Mt in 2009 when harvest rates reached the lowest point in the 30-year time series and declining slightly to a minimum value of 130 Mt in 2019.

Emissions from the Harvested Wood Products[4] category, which is closely linked to Forest Land, varied over the period 1990–2010 (see section 6.4), but have remained relatively stable at around 140 Mt since 2010 (Table 6–1). They are influenced primarily by the trend in forest harvest rates during the reporting period and the long-term impact of harvest levels before 1990, as some of the carbon in HWP from harvest prior to 1990 is emitted during the reporting period. As a result, annual emissions fluctuated between 130 Mt in 2009 (lowest harvest year) and 150 Mt in 1995.

The combined net flux from Forest Land and Harvested Wood Products—from forest harvest, not including HWP resulting from forest conversion activities since 1990—amounted to net emissions of 4.6 Mt in 2019, which is the combined total of net removals from Forest Land and net emissions from Harvested Wood Products.

Emissions and removals from stands dominated by uncontrollable natural disturbances are tracked separately from those in forest stands dominated by the impacts of anthropogenic activities. Natural disturbances result in important emissions and subsequent removals of GHGs within the managed forest and display large interannual variability that largely mask trends in forest management activities. Since 1990 emissions and removals from natural disturbances have ranged from removals of 50 Mt in 1992 to emissions of 260 Mt in 2015, including indirect CO_2. Emissions and removals have tended to be higher since the mid-2000s compared to the early

1 Emissions of CO are reported as CO in CRF Table 4, but not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF Table 6. Unless otherwise indicated, all emissions and removals reported for the LULUCF sector do not include emissions of indirect CO_2 from CO.

2 Unless otherwise indicated, all emissions and removals are in CO_2 equivalents.

3 All figures associated with estimates and activity data have been rounded according to the protocol described in Annex 8, except in cases where there is a requirement to explain specific details of estimates or trends that may be masked by rounding.

4 Includes harvested wood products from Forest Land conversion.

Table 6–1 **LULUCF Sector Net GHG Flux Estimates, Selected Years**

Sectoral Category		Net GHG Flux (kt CO_2 eq)[b]							
		1990	2005	2014	2015	2016	2017	2018	2019
Land Use, Land-Use Change and Forestry TOTAL[a]		**-57 000**	**8 200**	**-3 500**	**4 000**	**95**	**700**	**8 400**	**9 900**
a.	**Forest Land**	**-200 000**	**-130 000**	**-140 000**	**-130 000**	**-140 000**	**-140 000**	**-130 000**	**-130 000**
	Forest Land Remaining Forest Land	-200 000	-130 000	-140 000	-130 000	-140 000	-140 000	-130 000	-130 000
	Land Converted to Forest Land	-1 100	-950	-540	-500	-440	-390	-340	-300
b.	**Cropland**	**7 600**	**-10 000**	**-8 100**	**-7 000**	**-6 300**	**-5 700**	**-4 800**	**-4 200**
	Cropland Remaining Cropland	-1 900	-14 000	-12 000	-11 000	-10 000	-9 400	-8 600	-7 800
	Land Converted to Cropland	9 500	3 900	3 500	3 700	3 700	3 700	3 800	3 600
c.	**Grassland**	**0.6**	**0.9**	**0.8**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
	Grassland Remaining Grassland	0.6	0.9	0.8	1.2	1.2	1.2	1.2	1.2
	Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d.	**Wetlands**	**5 300**	**3 100**	**3 100**	**2 900**	**2 900**	**3 000**	**2 700**	**2 600**
	Wetlands Remaining Wetlands	1 500	2 600	2 400	2 500	2 600	2 600	2 500	2 400
	Land Converted to Wetlands	3 800	480	700	410	320	340	210	190
e.	**Settlements**	**1 800**	**1 700**	**2 300**	**2 600**	**2 400**	**2 200**	**2 400**	**2 200**
	Settlements Remaining Settlements	-4 200	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400
	Land Converted to Settlements	6 000	6 100	6 800	7 000	6 800	6 700	6 800	6 600
f.	**Other Land**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**
g.	**Harvested Wood Products**	**130 000**	**150 000**	**140 000**	**140 000**	**140 000**	**140 000**	**140 000**	**140 000**
	Forest Conversion[c]	*21 000*	*16 000*	*17 000*	*17 000*	*17 000*	*16 000*	*17 000*	*16 000*
	Indirect CO_2[d]	*820*	*970*	*700*	*770*	*690*	*630*	*610*	*560*
	Natural Disturbances[e]	*-22 000*	*60 000*	*170 000*	*260 000*	*100 000*	*230 000*	*250 000*	*160 000*

Notes:

NE = Not estimated

NO = Not occurring

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
b. Negative sign indicates net removals of CO_2 from the atmosphere.
c. Not a reporting category, it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products.
d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that results from controlled biomass burning, reported in CRF table 6.
e. Not a reporting category, this line is only for transparency purposes and shows the net balance of emissions/removals that result from natural disturbances in managed forests.

part of the inventory reporting period (Table 6–1) due to increased frequency of wildfires and the tracking of insect disturbances.

Changes in agricultural land management practices in Western Canada, such as the extensive adoption of conservation tillage practices and reduction in the use of summerfallow, have resulted in a decrease in emissions from Cropland in the 1990–2006 period, from emissions of 7.6 Mt in 1990 to net removals of 12 Mt in 2006. A decline in emissions from the conversion of forest land to cropland also contributes to this trend. After 2006, net removals remained relatively constant until 2011, but have since gradually declined to 4.2 Mt in 2019, largely as a result of the conversion of perennial lands to annual crop production, a decrease in the adoption rate of conservation tillage, and the fact that soil C in lands previously converted to conservation tillage is approaching equilibrium.

Over the 1990–2019 period, net fluxes in the Wetlands category (peat extraction and flooded lands) ranged from 5.4 Mt (1993) to 2.6 Mt (2019). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher emissions over the 1990–1993 period. Emissions from flooded lands accounted for 37% of all emissions in the Wetlands category in 2019, compared to 82% in 1990. Emissions from the Land Converted to Wetlands category decreased over the reporting period from 3.8 Mt to 0.2 Mt.

Net emissions reported in the Settlements category fluctuated between 1.2 Mt (1998) and 2.6 Mt (2015), mainly driven by rates of conversion from forested land that accounted for 6.6 Mt in 2019. Relatively steady removals of around 4.3 Mt per year from the growth of urban trees offset these emissions by an average of 72% over the reporting period.

Forest conversion is not a reporting category per se since it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. Greenhouse gas emissions due to forest conversion decreased from 21 Mt in 1990 to 16 Mt in 2019, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions combines decreases of 4.4 Mt and 1.8 Mt in immediate and residual emissions from Forest Land Converted to Cropland and Forest Land Converted to Wetlands, respectively, an increase of 0.6 Mt in immediate and residual emissions from Forest Land Converted to Settlements, and an increase of 1.1 Mt in emissions from the resulting HWP since 1990.

In order to avoid double counting, estimates of C stock changes in CRF Tables 4.A to 4.E exclude C emissions emitted as CO_2, CH_4 and CO due to biomass burning. Carbon emissions from biomass burning emitted as CO_2 and CH_4 are reported in CRF Table 4(V) along with emissions of N_2O. Carbon emissions in the form of CO are reported as CO in CRF Table 4, but not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF Table 6. Emissions and removals of CO_2 and emissions of CH_4, N_2O and CO are automatically tallied in CRF Table 4.

This year's submission includes significant recalculations in reported estimates for the Forest Land and Harvested Wood Products categories. The most notable recalculations were due to (1) changes in modelling of insect disturbances, (2) updates made to bioenergy activity data, (3) a correction to the areas associated with forest management and natural disturbance in the managed forest area, and (4) revisions to forest harvest activity data (Table 6–3).

Recalculations also occurred in estimates of woody biomass in Cropland Remaining Cropland mainly due to inclusion of an additional measurement point circa 2010 and the alignment with emissions of firewood sourced from Cropland but occurring in the Harvested Wood Products category. Other recalculations occurred in land categories associated with forest conversion, as a result of the completion of the measurement period 2013-2018 and in the Wetlands category due to updates in the activity data of peat extraction for the year 2018.

The combined impact of these and other minor recalculations in the LULUCF sector (Table 6–2) decreased the estimates of net removals by 2.8 Mt

Table 6–2 **Summary of Recalculations in the LULUCF Sector**

Sectoral Category			1990	2005	2014	2015	2016	2017	2018
Land Use, Land-Use Change and Forestry TOTAL[a]		**kt**	**2 800**	**21 000**	**21 000**	**22 000**	**19 000**	**17 000**	**21 000**
		%	**-4.7%**	**-164%**	**-86%**	**-122%**	**-101%**	**-104%**	**-165%**
a.	**Forest Land**	**kt**	**930**	**11 000**	**8 900**	**9 300**	**8 800**	**7 400**	**6 500**
		%	**-0.5%**	**-7.9%**	**-5.9%**	**-6.5%**	**-6.1%**	**-5.1%**	**-4.6%**
	Forest Land Remaining Forest Land	kt	930	11 000	8 900	9 300	8 800	7 400	6 500
		%	-0.5%	-7.9%	-5.9%	-6.5%	-6.1%	-5.2%	-4.6%
	Land Converted to Forest Land	kt	-	-	3.2	2.8	2.0	0.3	-1.6
		%	-	-	-0.6%	-0.6%	-0.4%	-0.1%	0.5%
b.	**Cropland**	**kt**	**-540**	**580**	**1 300**	**1 600**	**1 400**	**1 100**	**1 400**
		%	-6.6%	-5.3%	-14%	-19%	-18%	-17%	-23%
	Cropland Remaining Cropland	kt	-580	580	630	660	500.0	290	240
		%	43%	-3.9%	-5.1%	-5.8%	-4.8%	-3.0%	-2.8%
	Land Converted to Cropland	kt	38	5.6	700	950	880	850	1 200
		%	0.4%	0.1%	25%	35%	32%	30%	44%
c.	**Grassland**	**kt**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		%	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Grassland Remaining Grassland	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
d.	**Wetlands**	**kt**	**1.8**	**0.7**	**-9.6**	**-1.3**	**-6.2**	**-7.1**	**57**
		%	0.0%	0.0%	-0.3%	0.0%	-0.2%	-0.2%	2.2%
	Wetlands Remaining Wetlands	kt	0.3	0.4	0.1	-0.1	-0.2	-0.5	58
		%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%
	Land Converted to Wetlands	kt	1.5	0.2	-9.6	-1.2	-6.0	-6.6	-1.0
		%	0.0%	0.0%	-1.3%	-0.3%	-1.8%	-1.9%	-0.5%
e.	**Settlements**	**kt**	**-270**	**-320**	**41**	**340**	**300**	**370**	**540**
		%	**-13%**	**-15%**	**1.8%**	**15%**	**14%**	**20%**	**29%**
	Settlements Remaining Settlements	kt	-300	-310	-310	-310	-310	-310	-310
		%	7.6%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	Land Converted to Settlements	kt	32	-13	350	650	610	680	840
		%	0.5%	-0.2%	5.5%	10%	9.7%	11%	14%
g.	**Harvested Wood Products**	**kt**	**2 700**	**9 200**	**11 000**	**11 000**	**8 100**	**8 200**	**13 000**
		%	2.1%	6.6%	8.5%	8.5%	6.3%	6.4%	10%
	Forest Conversion[b]	kt	*-500*	*-81*	*1 500*	*2 300*	*2 100*	*2 300*	*2 900*
		%	*-2.3%*	*-0.5%*	*9.7%*	*16%*	*14%*	*16%*	*22%*

Notes:

Hyphen (-) indicates no recalculations

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

b. Not a reporting category.

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for 1990 and switched the previously reported net sink of 13 Mt in 2005 and 13 Mt CO_2 in 2018 to net sources of emissions of 8.2 Mt and 9.9 Mt, a net change of 21 Mt in both years.

Estimates for all forest-related categories are developed using the same modelling framework. Therefore, changes to the forest model and distribution of disturbances on the landscape can result in changes in the forest stands available for modelling subsequent events, such as forest conversion, resulting in indirect recalculations to land conversion categories as well as C transfers to HWP.

Environment and Climate Change Canada (ECCC) has established governance mechanisms for LULUCF sector reporting through memoranda of understanding (MOU) with Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCan-CFS) for planning, coordinating and developing estimates of Forest Land and Cropland, and it collaborates with many groups of scientists and experts across several government levels and research institutions to produce estimates from other categories of land use.

Planned improvements include continued refinements to the isolation of anthropogenic emissions and removals from Forest Land, refinements to the HWP model structure and activity data, completion of uncertainty estimates in all LULUCF categories, and the gradual integration of missing land use and land-use change categories. More details can be found in sections 6.3 to 6.9 and in Table 8-5.

The remainder of this chapter provides detail on each LULUCF sector category. Section 6.2 gives an overview of the representation of managed lands; section 6.3 provides a short description of Forest Land; section 6.4 describes the Harvested Wood Products category; sections 6.5 to 6.8 describe the Cropland, Grassland, Wetlands and Settlements land categories; and section 6.9 is devoted to the cross-category estimates of forest conversion to other land uses.

Table 6–3 **Summary of Changes in the LULUCF Sector**

List of Changes	Change Category	Years Affected
Forest Land		
New insect disturbances added and corrections made to existing insect disturbances; improved residential firewood activity data and modifications to model parameters and algorithms	Methodological updates	Complete time series
Revisions to forest harvest activity data: 1990-to-present forest harvest data were updated for consistency with latest National Forestry Database statistics	Activity data updates	Complete time series
Corrected past error in list of excludable natural disturbances, and some volume-to-biomass coefficients for areas of Western Canada were corrected after external QC identified issues; small correction in drainage estimates	Continuous improvement	Complete time series
Forest conversion activity data updates due to completion of the measurement period 2013–2018	Activity data updates	2005–2019
Cropland		
Revised rates of deforestation to Cropland due to completion of the measurement period 2013–2018	Activity data updates	2005–2019
Improved estimates of carbon emissions from woody biomass in croplands through additional data points and reconciliation of estimates of woody biomass data with residential firewood activity data considering firewood collection from agricultural lands, transfer of carbon to HWP	Methodological updates	Complete time series
Small change in Cropland estimates due to updates in an internal land-use source file which impacted area estimates	Methodological updates	Complete time series
Grassland		
No recalculations		
Wetlands		
Updates of 2018 activity data from NRCan for peat extraction	Activity data updates	2018–2019
Changes in C available in deforested lands for hydro-reservoirs after CBM updates	Methodological updates	Complete time series
Settlements		
Reconciliation of residential firewood activity data, to account for firewood collection from urban trees, transfer of carbon to HWP	Methodological updates	Complete time series
Revised rates of deforestation to Settlements due to completion of the measurement period 2013–2018	Activity data updates	2005–2019
Harvested Wood Products		
Updates to bioenergy activity data resulting from improved residential firewood data and a correction to moisture content of industrial fuelwood	Methodological updates	Complete time series
Revisions to forest harvest activity data: i) 1990-to-present forest harvest data updated according to latest National Forestry Database statistics, and ii) updates to 1990–2018 commodity production and trade parameters of the HWP model based on the most recent FAO forest products statistics for Canada	Activity data updates	Complete time series
Allocation of un-combusted C to bioenergy emissions	Continuous improvement	Complete time series

6.2. Land Category Definition and Representation of Managed Lands

In order to harmonize all land-based estimates, common working definitions were developed and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2006) land categories, while remaining relevant to land management practices, prevailing environmental conditions and available data sources in Canada. This framework applies to all LULUCF estimates reported under the United Nations Framework Convention on Climate Change (UNFCCC).

Forest Land includes all areas of trees of 1 ha or more, with a minimum tree crown cover of 25% and trees of 5 m in height— or having the potential to reach this height. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question "what areas properly embody 'managed forests'?" For the purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.5 provides more detail on the implementation of the "managed forests" definition.

Agricultural land comprises both Cropland and Grassland (for agricultural use). Cropland includes all lands in annual crops, summerfallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Grassland used for agriculture is defined as "unimproved" pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned, i.e., the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is de facto classified as Cropland, including unimproved pastures where natural vegetation would be forest (Eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of Forest Land or Cropland are generally classified as Grassland. Extensive areas of tundra in the Canadian North are considered unmanaged grassland.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil development typical of these conditions and that are not already included in the Forest Land, Cropland or Grassland categories. Currently, managed lands included in the Wetlands category are those where human interventions have directly altered the water table—which include peatlands drained for peat extraction and flooded lands (hydroelectric reservoirs) (IPCC, 2006).

The Settlements category includes all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded a complete assessment of its extent in the Canadian landscape. However, the conversion of Forest Land, Cropland and unmanaged Grassland (tundra) to Settlements and the area of urban trees are assessed in this GHG inventory.

Other Land comprises areas of rock, ice or bare soil, and all land areas that do not fall into any of the other five categories. Currently, only emissions from the conversion of Other Land to reservoirs and peat extraction are reported under the Wetlands category.

As a consequence of the land categorization scheme, some land-use transitions cannot occur—for example, forest conversion to agricultural grassland—since by definition these exclude areas where forests can grow naturally. Since grassland is defined as "native", creation of grassland does not occur.

The IPCC default land-use change transition period of 20 years is used for all land-use change categories except for land conversion to flooded lands (reservoirs), for which a 10-year transition period is used (IPCC, 2006), and for land conversion for peat extraction, for which a land-use change period of one year is used to represent the land conversion practices of draining and clearing of the surface vegetation layer (acrotelm) in preparation for peat extraction. However, the use of the 20-year land transition period for reporting land areas is simply procedural since higher tier estimation methods are utilized for developing emission and removal estimates.

The Canadian land use and land-use change matrix (Table 6–4) illustrates the land-use areas (diagonal cells) and annual land-use change areas (non-diagonal cells) in 2018. The diagonal cells related to Forest Land and Cropland refer to total land-use areas, those related to Grassland refer to total agricultural grassland, and those related to Wetlands and Settlements refer only to areas where activities causing emissions have occurred. Forest Land includes all managed forest areas comprising areas with anthropogenic impacts for which GHG estimates are reported in CRF Tables 4.A and 4(V), and areas with natural disturbance impacts (see Table 6–5). Grassland Converted to Settlements refers to land conversion of unmanaged tundra to Settlements in Northern Canada (section 6.8.2.2). Column totals equal the total land area as reported in the CRF for each category. The full time series of the land use and land-use change matrix is available in Table 4.1 of the CRF series.

The LULUCF land monitoring system includes the conversion of unmanaged forests, grassland and lands with previously undefined land use to other land categories. Unmanaged land converted to any use always becomes "managed." Parks and protected areas are included in managed lands.

The LULUCF estimates, as reported in the CRF tables, are spatially attached to "reporting zones" (Figure 6–1). These reporting zones are essentially the same as Canada's terrestrial ecozones (Marshall and Shut, 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones, and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 17 of the 18 reporting zones, leaving out the northernmost ecozone of Canada, the Arctic Cordillera, where no direct human-induced GHG emissions or removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.5.

Table 6–4 **Land Use and Land-Use Change Matrix for the 2019 Inventory Year**

Initial Land Use	Final Land Use (kha)					
	Forest Land[a]	Cropland	Grassland[b]	Wetlands[c]	Settlements[c]	Other
Forest Land	225 605	22	NO	0.0	27	NO
Cropland	NE	47 386	NO	NE	11	NO
Grassland	NO	5.5	6 315	NE	0.9	NO
Wetlands	NO	NE	NO	484	NE	NO
Settlements[b]	NO	NE	NO	NO	980	NO
Other	NO	NO	NO	0.5	NO	NE

Notes:

NE = Not estimated

NO = Not occurring

kha = kilohectare

Non-diagonal cells refer to annual rates of land-use change, i.e., total land converted during the latest inventory year.

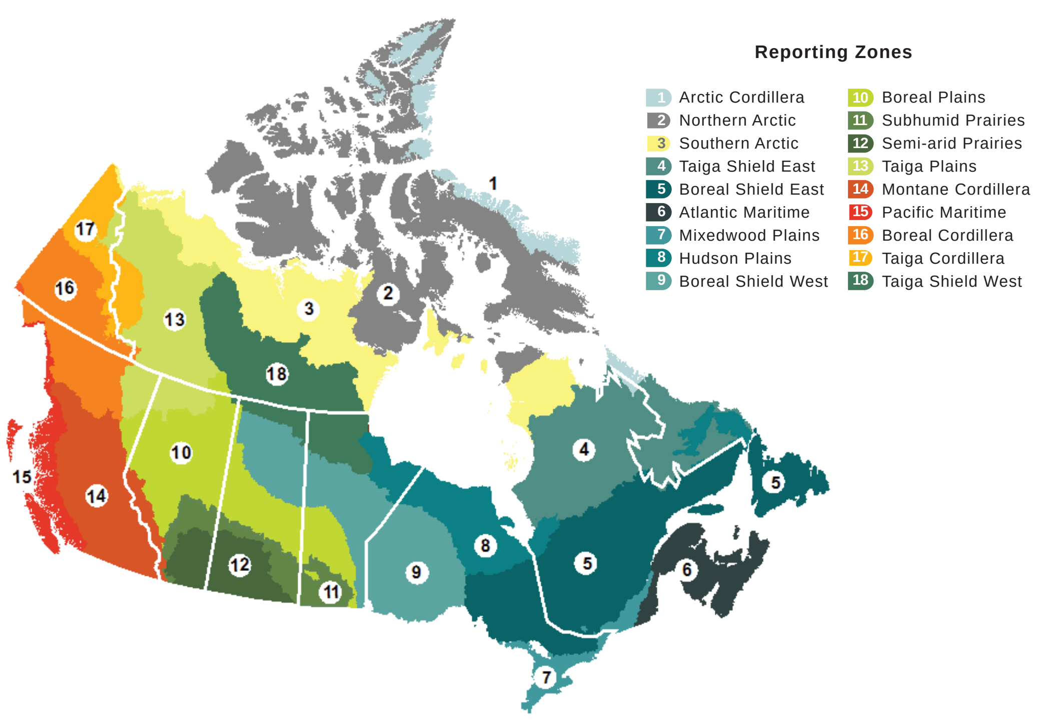
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRF Tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

a. Includes all managed forest areas.

b. Only includes areas of agricultural grassland.

c. Only includes areas for which estimates are reported in the CRF.

Figure 6–1 **Reporting Zones for LULUCF Estimates**



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The areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. For example, areas of land converted to flooded land (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the relevant sectoral background tables of the CRF refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs and 1 year for peat extraction) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g., Land Converted to Forest Land, Land Converted to Cropland) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs and 1 year for peat extraction) into the "land remaining land" categories.

The remaining unmanaged land area reported in CRF Table 4.1 ("Land Transition Matrix") includes both unmanaged and managed land for which there are no estimates of emissions and removals. It is currently reported in this table to fulfill the requirement of the UNFCCC Reporting Guidelines to report the total land mass area of the country.

6.3. Forest Land (CRF Category 4.A)

Forest and other wooded lands cover 400 million hectares (Mha) of Canadian territory; forest lands alone occupy 350 Mha (NRCan, 2018b). Managed forests account for 230 Mha, or 65% of all forests. Four reporting zones (Boreal Shield East, Boreal Plains, Montane Cordillera and Boreal Shield West) account for 69% of managed forests.

In 2019, the net GHG balance of managed Forest Land amounted to removals of 130 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 140 Mt.

The Forest Land estimate includes net emissions and removals of CO_2, as well as N_2O and CH_4 emissions from slash burning. For the purpose of UNFCCC reporting, managed Forest Land is divided into the Forest Land Remaining Forest Land (230 Mha, net removals of 130 Mt in 2019) and Land Converted to Forest Land (0.04 Mha, net removals of 0.3 Mt in 2019) subcategories.

6.3.1. Forest Land Remaining Forest Land (CRF Category 4.A.1)

6.3.1.1. Sink Category Description

As trees grow, they absorb CO_2 from the atmosphere through photosynthesis, some of which is stored in vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide and other GHGs are returned to the atmosphere by respiration and the decay and burning of organic matter. Human interactions with the land can directly alter the size and rate of these natural exchanges of GHGs in both the immediate and long term. Land-use change and land-use practices in the past still affect current GHG fluxes to and from the managed forest. This long-term effect is a unique characteristic of the LULUCF sector, which makes it very distinct from other inventory sectors.

Forest management practices (including harvesting, silvicultural treatments and regeneration) are the primary direct human influences on emissions and removals in forests. Forest harvest transfers carbon (C) to Harvested Wood Products (HWP) (section 6.4) and produces harvest residues (branches, foliage and non-commercial species), which are left to decay or are burned. Clear-cut harvesting resets stand age to 0; this changes the rate of C accumulation in biomass, as young trees accumulate little biomass in the first 30 to 40 years. The combination of GHG emissions and removals from Forest Land and emissions of CO_2 from wood products harvested from the forest represents the net flux between managed forests and the atmosphere (Figure 6–2).

Reported estimates for net removals from Forest Land differentiate the impacts of non-anthropogenic natural disturbances (wildfires, insect infestations and windthrow, Table 6–5) from the impacts of direct anthropogenic management of the forest resource.[5] Net removals from Forest Land decreased from 200 Mt in 1990 to 130 Mt in 2007 and have since remained relatively constant (Figure 6–2). The decrease in removals that occurred between 2000 and 2007 is mainly due to trends in the Montane Cordillera and Boreal Plains reporting zones. In the Montane Cordillera, insect infestations and salvage harvesting of infested stands resulted in a shift in the average age of the forests of this region to younger age classes and an overall decrease in the rate of C accumulation in biomass[6] in the reporting zone. At the same time, low-level insect infestations increased tree mortality over large areas, resulting in increased emissions from decomposition. On the Boreal Plains, harvest rates also resulted in a shift in the average age of forests of that reporting zone, but insect infestation and fire also caused a reduction in the area of commercially

5 Impacts of natural disturbances with greater than 20% tree mortality.

6 Average age of the forest in this context refers to the age class structure of the forest and carbon uptake refers to net primary production.

Table 6–5 **Forest Land Remaining Forest Land Areas, GHG Fluxes and C Transfers, Selected Years**

Subcategories	1990	2005	2014	2015	2016	2017	2018	2019
Total Managed Forest Area (kha)	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**
Areas with anthropogenic impacts	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000
Areas with natural disturbance impacts	56 000	57 000	54 000	55 000	54 000	54 000	55 000	55 000
Net Flux – Reported and Not Reported (kt CO_2 eq)[a, b]	**-220 000**	**-72 000**	**27 000**	**120 000**	**-31 000**	**90 000**	**120 000**	**24 000**
Reported estimates[c]	-200 000	-130 000	-140 000	-130 000	-140 000	-140 000	-130 000	-130 000
Indirect CO_2[d]	400	720	430	500	430	380	350	340
Emissions/removals from lands impacted by natural disturbances	-22 000	60 000	170 000	260 000	100 000	230 000	250 000	160 000
Wildfires – direct immediate emissions[e]	35 000	61 000	160 000	240 000	100 000	210 000	230 000	150 000
Wildfires – indirect CO_2 immediate emissions[e]	3 000	5 300	14 000	21 000	8 700	18 000	20 000	13 000
Post-wildfire CO_2 emissions and removals[e]	-60 000	-47 000	-43 000	-34 000	-33 000	-28 000	-22 000	-22 000
Insects – emissions and removals[f]	310	42 000	33 000	31 000	27 000	24 000	22 000	21 000
Other natural disturbances – emissions and removals[g]		44	7.3	6.6	5.9	5.3	1.9	1.7
Carbon Transferred to HWP (kt C)[h]	**44 000**	**54 000**	**42 000**	**44 000**	**43 000**	**43 000**	**44 000**	**44 000**

Notes:

Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. Net flux corresponds to the sum of net GHG balance due to reported anthropogenic forest management activities, and emissions/removals due to natural disturbances, tracked but not reported in the CRF tables. Includes emissions/removals of CO_2 and emissions of CH_4, N_2O and CO.

c. Includes emissions/removals of CO_2 and emissions of CH_4 and N_2O, from forest stands dominated by the impact of anthropogenic activities.

d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that result from slash burning after forest harvest are reported in CRF table 6.

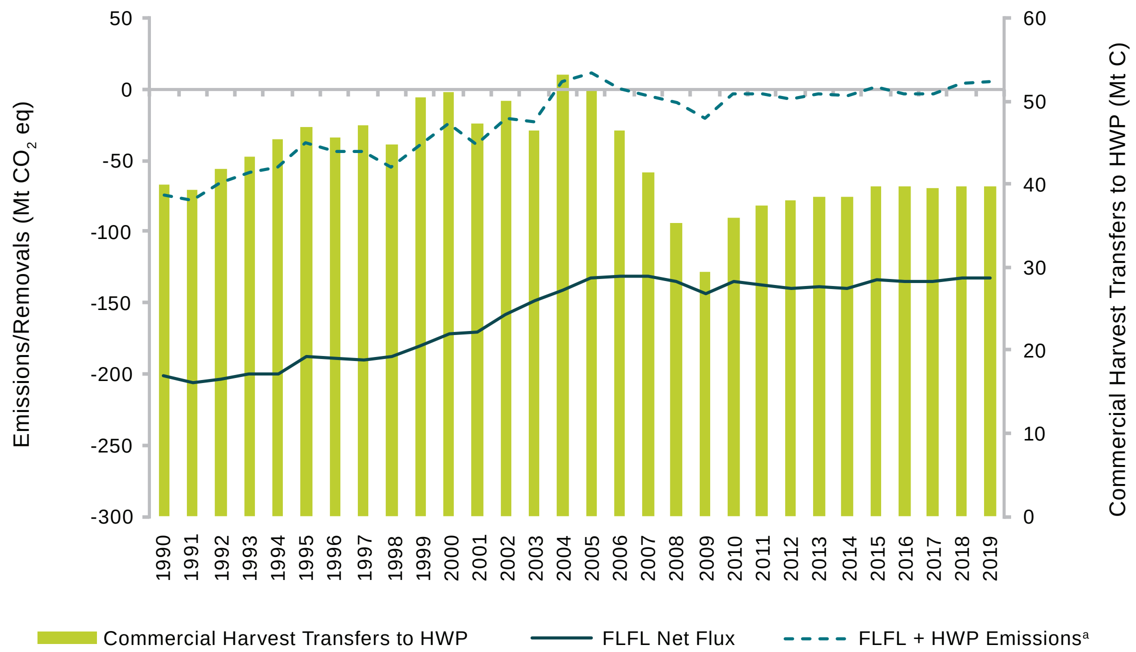
e. Immediate emissions include direct and indirect CO_2 and direct non-CO_2 emissions resulting from the immediate impact of wildfires. Post-wildfire CO_2 emissions are associated with the long-term effect of wildfires on dead and soil organic matter; they include small emissions associated with insect infestations on wildfire-impacted areas. Removals of CO_2 are associated with natural stand regeneration following wildfire.

f. Includes emissions due to insect infestations, mainly residual, and removals associated with subsequent natural stand regeneration.

g. Includes the remnant impact in emissions of Hurricane Juan on Nova Scotia forests in 2003 and removals from subsequent natural stand regeneration.

h. This transfer from land categories to HWP is presented here for information purposes. Includes salvage logging after natural disturbances. The current design of the CRF tables for the LULUCF Sector does not enable representation of C transfer to the HWP in-use pool.

Figure 6–2 **Emissions and Removals Related to Forest Land**



Note:
a. Includes emissions from HWP originating from harvesting and salvage logging after natural disturbances

mature forest stands and, consequently, a reduction in the rate of C uptake for the region. Reduced C uptake and increased emissions from decomposition in these regions resulted in a decrease in removals large enough to impact the national trend. More recently, low-mortality insect infestations have impacted large areas of the Boreal Shield East and Atlantic Maritime reporting zones and, since 2010, have had an effect on reported emissions and removals in these regions that will likely continue over the next few decades.

The total net flux in managed forests shown in Table 6–5 is calculated by adding reported estimates of emissions and removals caused by human activities, including indirect CO_2, to emissions and removals that occur in areas dominated by the impact of uncontrollable natural disturbances. When all direct and indirect emissions and removals from lands impacted by natural disturbances are included, net fluxes in managed forests (reported and not reported) switch from net removals of 220 Mt in 1990 and 72 Mt in 2005 to net emissions of 24 Mt in 2019. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year.

6.3.1.2. Methodological Issues

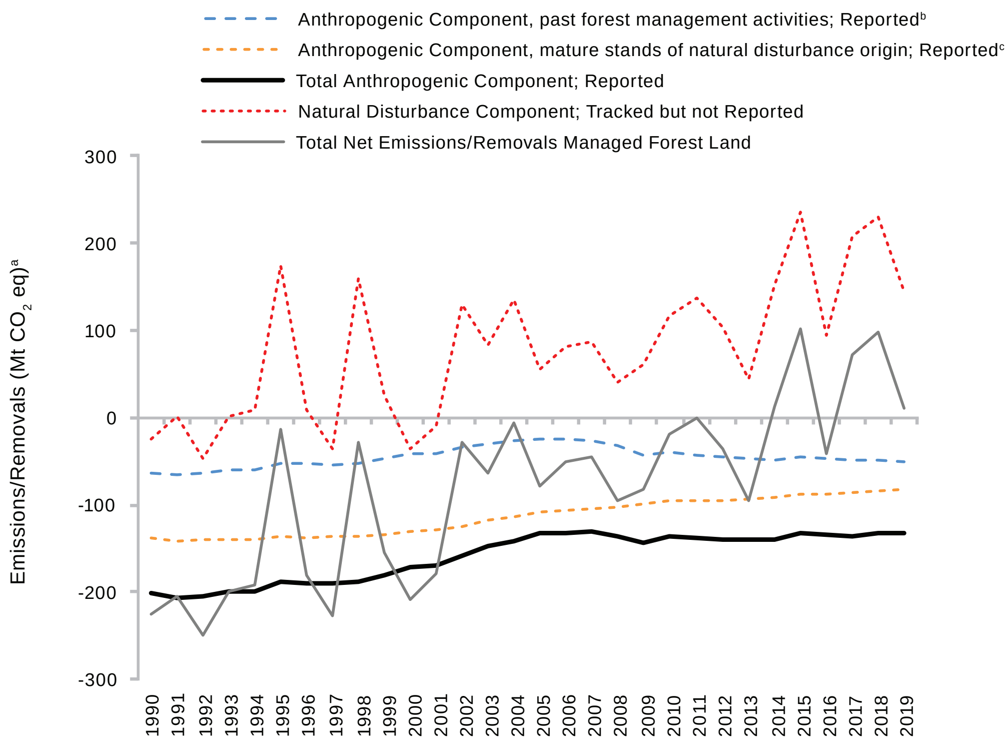
Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, or CBM-CFS3) (Kull et al., 2019; Kurz et al., 2009). This model integrates forest inventory data and yield curves with spatially referenced activity data on forest management and natural disturbances to estimate forest C stocks, stock changes and CO_2 emissions and removals. The model uses regional ecological and climate parameters to simulate C transfers among pools in the forest ecosystem as well as to the HWP pool and the atmosphere. A more detailed description of forest C modelling can be found in Annex 3.5.2.1.

Prior to the 2017 inventory edition, emissions and removals of Forest Land displayed large interannual variability due to the impact of natural disturbances that masked the impact of forest management activities. The IPCC has recognized the issue of reporting emissions from natural disturbances for some countries and encouraged countries that use Tier 3 methodologies to work towards the development of new approaches that can improve the isolation of anthropogenic impacts (IPCC, 2010). Further, the 2019 IPCC Refinement to the 2006 Guidelines (IPCC, 2019) provides examples of approaches that have been used by countries (including Canada) to resolve this issue. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effect of anthropogenic activities on managed forests. This approach is based on the monitoring and compiling of emissions from forest stands impacted by anthropogenic and natural drivers separately (referred to as "anthropogenic component" and "natural disturbance component"). The anthropogenic component includes emissions and removals associated with stands that have been (1) directly affected by past forest management activities (e.g., clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging), (2) mature stands affected by natural disturbances causing less than or equal to 20% biomass mortality (i.e., insect defoliation), or (3) mature stands affected by stand-replacing natural disturbances in the past but that have reached a regionally-determined minimum operable age (i.e., commercial maturity or pre-disturbance biomass, and therefore eligible to be scheduled for harvest). The natural disturbance component includes emissions and removals associated with large, uncontrollable natural disturbances, such as wildfires or insect outbreaks causing more than 20% biomass mortality. For transparency, all emissions and removals are presented here (Table 6–5; Figure 6–3), but reporting is based on the anthropogenic component in an effort to better capture emissions and removals more closely linked to land management and to better inform policy. A full accounting of natural disturbances and C balance in managed forests can also be found in the State of Canada's Forests report (NRCan, 2020). Additional information on the estimation approach is provided in Annex 3.5.2.4 and in Kurz et al. (2018).

Carbon stock changes in the anthropogenic component of managed forests are reported, by reporting zone, in CRF Table 4.A. For any given pool, C stock changes include not only exchanges of GHG with the atmosphere, but also the C transfers to and from pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore, individual C stock changes give no indication of the net fluxes between C pools in managed forests and the atmosphere. In addition, to meet transparency reporting requirements, areas in the natural component of managed forests are reported separately, by reporting zone, in CRF Table 4.A.

Harvesting wood from managed forests results both in a transfer of C from the Forest Land category to the Harvested Wood Products category (Figure 6–2, Table 6–5) and in debris or residues that remain on site and decompose. The fate of the C embedded in wood material taken off-site is tracked in the HWP pool and reported in the Harvested Wood Products category, and the emissions from the C that decomposes on site are reported in the Forest Land category. Due to limitations in the current design of the CRF tables, the C transferred from the forest to the HWP pool is not reported in CRF Table 4.A since it would result in an automatic calculation of CO_2 emissions in the "net CO_2 emissions/removals" column of that table, which would amount to using the instant oxidation approach for HWP. Instead, and for transparency purposes, this C transfer is reported as C input into the HWP in-use pool in CRF Table 4.G without removing it from the emissions reported in the "Net emissions/ removals from HWP in use" column of CRF Table 4.G. For this reason, it is important to caution

Figure 6–3 **Emissions and Removals in Forest Land Remaining Forest Land by Stand Component**



Notes:

a. Not including indirect CO_2 and emissions from HWP

b. Clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging

c. Stands that have reached minimum operable age (either commercial maturity threshold or pre-disturbance biomass) and are eligible to be scheduled for harvest

against interpreting the net C stock change in the forest biomass and DOM pools as shown in the current design of CRF Table 4.A since the losses of C from these pools are not completely represented in this table. More information on Canada's approach to HWP modelling is available in Annex 3.5.3.

Emissions of CO_2, CH_4 and N_2O from drained forest organic soils are reported in CRF Table 4(II). They are calculated using activity data derived from a combination of historical documents, consultations and provincial statistics, and Tier 1 emission factors from the 2013 IPCC Wetland Supplement to the 2006 Guidelines (IPCC, 2014). Details are provided in Annex 3.5.2.2.

Calculations of direct and indirect soil N_2O emissions from net soil organic carbon (SOC) losses in stands under anthropogenic influence aggregated at the RU level indicate that potential emissions from this source can be deemed insignificant in accordance with the provisions of paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. Emissions aggregated at the RU level varied from 0 kt in 2011, 2016 and 2017 to 56 kt in 1990, which are significantly lower than 0.05% of the national total GHG emissions without LULUCF, and do not exceed 500 kt.

6.3.1.3. Uncertainties and Time-Series Consistency

Uncertainty Estimates

Numerical techniques are used to quantify uncertainties about the outputs of the CBM-CFS3 (Metsaranta et al., 2017). Modelling of Canada's managed forests is not done as a single run, but in separate "project runs" whose output is subsequently assembled. For each "project," 100 Monte Carlo runs are conducted using the base input data for the 2021 submission (covering the entire 1990–2019 time series). Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each gas. Given the substantial changes implemented in this submission, a comprehensive uncertainty analysis using Monte Carlo simulation was performed.

Throughout the entire time series, the uncertainties associated with annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertainty range of the CO_2 estimates is 67 Mt in 1990, 80 Mt in 2005 and 73 Mt in 2019 (Table 6–6). On average, uncertainty was ±58 Mt of the median result from the Monte Carlo runs over

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Table 6–6 **Estimates of the Net Annual CO_2, CH_4 and N_2O Fluxes for Forest Land Remaining Forest Land, with 2.5th and 97.5th Percentiles, for Selected Years**

Gas	Inventory Year	Net Flux (Mt)	2.5th Percentile (Mt)	% Uncertainty[a] (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	-202	-267	33	-200	-0.7
	2005	-135	-188	39	-107	-20
	2019	-134	-185	38	-112	-16
CH_4	1990	0.4	0.3	-36	0.60	39
	2005	0.7	0.5	-33	1.36	85
	2019	0.3	0.2	-38	0.75	115
N_2O	1990	0.2	0.1	-39	0.28	38
	2005	0.4	0.2	-36	0.68	85
	2019	0.2	0.1	-42	0.37	112

Note:

a. Uncertainty ranges remain relatively constant throughout the time series. As a result, as the absolute value of emissions and removals decreases, the proportional error increases. Uncertainty reported for Annex 2.3 are taken from the error associated with the proportional error of 2019.

the entire time series. Non-CO_2 emissions contribute little to total uncertainty. Probability distributions are asymmetrical around the net flux estimate and are skewed to the lower bound (greater sink), representative of the nature of the distributions of the activity data and parameters tested in the Monte Carlo analysis as they are expressed in the model. More information on the general approach used to conduct this analysis is provided in Annex 3.5.2.8, and a detailed description of methods, assumptions and discussions of the skewed nature of uncertain distribution can be found in Metsaranta et al. (2017).

Uncertainty associated with forestry drainage is not presented in Table 6–6. Due to the magnitude of the emissions from this source relative to net emissions and removals from the forest sector, it is highly unlikely to have an impact on the global uncertainty estimates of the Forest Land category.

Time-Series Consistency

All estimates have been developed in a consistent manner, but some sources of activity data do not provide full coverage for the entire reporting period. Estimates of wildfire areas burned in the managed forest for the 1990–2003 period were derived from the Canadian National Fire Database,[7] which comprises information from provincial resource management agencies, compiled and updated by the Canadian Forest Service. Estimates of area burned for the period 2004–2018 were obtained from the National Burned Area Composite (NBAC).[8] This composite of data is derived from various remote sensing sources, monitoring data collected by provincial resource management agencies, and a rule set that, for each fire, identifies the most accurate available data source. An analysis of the period of overlap in the data shows that the differences between the two time series are small and not biased. The processes used to quantify the estimates of area burned in NBAC generate improved estimates of the burned area of individual fires, because, in general, more detailed information about unburned areas within the fire perimeter is generated. Individual fire events may thus generate less burned area, but the total number of events included in the NBAC can be higher.

The forest inventory data incorporated in the analyses were not all collected in the same year across the country. Annex 3.5 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990.

6.3.1.4. Quality Assurance / Quality Control and Verification

Systematic and documented quality assurance/ quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. Check results are systematically documented, and an issue-logging system identifies each issue and facilitates tracking and resolution management. Tier 2 QC checks (White and Dymond, 2008; Dymond, 2008) specifically address estimate development in the Forest Land category.

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented category-specific Tier 2 checks for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF data warehouse and entered into the CRF Reporter. These procedures and their outcome are fully documented in the centralized archives.

Shaw et al. (2014) compared the C stocks predicted by the CBM-CFS3 with ground plot-based estimates of ecosystem C stocks from Canada's new National Forest Inventory (NFI). Carbon stock data sets from the NFI were entirely independent of the input data used for model simulations for each ground plot. The mean error in total ecosystem stocks between model

7 http://www.nrcan.gc.ca/node/13159

8 http://www.nrcan.gc.ca/node/13159

predictions and ground plot measurements was 1%, while the error in above-ground biomass, deadwood, litter and mineral soil pools was 7.5%, 30.8%, 9.9% and 8.4%, respectively. The contribution of above-ground biomass and deadwood to the error in ecosystem subtotal pools was small. However, the contribution from soils was large. The error in above-ground biomass and deadwood pools compared favourably to the standards proposed in the IPCC Good Practice Guidance (IPCC, 2003) for these pools (8% and 30% respectively). Results from this research indicate that there are important pool-, region- and species-specific variations that require further study.

As part of quality assurance efforts, the 2017 National Inventory Report (NIR) approach for estimating anthropogenic emissions and removals was reviewed by an international panel of forest scientists convened by Environment and Climate Change Canada in October 2016. The panel found that the new approach effectively isolates anthropogenic emissions and removals due to forest management from the impacts of natural disturbances. The panel also stated that the criterion established to classify stands impacted by insect infestations as being under anthropogenic or natural influence was justifiable. However, it recommended that the threshold criterion used to differentiate anthropogenic or natural emissions and removals after stand-replacing natural disturbances should be regionally specific to incorporate variations in forest ecology. Changes were implemented in the 2018 submission and the revised approach was reviewed and approved by provincial forest experts.

6.3.1.5. Recalculations

There were significant recalculations in this reporting category due to (1) the addition of new types of insect disturbance and corrections made to existing disturbance matrices, (2) correction of past error in the list of stands tracked as natural disturbances, (3) improved residential firewood activity data based on a more robust national survey data and revisions to model algorithms, and (4) updates to 1990-to-present forest harvest activity data according to latest National Forestry Database statistics.

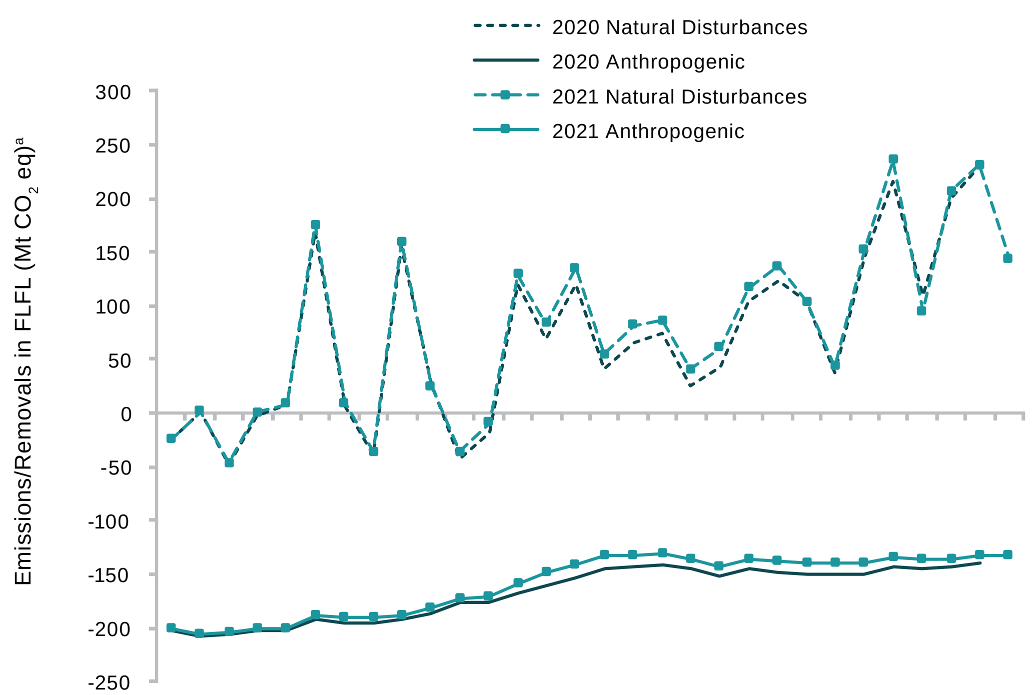
Other less significant recalculations were due to corrections to volume-to-biomass conversion parameters for areas of Western Canada following an external quality control review, implementation of a new measurement period for forest conversion activities from 2013 to 2018, and a revision to forest drainage estimates.

The combined effect of these changes resulted in a decrease of net removals by 0.9 Mt (-0.5%), 11 Mt (-7.9%) and 6.5 Mt (-4.6%) in 1990, 2005 and 2018 respectively (see Figure 6–4).

Improved Estimates of Post-1990 Insect Disturbances

Changes implemented in this submission include (1) addition of spruce budworm (*Choristoneura fumiferana* [Clem.]) disturbances in Alberta, Saskatchewan, Manitoba and the Northwest Territories; (2) addition of western balsam bark beetle (*Dryocoetes confuses*), Douglas-fir beetle (*Dendroctonus pseudotsugae*), and spruce bark

Figure 6–4 **Recalculations in Forest Land Remaining Forest Land**



Note:
a. Not including indirect CO_2

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beetle (*Dendroctonus rufipennis*) disturbances in British Columbia; (3) correction to existing aspen defoliator disturbances in Alberta; (4) correction to existing spruce budworm (*Choristoneura fumiferana* [Clem.]) disturbances in Quebec; and (5) update to existing spruce bark beetle (*Dendroctonus rufipennis*) disturbances in the Yukon Territories (Hafer et al., 2020).

Activity Data Updates

Commercial forestry activities (clear-cut harvesting, commercial thinning and slash burning) were retroactively reviewed and updated on the basis of historic statistics from the National Forestry Database of the Canadian Council of Forest Ministers[9] to replace the estimated activity levels used for the 1990–2018 period in the 2020 NIR. Significant revisions to the activity data and methods used to estimate CO_2 emissions from residential and industrial bioenergy consumption were implemented in this submission (see section 6.4.4 and Annex 3.5.3 for more details). Deforestation activity estimates were revised adding a new mapping period for 2013–2018 (see section 6.9.4).

6.3.1.6. Planned Improvements

Planned improvements include updates to baseline inputs (data, processes and parameters) such as (1) activity data on fire and stand origin characterization as well as continuous refinements to certain parameters in the CBM-CFS3 modelling framework, such as the volume-to-biomass coefficients; and (2) improvements to the modelling of Eastern Canada's hardwood forests to better represent partial harvesting in CBM-CFS3 and to validate modelled trends using an independent Earth observation (EO)-based validation analysis. Longer-term plans also include a trend uncertainty and sensitivity analysis and an examination of how various components contribute to the asymmetrical distribution of uncertainty estimates around net flux. More details can be found in Table 8-5.

6.3.2. Land Converted to Forest Land (CRF Category 4.A.2)

6.3.2.1. Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to establish. More precisely, the category refers to active forest establishment where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area reported under the Land Converted to Forest Land category declined from 170 kha in 1990 to 35 kha in 2019. Given that activity data after 2008 are only for Ontario (see section 6.3.2.2), the trend mainly reflects the gradual transfer of lands afforested more than 20 years ago to the Forest Land Remaining Forest Land category. Nearly 81% of all farmland converted to Forest Land over the last 20 years occurred in Eastern Canada (Atlantic Maritime, Mixedwood Plains and Boreal Shield East reporting zones), with only 12% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones) and the remaining 6.6% in Western Canada (Pacific Maritime and Montane Cordillera reporting zones).

Net removals declined throughout the period, from 1.1 Mt in 1990 to 0.3 Mt in 2019. Net C accumulation largely occurs in biomass (71 Gg C in 2019, CRF Table 4.A). Soil C sequestration is negligible and will remain so because this category is restricted to plantations that are younger than 20 years. For the same reason, and considering the relatively low net increment of planted trees in the early years, it is important to emphasize that the category as a whole is not expected to contribute significantly to the net greenhouse gas balance of Forest Land. In considering these trends, it must also be noted that the data used in this analysis are not comprehensive.

6.3.2.2. Methodological Issues

Under the Government of Canada's Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative, afforestation records for 1990–2002 were collected and compiled (NRCan, 2005a). In that period, softwood plantations, especially spruce and pine, accounted for 90% of the area planted. Activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data, complemented with information from the Forest 2020 Plantation Demonstration Assessment (NRCan, 2005b). In addition, this submission includes the effect of new afforestation activity data for Ontario for the years 2007 to 2016 obtained through a data sharing agreement established with Forests Ontario to access their database of tree planting activities for inclusion in NIR estimates.

GHG emissions and removals on lands newly converted to forest land were estimated using CBM-CFS3, as described in Annex 3.5. Changes in soil C stocks are highly uncertain because of difficulties in locating data about the C stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil C at a slow rate. The limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

6.3.2.3. Uncertainties and Time-Series Consistency

Significant challenges remain in estimating uncertainty for this category due to the lack of a consistent national system for tracking afforestation and because it is currently not possible to run a Monte Carlo simulation using the model data input structure for this category. Given these

9 Available online at http://nfdp.ccfm.org/

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limitations, initial uncertainty estimates were developed based on expert judgement. It was assumed that the 95% confidence intervals for this category could be estimated at 10% smaller or 200% larger than the reported value.

6.3.2.4. Quality Assurance / Quality Control and Verification

Tier 2 QC checks (Dymond, 2008) specifically address estimate development in the Forest Land category. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from data partners, as well as for all estimates and activity data contained in the LULUCF data warehouse and entered into the CRF Reporter.

6.3.2.5. Recalculations

Minor recalculations occurred in this category due to the addition of new afforestation activity data for Ontario for the years 2007 to 2016. As a result, total net removals were increased by 1.6 kt (+0.5%) in 2018.

6.3.2.6. Planned Improvements

There is still limited access to information on afforestation activity, but continued efforts are underway to obtain more data in recent years from provincial and territorial resource management agencies. As more information becomes available in the future, uncertainty estimates will be further refined as well.

6.4. Harvested Wood Products (CRF Category 4.G)

6.4.1. Source Category Description

The Harvested Wood Products category is reported following the Simple Decay Approach as described in the annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006). The approach is similar to the Production Approach, but differs from it in that the HWP pool is treated as a C transfer related to forest harvest and hence does not assume instant oxidation of wood in the year of harvest (more details provided in Annex 3.5).

Emissions associated with this category result from the use and disposal of HWP manufactured from wood coming from forest harvest, forest conversion and firewood collection activities in Canada and consumed either domestically or elsewhere in the world. Products disposed of at the end of their useful life are assumed to be immediately oxidized.

Emissions from this source are mainly influenced by the trend in forest harvest rates and the long-term impact of harvest levels starting in the year that C begins to be stored in a pool of HWP that are in use. As a result, emissions fluctuated between 130 Mt in 2009 (lowest harvest year) and a peak of 150 Mt in 1995. In 2019, HWP amounted to total emissions of 140 Mt, 12 Mt above 1990 value (Table 6–7).

Harvested Wood Products emissions are inextricably linked to emissions/removals from Forest Land, such that the sum of net emissions/removals from Forest Land and emissions from HWP provides an estimate of total net emissions/removals from the managed forest (Figure 6–2).

6.4.2. Methodological Issues

A country-specific model, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products, is used to monitor and quantify the fate of C off-site from the point of forest harvest or forest conversion. The model tracks HWP sub-pools and C flows between sub-pools through the life-cycle of wood products (e.g., manufacturing, use, trade and disposal).

In more concrete terms, the harvested wood products model takes the C output from wood harvest, exports a portion as roundwood, converts all harvested wood into commodities, exports some of the commodities produced, and keeps track of the additions to and removals from HWP in-use and from bioenergy.

Inputs to the model (Table 6–7) include: (1) the annual mass of C from conventional contemporary harvest and residential firewood collection in forest lands and a relatively small amount from forest conversion activities (around 2.7% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2); and (2) an additional annual quantity of C from woody biomass collected from croplands and from urban trees on land in the Settlements category and used for residential bioenergy. For the historical harvest, the input comes from the historical commodity production from Statistics Canada at a national level of spatial resolution, covering the 1900–1989 period.

Data on the annual volume of residential firewood and industrial fuelwood are provided by the Energy sector. Residential firewood data come from surveys of residential wood use for the years 1997, 2003, 2007, 2015 and 2017 (Statistics Canada 1997, 2003, 2007, 2015, 2017), and pellet and manufactured log consumption data come from surveys for the years 1996, 2006, 2012, and 2017 (Canadian Facts 1997; TNS 2006; TNS 2012; Statistics Canada 2017). Data on firewood consumption for the territories come from fuelwood and firewood harvest statistics provided by the National Forestry Database,[10] and data on industrial fuelwood come from the annual *Report on Energy Supply and Demand in Canada* (RESD).

10 National Forestry Database, available online at http://nfdp.ccfm.org/en/data/harvest.php

More information on the estimation methodology, data sources and parameters used in the model are available in Annex 3.1 (data sources) and Annex 3.5.3.

The trend in emissions from HWP disposal results from historical commodity production combined with the duration of the life cycle of various commodities (Table 6–7). The impact of any significant changes in harvest levels or in the mix of products is therefore redistributed over several subsequent years and decades as commodities are gradually retired from use.

Activity data and annual estimates of C inputs, stock changes in the HWP pool and resulting net emissions for each commodity are reported in CRF Table 4.G. In line with the Simple Decay Approach, Canada has made the following assumptions to report data related to HWP in this table: (1) Column "B" for Gains: correspond to C inputs associated with C transferred from any wood producing land category (e.g., Forest Land) to the HWP pools used domestically and exported; these C inputs would represent C losses in CRF tables 4.A-4.F if using a reporting approach other than the Simple Decay Approach and are reported in this table for completeness and transparency purposes; (2) Column "C" for Losses: corresponds to C losses calculated from the combustion of firewood, from the oxidation of milling waste, and via the decay equation 12.1 from Volume 4, Chapter 12, of the 2006 IPCC Guidelines for HWP with longer half-lives; (3) Column "E", the annual change in stocks: calculated as the net interannual change in stocks in the HWP pool; the total annual values for these net stock are reported in Table 6–7; and (4) Column "F", for net E/R of CO_2 from the HWP: values reported in this column correspond to CO_2 emissions associated to the C losses reported in column "C"; C gains reported in column "B" are not considered in the calculation of this column to avoid double counting of removals in the sector given that emissions due to instant oxidation of harvested wood are not reported in any of the CRF tables 4.A through 4.F.

For the 1990–2007 period, emissions resulting from the inclusion of the HWP pool (stacked areas in Figure 6–5) are considerably lower than the emissions that would result from using an instant oxidation approach (dotted line in Figure 6–5), as used in submissions prior to 2015, with differences fluctuating between -38 Mt in 1992, and -64 Mt in 2004 (highest harvest year) (bars in Figure 6–5). These large differences occur because C in wood removed from the forests in the reporting year was much higher than the C transferred to the HWP pool in past

Table 6–7 **Carbon Stocks in the HWP Pool and Emissions Resulting from Their Use and Disposal**

Source Subcategories / Commodities	1990	2005	2014	2015	2016	2017	2018	2019
Carbon Stocks (Mt C)[a]								
Inputs	46	56	44	45	45	45	45	45
Conventional Harvest[b]	40	51	38	40	40	39	40	40
Forest Conversion[b]	1.6	1.3	1.3	1.5	1.4	1.3	1.3	1.3
Residential Firewood[c]	4.5	3.3	4.2	4.1	3.9	4.0	4.3	4.4
Exports	19	31	21	22	23	23	21	21
Net Stocks[d]	330	520	580	580	590	600	610	610
Emissions (Mt CO_2)[a]	**130**	**150**	**140**	**140**	**140**	**140**	**140**	**140**
Domestic Harvest	88	75	75	75	72	73	78	79
Solid Wood – Sawnwood	5.5	7.8	9.2	9.4	9.5	9.6	9.8	10.0
Solid Wood – Wood Panels	2.7	3.3	4.0	4.1	4.1	4.1	4.2	4.3
Other Solid Wood Products	0.9	1.9	2.2	2.2	2.2	2.2	2.2	2.2
Paper and Market Pulp	8.3	0.7	2.8	3.0	3.2	3.4	3.3	3.1
Firewood – Residential and Industrial	61	60	56	55	51	52	57	59
Mill Residue[e]	10	1.6	0.9	1.0	1.4	1.3	1.0	1.0
Worldwide from Canadian Harvest	42	73	65	64	65	64	64	63
Solid Wood – Sawnwood	9.9	16	18	18	19	19	19	19
Solid Wood – Wood Panels	0.8	4.3	5.4	5.5	5.7	5.8	6.0	6.1
Other Solid Wood Products	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Paper and Market Pulp	31	50	39	39	38	37	36	36
Mill Residue[e]	0.5	2.1	2.1	1.9	2.6	2.4	2.1	2.1

Notes:

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

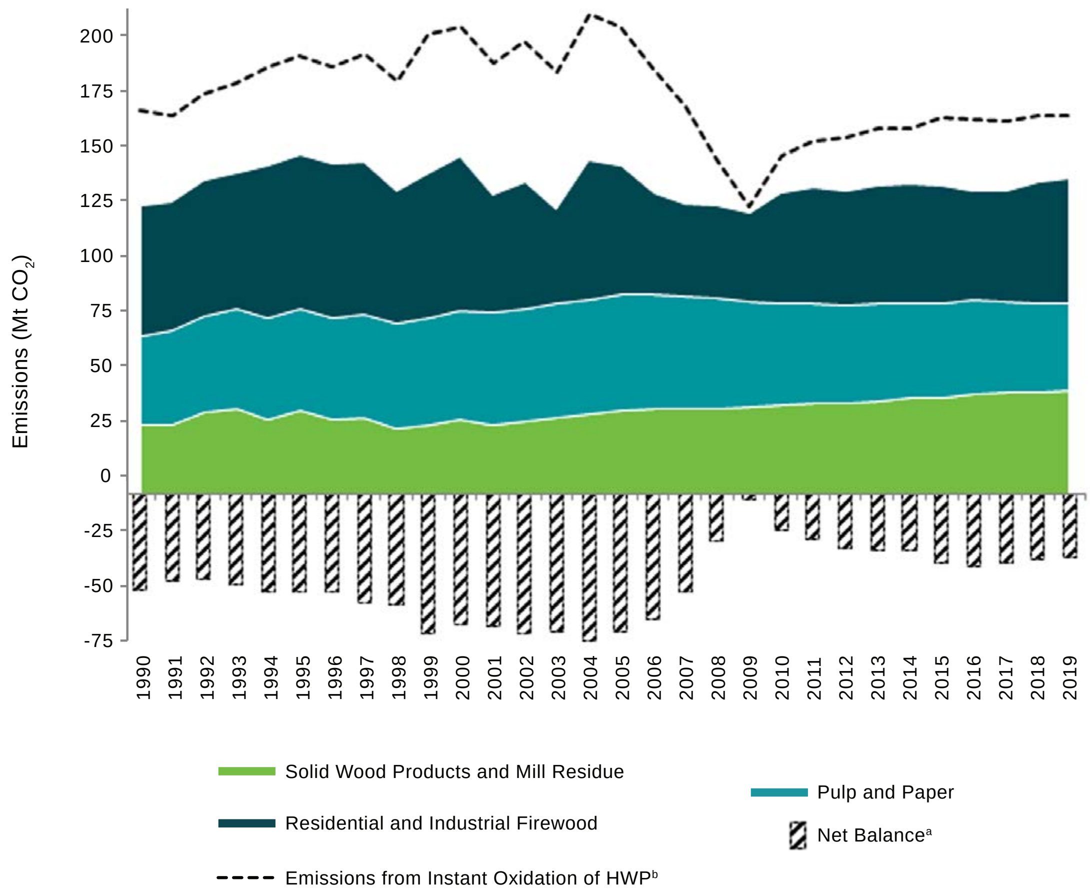
b. Carbon estimated by the CBM-CFS3 model in the form of wood biomass that results from forest harvest (including salvage logging after natural disturbances on Forest Land) and forest conversion activities in Canada and that would be reported as C losses in CRF table 4.A under Forest Land Remaining Forest Land and in tables 4.B, 4.D and 4.D under subcategories related to Forest Conversion, if using the instant oxidation approach for HWP.

c. Includes carbon collected for residential firewood from forest, agricultural woody biomass and urban trees and assumed to be burned in the year of harvest. This C would be reported as C losses in CRF tables 4.A under Forest Land Remaining Forest Land, 4.B under Cropland Remaining Cropland, and 4.E under Settlements Remaining Settlements, if using instant oxidation approach for HWP.

d. Represent the quantity of carbon in the HWP pool at the end of the reporting year. Because inputs to the model consider harvest since 1900, net stocks over the reporting period may include C harvested before 1990.

e. Assumed to be disposed of in the year of harvest.

Figure 6–5 **Emissions from the HWP Pool Using the Simple Decay Approach**



Notes:

a. The "Net Balance" is the difference between C transferred to the HWP pool and emissions from the HWP, a value that cannot be reported in the current structure of the CRF tables.

b. This data series represents the carbon transferred annually from the forest and other land-use categories into the HWP pool in units of CO_2, i.e. the emissions that would result from using an instant oxidation approach, and is presented for reference purposes only. It includes salvage logging after natural disturbances on Forest Land.

years with lower harvest rates and contained in products that were disposed of in the reporting year. By contrast, after 2007, though harvest rates are lower (notably in 2009), HWP emissions remain elevated relative to estimates based on instant oxidation due to the higher harvest rates in previous years that continue to contribute to estimated emissions in the reporting year.

6.4.3. Uncertainties and Time-Series Consistency

In the assessment of the uncertainty of the Harvested Wood Products category, model parameters were varied for Monte Carlo simulations while carrying out two additional runs using minimum and maximum HWP inputs resulting from CBM-CFS3 (ecosystem) uncertainty analyses. These are used to estimate the combined uncertainty of the two systems for all C harvested since 1990 (Table 6–8). Additional parameters were added to the Monte Carlo analysis for this submission including uncertainty distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvest since 1990) and five allocation parameters related to bioenergy that were added to the HWP model structure. Given the significant updates and improvements applied to this submission, a comprehensive uncertainty analysis using Monte Carlo simulation was performed. More details are provided in Annex 3.5.3.

Table 6–8 **Estimates of CO_2 Emissions from Harvested Wood Products, with 2.5th and 97.5th Percentiles, for Selected Years**

Inventory Year	Source of C inputs	Emissions (Mt CO_2)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Conventional Harvest – since 1990	59	41	-30	73	25
	Forest Conversion – since 1990	2.4	1.4	-43	3.3	35
	Residential Firewood Collection	16	16	-3.3	17	3.7
	Historical Harvest – before 1990	53	40	-25	66	23
2005	Conventional Harvest – since 1990	117	99	-15	131	12
	Forest Conversion – since 1990	3.0	2.2	-26	3.5	19
	Residential Firewood Collection	12	11	-3.7	12	4.4
	Historical Harvest – before 1990	15	12	-24	20	29
2019	Conventional Harvest – since 1990	112	102	-9.3	120	6.7
	Forest Conversion – since 1990	3.5	2.5	-30	3.9	10
	Residential Firewood Collection	16	15	-7.4	17	4.2
	Historical Harvest – before 1990	11	8.3	-24	14	24

6.4.4. Recalculations

There were significant recalculations in the Harvested Wood Products category driven by (1) updates made to bioenergy activity data resulting from improved residential firewood data from the 2017 Households and the Environment Survey (Statistics Canada 2017) and revisions to spatial allocation and distribution of firewood harvest to their appropriate land use, (2) correction to moisture content of industrial fuelwood, (3) updates to 1990-to-present forest harvest data according to latest National Forestry Database statistics, (4) updates to 1990–2018 commodity production and trade parameters of the HWP model based on the most recent FAO forest products statistics for Canada,[11] and (5) allocation of un-combusted C to bioenergy emissions. As a combined effect of these changes, total emissions from this category were increased by 2.7 Mt (+2.1%), 9.2 Mt (+6.6%) and 13 Mt (+10%) in 1990, 2005 and 2018, respectively.

6.4.5. Planned Improvements

Improvements are planned to enhance the uncertainty analysis of Harvested Wood Products estimates by considering the uncertainty inherent in the C inputs.

Research is ongoing to include the effects of wood and paper waste at solid waste disposal sites, the development of country-specific half-lives, the expansion of temporal coverage—which is currently limited by available data—and the development of a better regional representation of commodity production and foreign resolution (addition of more export regions). Further research is underway to improve the regional differentiation of HWP production and trade, so that provincial/territorial summaries more accurately reflect regional conditions.

11 FAOSTAT Forestry Production and Trade, available online at http://www.fao.org/faostat/en/#data/FO and FAOSTAT Forestry Trade Flows, available online at http://www.fao.org/faostat/en/#data/FT.

6.5. Cropland (CRF Category 4.B)

Cropland covers approximately 47 Mha of the Canadian territory. In 2019, the net GHG balance in the Cropland category amounted to removals of 4.2 Mt (Table 6–1). For the purpose of reporting under the UNFCCC, Cropland is divided into Cropland Remaining Cropland (net removals of 7.8 Mt in 2019) and Land (either forest or grassland) Converted to Cropland (net emissions of 3.3 Mt and 0.3 Mt, respectively, in 2019). The estimates of Land Converted to Cropland include net emissions and removals of CO_2, as well as N_2O and CH_4 emissions.

6.5.1. Cropland Remaining Cropland (CRF Category 4.B.1)

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hay fields and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of Western Canada, made up of the Semiarid Prairies, Subhumid Prairies and Boreal Plains reporting zones. Another 12% of cropland is found in the Mixedwood Plains reporting zone.

The Cropland Remaining Cropland subcategory includes CO_2 emissions/removals in mineral soils, CO_2 emissions from cultivation of organic soils and CO_2 emissions/removals resulting from changes in woody biomass from specialty crops, trees and shrubs and lands not fulfilling the definition of a forest. An enhanced Tier 2 approach is used for estimating CO_2 emissions from and removals by mineral soils triggered by changes in land management practices.

Table 6–9 **Base and Recent Year Emissions and Removals Associated with Various Land Management Changes to Cropland Remaining Cropland**

Categories	Land Management Change (LMC)	Emissions/Removals (kt CO_2)[a]							
		1990	2005	2014	2015	2016	2017	2018	2019
Total Cropland Remaining Cropland		**-1 900**	**-14 000**	**-12 000**	**-11 000**	**-10 000**	**-9 400**	**-8 600**	**-7 800**
Cultivation of histosols		**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Perennial woody crops		**-990**	**120**	**160**	**190**	**22**	**-200**	**-270**	**-300**
Total mineral soils		**-1 200**	**-15 000**	**-12 000**	**-11 000**	**-10 000**	**-9 500**	**-8 600**	**-7 800**
Change in crop mixture	Increase in perennial	-4 300	-12 000	-11 000	-11 000	-11 000	-11 000	-10 000	-10 000
	Increase in annual	6 500	7 500	11 000	12 000	12 000	13 000	13 000	14 000
Change in tillage	Conventional to reduced	- 890	-1 100	-790	-760	-720	-690	-660	-620
	Conventional to no-till	-440	-3 600	-3 700	-3 700	-3 600	-3 600	-3 500	-3 500
	Other	-0.4	-860	-1 000	-1 000	-1 000	-980	-960	-940
Change in summerfallow (SF)	Increase in SF	2 500	2 000	1 600	1 600	1 500	1 500	1 400	1 400
	Decrease in SF	-4 800	-8 500	-9 500	-9 600	-9 700	-9 700	-9 800	-9 800
Land conversion – Residual emissions[b]		170	1 700	1 800	1 800	1 800	1 700	1 700	1 700

Notes:

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. Net residual CO_2 emissions from the conversion of Forest Land and Grassland to Cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

6.5.1.1. CO_2 Emissions and Removals in Mineral Soils

Mineral soils constitute the majority of cropland areas (>99%). The amount of organic C retained in these soils is a function of crop production and the rate of decomposition of SOC. Cultivation and management practices can lead to an increase or decrease in the organic C stored in soils. This change in SOC results in a CO_2 emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to a net CO_2 removal of 1.2 Mt (Table 6–9). The soil C sink steadily increased to 16 Mt in 2006 and then gradually decreased to 7.8 Mt in 2019. The increasing trend in removals in the first 17 years partly reflects the 98% reduction in summerfallow area from 1990 to 2019 and the increase in the area under conservation tillage (from 11 Mha in 1990 to 28 Mha in 2019) (Campbell et al., 1996; Janzen et al., 1998; McConkey et al., 2003). Furthermore, the proportion of perennial crops relative to annual crops increased between 1990 and 2006, with the net change in crop mixture resulting in an emission of 2.2 Mt in 1990 and removals of 5.0 Mt in 2006.

Since 2006, however, there has been an increase in the proportion of annual crops in the crop mixture and a decline in the rate of adoption of conservation tillage. Furthermore, the soil sink from past management changes is approaching a steady state where organic C additions to the soil are balanced by losses of organic C from decomposition. As a result, since 2006 net removals have decreased by roughly 7.8 Mt, mainly driven by the decrease in the proportion of perennial crops in the crop mixture.

Methodological Issues

According to the 2006 IPCC Guidelines, changes in SOC are driven by changes in soil management practices. Where no change in management is detected, it is assumed that mineral soils are neither sequestering nor losing C.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management on SOC and selected the key management practices and management changes likely to cause changes in soil C stocks for which activity data (time series of management practices) from the *Census of Agriculture* were available. A number of management practices are known to increase SOC in cultivated cropland. They include a reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). Other land management changes (LMCs), such as changes in irrigation, manure application and fertilization, are also known to have positive impacts on SOC. Lack of activity data for all of these LMCs associated with specific crops prevented their inclusion in the inventory at this time. Estimates of CO_2 changes in mineral soils were derived from the following LMCs:

- change in the proportion of annual and perennial crops
- change in tillage practices
- change in area of summerfallow

Carbon emissions and removals were estimated by applying country-specific C emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at the scale of the Soil Landscapes of Canada (SLC) polygons (see Annex 3.5.1). The C emission/removal factors represent the rate of SOC change per year and per unit area that underwent a land management change.

The impact of land management changes on SOC varies with initial conditions. The most accurate estimate of soil C stock change would therefore be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. The inventory relies mainly on the *Census of Agriculture* for estimates of areas of LMC (i.e., changes in tillage, types of crop and fallow) which are not spatially explicit. The area of LMC was determined individually for 3404 SLC polygons having agricultural activities, each one with an agricultural area in the order of 1000 to 1 000 000 ha. This is the finest possible resolution of activity data linked to an ecological land strata. The census provides information about the area of each practice for each census year, so only the net area of change for each land management practice can be estimated. Estimates of these LMCs are as close to gross area of LMC as is feasible for regional or national analyses.

The validity of LMC estimates using census data relies on two key assumptions: additivity and reversibility of C factors. Additivity assumes that the combined effects of different LMCs or LMCs at different times would be the same as the sum of the effect of each individual LMC. Reversibility is the assumption that the C effects of an LMC in one direction (e.g., converting annual crops to perennial crops) is the opposite of the C effects of the LMC in the opposite direction (e.g., converting perennial crops to annual crops).

The various C factors associated with each particular situation (in both space and time) were derived using the CENTURY model (Version 4.0) by comparing output for scenarios “with” and “without” the management change in question. In specific instances, empirical data were used to complement the results of the CENTURY runs.

A more detailed description of methodologies for determining C factors and other key parameters can be found in Annex 3.5.4.1.

Uncertainties and Time-Series Consistency

Uncertainty was estimated analytically with a Tier 1 approach. The uncertainties associated with estimates of CO_2 emissions or removals involve estimates of uncertainties for area and C factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al., 2007).

The uncertainty associated with the area in a management practice for an ecodistrict varied inversely with the relative proportion of the total area of agricultural land in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of an assumed normal population) decreased from 10% to 1.25% of the area as the relative area of that practice increased.[12]

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were partitioned in two main sources: (1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of management practice was defined perfectly, and (2) situational uncertainty in C change due to variation in the location or timing of the management practice. Further details on estimating process and situational uncertainties can be found in Annex 3.5. Uncertainty estimates associated with emissions/removals of CO_2 from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at ±19% for the level and ±27% for the trend. These uncertainty estimates have not been updated since the 2011 annual submission. Changes in agricultural activity data from the incorporation of EO data may have modified uncertainty estimates slightly. However, a complete evaluation of uncertainty will not be carried out until significant changes are incorporated in the estimate methodology.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2019).

Quality Assurance / Quality Control and Verification

Tier 1 QC checks implemented by Agriculture and Agri-Food Canada specifically address estimate development in the Cropland Remaining Cropland subcategory. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (see section 1.3, Chapter 1), has implemented additional QC checks for estimates obtained from partners, as well as for all estimates and activity data contained in its LULUCF data warehouse and entered into the CRF Reporter. In addition, the activity data, methodologies and changes are documented and archived in both paper and electronic form.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC in response to no tillage were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year; this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. For Eastern Canada, only two empirical change factors were available,

12 T. Huffman 2007. Personal communication (Huffman T. Agriculture and Agri-Food Canada to Brian McConkey).

but they fell within the range of the modelled values (0.60–1.07 Mg C/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of C storage obtained (0.33 Mg C/ha per year) was more than twice the average rate of 0.15 ± 0.06 Mg C/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory. More details can be found in Annex 3.5.4.1.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation and the United States to conduct a quality assurance assessment of the methods. Some limitations of the current system were found with respect to activity data, which could possibly create some bias in the current C stock change estimates. In particular, the lack of a complete and consistent set of land-use data and issues with the concept and application of pseudo-rotations will be addressed in future method improvement.

Recalculations

Small recalculations occurred due to an update to an internal land-use source file that impacted annual cropland area estimates by less than 10 ha.

Changes were made in reported residual emissions resulting from Forest Land Converted to Cropland for more than 20 years, as an indirect consequence of the random selection algorithms used by the forest ecosystem model to select forest land conversion sites. Changes to site selections slightly modified the total amount of biomass removed and the amount of deadwood and litter decaying on sites attributed to forest land conversion events.

These changes resulted in small decreases in net removals by 0.02 kt in 1990 and 1.3 kt in 2005, and an increase in net removals by 2.5 kt in 2018.

Planned Improvements

Improvements to the CENTURY model and the use of alternative models, such as Campbell, ICBM, IPCC Tier 2 steady state and RothC, are being explored to improve the simulation of Canadian agricultural conditions.

6.5.1.2. CO_2 Emissions from Cultivation of Organic Soils

Category Description

In Canada, the cultivation of organic soils is defined as the conversion of organic soils to annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include peaty-phase gleysols, fibrisols over 60 cm thick, and mesisols and humisols over 40 cm thick (Soil Classification Working Group, 1998).

Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 5 Mg C/ha per year (IPCC, 2006).

Areas of cultivated histosols are not provided by the *Census of Agriculture*; area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al., 2004). The total area of cultivated organic soils in Canada (constant for the period 1990–2019) was estimated to be 16 kha, or 0.03% of the cropland area. Close to 90% of the area of cultivated histosols is located in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimates for the cultivated histosols and the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50% (Hutchinson et al., 2007). The 95% confidence limits of the default emission factor are ±90% (IPCC, 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 Mt for the level uncertainty and 0 ± 0.13 Mt for the trend uncertainty (McConkey et al., 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2018).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were no recalculations for this source category.

Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

6.5.1.3. CO_2 Emissions and Removals in Woody Biomass

Category Description

Emission and removal estimates of woody biomass include trees and shrubs that occur on agricultural lands as well as perennial woody crops such as vineyards, fruit orchards and Christmas trees. A portion of tree biomass lost in croplands has been transferred to the HWP pool to meet residential bioenergy requirements. Accordingly, this C transfer is not reported as biomass loss under Cropland Remaining Cropland to avoid a double counting of emissions with the emissions from combustion as firewood, which are reported under the Harvested Wood Products category. See more details in section 6.4 and Annex 3.5.4.1.

In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered Cropland until there is evidence of a new land use. However, there is little information on the dynamics of cropland abandonment or re-cultivation. Owing to these data limitations, only vineyards, fruit orchards, Christmas trees, and trees and shrubs are considered for changes in woody biomass, and no abandoned or re-cultivated croplands are included in this category.

Net CO_2 fluxes from woody biomass on agricultural lands amounted to net removals of 1.0 Mt in 1990 and 0.3 Mt in 2019 and net emissions of 0.1 Mt in 2005. Emissions associated with woody biomass transferred to the HWP pool and used for residential bioenergy accounted for 0.8 Mt, 0.5 Mt and 0.8 Mt of the total firewood emissions reported under the Harvested Wood Products category in 1990, 2005 and 2019, respectively. The net contribution of agricultural woody biomass to the LULUCF sector was on average an annual sink of 0.2 Mt throughout the first decade of the time series and an annual source of 0.6 Mt throughout the second and third decades of the time series.

Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. For all three crops, it is assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass. More information on assumptions and parameters can be found in Annex 3.5.4.1.

The category of trees and shrubs in Cropland include perennial woody cover types in farmyards, shelterbelts and hedgerows. The method tracks woody volume lost as a result of clearing and gained as a result of planting and annual growth through the use of an EO-based monitoring approach and ecozone-specific growth parameters. More information on assumptions and parameters can be found in Annex 3.5.4.1.

Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all C in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for C loss equals the uncertainty associated with mass of woody biomass C. The default uncertainty of ±75% (i.e., 95% confidence limits) for woody biomass on Cropland from the 2006 IPCC Guidelines was used for vineyards, fruit orchards and Christmas trees.

If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to C change uncertainty. For an area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual C change was also assumed to be the default uncertainty of ±75% (i.e., 95% confidence limits) (IPCC, 2006).

The overall mean and uncertainties associated with emissions or removals of CO_2 from vineyards, fruit orchards and Christmas trees were estimated to be 2 ± 0.2 kt for the level uncertainty and -29 ± 42 kt for the trend uncertainty (McConkey et al., 2007). The overall mean and uncertainty associated with removals of CO_2 from trees and shrubs is described in Huffman at al. (2015b) and is estimated to be -440 ± 180 kt for the annual estimate. Since removals resulting from the growth of trees and shrubs represent the biggest contribution to the overall removal/emission estimates, these two land cover types drive the uncertainty for the woody biomass subcategory, estimated to be an average of 41% for the level uncertainty. More information on the method and factors considered for the uncertainty of C stock changes in trees and shrubs can be found in Huffman et al. (2015b).

The same methodology was used for the entire time series of emission estimates (1990–2019).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were recalculations for this category due to (1) the addition of a new activity data measurement point (2010), (2) the correction of minor area discrepancies, and (3) the transfer of tree biomass to the HWP pool as a source of residential firewood that caused an annual decrease in C losses from Cropland Remaining Cropland and an increase in emissions in the Harvested Wood Products category (see section 6.4). As a combined result of these changes, net removals from perennial woody biomass reported under Cropland Remaining Cropland increased by 0.6 Mt (140%) in 1990 and decreased by 0.2 Mt (-48%) in 2018. The net removals previously reported in 2005 decreased by 0.6 Mt (-127%) which resulted in a change in this category from a net sink to a net source.

Planned Improvements

Work has begun to explore new methodologies to improve the classification and automated quantification of changes in areas under trees and shrubs in agricultural regions of Canada.

6.5.2. Land Converted to Cropland (CRF Category 4.B.2)

This subcategory includes the conversion of Forest Land and Grassland to Cropland. Emissions from the conversion of Forest Land to Cropland account for more than 90% of the total annual emissions in this category, which decreased from 9.5 Mt in 1990 to 3.6 Mt in 2019. Emissions from the conversion of Grassland are relatively small.

6.5.2.1. Forest Land Converted to Cropland (CRF Category 4.B.2.1)

Clearing forest for use as agricultural land is still an ongoing practice in Canada, accounting for 46% of forest area conversion in 2019). The cumulative area reported under the Forest Land Converted to Cropland subcategory in CRF Table 4.B was 1300 kha over the 20 years prior to 1990 and 370 kha over the 20 years prior to 2019. Methods to determine the area converted annually are the same as those used for all forest conversion to other land-use categories and are outlined in section 6.9. In 2019, immediate emissions from Forest Land Converted to Cropland accounted for 1.3 Mt, while residual emissions from events that occurred in the last 20 years accounted for 2.0 Mt.

Methodological Issues – Dead Organic Matter and Biomass Pools

Approximately 90% of emissions originate from the biomass and dead organic matter pools during and after conversion, with the remainder being attributed to the soil pool. Their estimation is performed in the same modelling environment as that used for Forest Land Remaining Forest Land. A general description of this modelling environment is provided in section 6.3.1.2. More information is provided in Annex 3.5.4.3.

Methodological Issues – Soils

Emissions from soils in this category include the net C stock change due to the actual conversion, a very small net CO_2 source from change in management practices in the 20 years following conversion, and the N_2O emissions from the decay of soil organic matter. The soil emissions from Forest Land Converted to Cropland were calculated by multiplying the total area of conversion by the empirically derived emission factor along with modelling-based SOC dynamics (see Annex 3.5). Patterns of change in SOC after the conversion of forest land to cropland clearly differ between Eastern and Western Canada.

Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many observations of forest SOC comparisons with adjacent agricultural land in Eastern Canada—either in the scientific literature or the Canadian Soil Information System—show a mean C loss of 20% at depths to approximately 20–40 cm (see Annex 3.5). Average N change was -5.2%, equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha. Therefore, it was assumed that N loss was a constant 2% of C loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from conversion of forest land to cropland in Eastern Canada. More details of methodologies for determining the maximal C loss and its rate constant associated with the conversion of forest land can be found in Annex 3.5.4.3.

Following an IPCC Tier 2 method, as noted for direct N_2O emissions from agricultural soils (see Agriculture sector, Chapter 5), emissions of N_2O from conversion of forest land to cropland were estimated by multiplying the amount of C loss by the fraction of N loss per unit of C and by an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.4).

Western Canada

Much of the current agricultural land in Western Canada (Prairies and British Columbia) was grassland in the native condition. Hence, forest land that has been converted to cropland consists primarily of forests on the fringe of former grassland areas.

The Canadian Soil Information System represents the best available data source for SOC under forest and agriculture. On average, these data suggest that there is no loss of SOC from forest conversion and that, in the long term, the balance between C input and SOC mineralization under agriculture remains similar to what it was under forest. It is important to recognize that along the northern fringe of western Canadian agriculture, where most forest conversion is occurring, the land is marginal for arable agriculture; pasture and forage crops are the dominant management practices. As a result, for Western Canada, no loss of SOC over the long term was assumed from forest land converted to cropland managed exclusively for seeded pastures and hayland.

The C loss from forest conversion in Western Canada results from the loss of above- and below-ground tree biomass and from loss or decay of other above- and below-ground coarse woody DOM that existed in the forest at the time of forest conversion. The average N change in Western Canada for sites at least 50 years from the breaking of the land for cultivation was +52% (see Annex 3.5), reflecting substantial added N in agricultural systems compared with forest management practices. However, recognizing the uncertainty associated with actual C-N dynamics for forest conversion, conversion of forest land to cropland in Western Canada was assumed not to be a source of N_2O.

Uncertainties and Time-Series Consistency

Greenhouse gas fluxes from Forest Land Converted to Cropland result from the combination of (1) logging and burning—immediate emissions from biomass and dead organic matter, (2) organic matter decay and subsequent CO_2 emissions in the DOM pool, and (3) net C losses from SOC. Immediate CO_2 emissions always refer to area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO_2 emissions are produced only by burning and occur during the conversion process.

Immediate and residual CO_2 emissions from the biomass and DOM pools represent the largest components of this category and contribute the most to the category uncertainty (Table 6–10). In all cases, uncertainty values are presented as the 95% confidence interval about the median (biomass and DOM pools) or mean (soil pool) estimate values.

Using the estimation approach, uncertainty estimates were derived independently for the biomass and dead organic matter pools and for soil organic matter. The uncertainty in activity data described in section 6.9.2 was incorporated in all analyses.

The fate of biomass and DOM upon forest conversion and the ensuing emissions are modelled using the same framework as that used for Forest Land. The corresponding uncertainty estimates were therefore also developed within this framework and with the same Monte Carlo runs that generated uncertainty estimates in the Forest Land category. A description of the general approach is provided in section 6.3.1.3. More information can be found in Annex 3.5.4.3.

The uncertainty in the net CO_2 flux from the soil pool was estimated analytically (McConkey et al., 2007). More information on the general approach used to conduct this analysis is provided in Annex 3.5.4.3.

Table 6–10 **Uncertainty Associated with CO_2 Emission Components and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2019 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	1 105	±535
Residual CO_2 emissions from the DOM[a] pool	1 750	±406
Residual CO_2 emissions from the soil pool	253	±157
CH_4 emissions	114	±53
N_2O emissions	66	±17

Note:

a. DOM = dead organic matter

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. Quality checks were also performed externally by Agriculture and Agri-Food Canada, which derived the estimates of SOC change. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were changes in the area reported under the Forest Land Converted to Cropland subcategory due to the implementation of a new time period of deforestation mapping for 2013–2018 that increased the total area of forest cleared for agriculture by 61 kha. In addition, changes implemented in the forest ecosystem model indirectly impact the amounts of biomass removed from deforested lands. These changes resulted in adjustments of estimates under this subcategory mainly in recent years, increasing the emissions reported in 2018 by 1.1 Mt (+47%).

Planned Improvements

Planned improvements described under section 6.9 will also affect this category.

6.5.2.2. Grassland Converted to Cropland (CRF Category 4.B.2.2)

Conversion of native grassland to Cropland occurs in the Canadian Prairies and generally results in losses of SOC and soil organic N and emissions of CO_2 and N_2O to the atmosphere. According to the findings of a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada, carbon losses from the above-ground or below-ground biomass or DOM upon conversion are insignificant. The authors reported that the average above-ground biomass was 1100 kg ha^{-1} in the Brown Chernozem, and 1700 kg ha^{-1} in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its respective yield under crop production (Liang et al., 2005). Total emissions in 2019 from soils amounted to 300 kt, up from 260 kt in 1990, including C losses and N_2O emissions from the conversion.

Methodological Issues

A number of studies on changes of SOC and soil organic N in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies. The average loss of SOC was 22%, and the corresponding average change in soil organic N was 0.06 kg N lost/kg C (see Annex 3.5.4.2).

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal C loss and its rate constant associated with the breaking of grassland can be found in Annex 3.5.4.2.

Similar to N_2O emissions in Forest Land Converted to Cropland, emissions of N_2O in Grassland Converted to Cropland were estimated by a Tier 2 methodology, multiplying the amount of C loss by the fraction of N loss per unit of C by a base emission factor (EF_{BASE}). EF_{BASE} is determined for each ecodistrict based on climate and topographic characteristics (see Annex 3.4.3).

Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland occurs, but within the definitional framework for managed lands, the conversion to grassland from cropland cannot occur (see section 6.2). Therefore, the uncertainty in absolute value of the area of this conversion cannot be larger than the uncertainty about the area of cropland or grassland. Hence, the uncertainty of the area of conversion was considered to be equivalent to the lower of the uncertainties of the area of either cropland or grassland in each ecodistrict. The uncertainty of SOC change was estimated as in Forest Land Converted to Cropland. The overall mean and uncertainty associated with emissions due to SOC losses from Grassland Converted to Cropland were estimated to be 219 ± 104 kt for the level uncertainty and -44 ± 21 kt for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2018).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

Small recalculations occurred due to an update to an internal land-use source file that impacted the reconciliation of changes in cropland management with changes in land use for the period 1992–2013. Revisions to estimates over the period 2014 to 2018 were also due to updates to grassland activity data over these years. These updates were attributable to the impact of an additional year on the generation of grassland activity data using an 11-year weighted moving average window. All these changes mainly impacted estimates for recent years reported under the Grassland Converted to Cropland subcategory, increasing net emissions in 2018 by 22 kt (+8.3%).

Planned Improvements

Canada plans to validate the modelled soil C change factors with measured and published soil C change factors from grassland conversion as these become available.

6.6. Grassland (CRF Category 4.C)

Grassland used for agriculture is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity has been the grazing of domestic livestock (i.e., the land has never been cultivated). It occurs only in geographical areas where the grassland would not naturally grow into forest if abandoned, i.e., the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semiarid Prairies (6.2 Mha), Montane Cordillera (87 ha) and Pacific Maritime (5 ha). As with Cropland, the change in management triggers a change in C stocks (IPCC, 2006). Very little information is available on management practices on Canadian agricultural grassland, and it is unknown whether grazed land is improving or degrading. Therefore, Canada reports this Grassland Remaining Grassland subcategory using the IPCC Tier 1 method based on no change in management practices since 1990. Within the current definitional framework as explained in section 6.2, the conversion of land to grassland is reported as not occurring under the subcategory Land Converted to Grassland (Table 6–4).

6.6.1. Grassland Remaining Grassland (CRF Category 4.C.1)

6.6.1.1. Category Description

In Canada, fires sometimes occur on managed grasslands in the form of prescribed burns to control invasive plants and stimulate the growth of native species or caused by lightning, accidental ignition, or military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O (IPCC, 2006).

6.6.1.2. Methodological Issues

Emissions of CH_4 and N_2O from burning of managed agricultural grassland were estimated using the IPCC Tier 1 method by taking into consideration the area of burn, fuel load and combustion efficiency for each burning

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event. CH_4 emission factors (2.7 g CH_4 kg^{-1} dry matter burned and 0.07 g N_2O kg^{-1} dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC, 2006).

Activity data from 1990 to 2012 on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). The activity data on burning of managed agricultural grassland from 2013 to 2015 were updated in the 2018 submission.

6.6.1.3. Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimate, average fuel load per hectare and combustion efficiency, along with emission factors. The 95% confidence limits associated with the amount of burned materials based on expert judgement are assessed to be ±50%. The 95% confidence limits of the default emission factors are ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The overall uncertainties associated with this source of emissions using error propagation were estimated to be ±64% for CH_4 and ±69% for N_2O, respectively.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2018).

6.6.1.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in both paper and electronic form.

6.6.1.5. Recalculations

There were no recalculations in emission estimates for this source category.

6.6.1.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

6.7. Wetlands (CRF Category 4.D)

In Canada, a wetland is defined as land that is saturated with water long enough to promote anaerobic processes, as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to a wet environment. In other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (ECCC, 2016). The Canadian Wetland Classification System groups wetlands into five broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group, 1997).

However, for the purpose of this report and in line with the land categories as defined in IPCC (2006), the Wetlands category is restricted to those wetlands that are not already in the Forest Land, Cropland or Grassland categories. There is no corresponding area estimate for these wetlands in Canada.

In accordance with IPCC guidance (IPCC, 2006), two types of managed wetlands are considered where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: (1) peatlands drained for peat extraction and (2) flooded land (namely, the creation of hydroelectric reservoirs). Owing to their differences in nature, GHG dynamics and the general approaches for estimating emissions and removals, these two types of managed wetlands are considered separately.

6.7.1. Peat Extraction (CRF Categories 4.D.1.1 and 4.D.2.1)

6.7.1.1. Source Category Description

Of the estimated 12 Mha of peatlands in Canada (NRCan, 2011), approximately 35 kha have been drained for peat extraction. Some 18 kha are currently being actively managed. The other 17 kha consist of peatlands that are no longer under production. In the Canadian context, generally only bog peatlands with a peat thickness of 2 m or greater and an area of 50 ha or greater are of commercial value for peat extraction (Keys, 1992). Peat production is concentrated in the provinces of New Brunswick, Quebec, Alberta and Manitoba. Canada produces peat for non-energy applications such as horticulture.

Emissions from peat extraction increased from 0.9 Mt in 1990 to 1.6 Mt in 2019 (Figure 6–6). The largest sources of emissions are from the decay of extracted peat and peatland drainage. Trends in extracted peat are driven by both an expansion in the active peat production area from 13 kha in 1990 to 18 kha in 2006 and interannual variations in weather conditions, which impact peat drying and thus harvesting. Emissions from peatland drainage continue to grow as more peatland areas are drained and subsequently de-commissioned, with an increasing proportion of de-commissioned sites undergoing rehabilitation, rewetting and restoration.

6.7.1.2. Methodological Issues

Estimates were developed using a Tier 2 methodology, in accordance with guidance from a combination of the 2006 IPCC Guidelines (IPCC, 2006) and 2013 IPCC Wetlands Supplement (IPCC, 2014). The approach is based on domestic science and land management practices specific to peat extraction in Canada. Emission estimates for drained and rewetted sites include on-site CO_2, CH_4 and N_2O emissions and off-site CO_2 emissions from waterborne C losses and from the decay of extracted peat. Domestic emission factors were derived from flux measurements reported by multiple research studies (refer to Annex 3.5). An EO mapping approach was used to determine the extent of peatland areas converted for peat extraction for 1990, 2007 and 2013 time periods and to identify the proportion of land category types converted (Forest Land and Other Land). Converted areas were allocated into four land management subcategories based on image interpretation and industry information: active extraction, abandoned, rehabilitated and restored areas. National peat production statistics were used to estimate the annual amount of extracted peat (NRCan, 2018a). Emissions from peat extraction are reported under Land Converted to Wetlands for the first year after conversion and under Wetlands Remaining Wetlands thereafter. More information on estimation methodology can be found in Annex 3.5.

6.7.1.3. Uncertainty and Time-Series Consistency

There was no formal uncertainty assessment for this category. The most important sources of uncertainty are in the converted areas estimated from mapping, emission factors for the various categories of de-commissioned sites (e.g., rehabilitated and restored) and variations in the moisture content of extracted peat.

6.7.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well. Industry and academic experts associated with the Canadian Sphagnum Peat Moss Association and Peatland Ecology Research Group provided QC, validation of mapping estimates and a review of domestically derived emission factors.

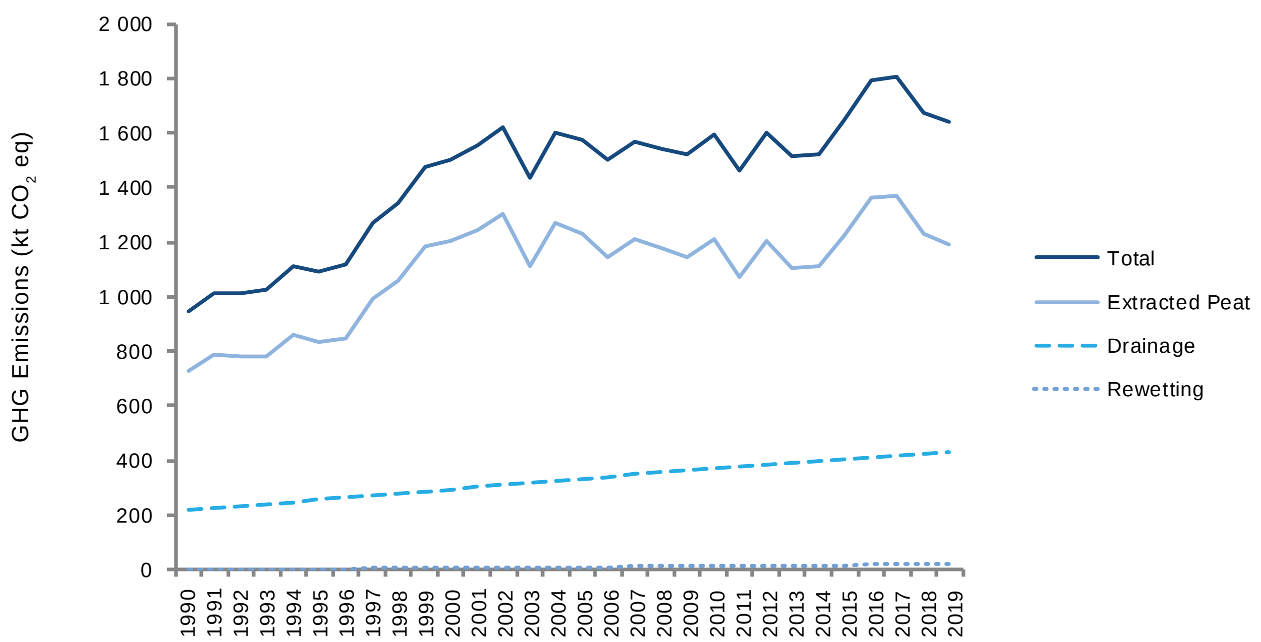
6.7.1.5. Recalculations

Recalculations for this category were mainly due to updated peat production statistics in 2018 and resulted in an increase in emissions of 58 kt for that year.

6.7.1.6. Planned Improvements

Refinements in the approach for estimating emissions and removals from non de-commissioned peat extraction sites will depend on the availability of monitoring data indicating the state of naturally regenerating sites and the success rate of rehabilitation, rewetting and restoration activities. Advances in domestic science combined with increased monitoring of sites post-extraction will inform further improvements. An uncertainty assessment is planned for future submissions.

Figure 6–6 **Emissions from Peatlands Converted for Peat Extraction**



6.7.2. Flooded Lands (CRF Categories 4.D.1.2 and 4.D.2.2)

6.7.2.1. Source Category Description

This category includes, in theory, all lands that have been flooded regardless of purpose. Owing to methodological limitations, only large hydroelectric reservoirs created by land flooding were included. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g., Manitoba's Lake Winnipeg, the Great Lakes).

Since 1970, land conversion to flooded lands occurred mainly in reporting zones 4, 5, 8, 10 and 14 (i.e., Taiga Shield East, Boreal Shield East, Hudson Plains, Boreal Plains and Montane Cordillera). The total land area flooded for 10 years or less fluctuated throughout the time series, from 960 kha in 1993 to 37 kha in 2005 as new lands were flooded. In 2019, 50% of the 39 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests). Total emissions from reservoirs declined from 4.4 Mt in 1990 to 1.0 Mt in 2019.

6.7.2.2. Methodological Issues

Two concurrent estimation methodologies were used to estimate GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass removal prior to flooding, the corresponding C stock changes for all non-flooded C pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to section 6.9 and Annex 3.5). Emissions from the burning and decay of all non-flooded dead organic matter are reported under Land Converted to Wetlands for the first 10 years post-clearing and in Wetlands Remaining Wetlands beyond this period. The construction of large reservoirs in northern Quebec (Toulnustuc, Eastmain-1, Peribonka), whose impoundments were completed in 2005, 2006 and 2008, respectively, resulted in this type of forest clearing prior to flooding. Note that emissions from forest clearing in the general area surrounding future reservoirs (e.g., for infrastructure development) are reported under Forest Land Converted to Settlements.

The second methodology is applied to estimate CO_2 emissions from the surface of reservoirs whose flooding has been completed. The default approach to estimate emissions from flooding assumes that all biomass C is emitted immediately (IPCC, 2006). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO_2 fluxes above reservoir surfaces from multiple research studies (refer to Annex 3.5), consistent with the descriptions of IPCC Tier 2 methodology (IPCC, 2006) and following the guidance in Appendix 2 of the 2006 IPCC Guidelines (IPCC, 2006). Annex 3.5 of this National Inventory Report contains more detail on this estimation methodology. The assessment includes CO_2 emissions only. Emissions from the surface of flooded lands are reported for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon (DOC) lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO_2 emissions are calculated for hydroelectric reservoirs where flooding had been completed between 1981 and 2019.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the subcategories Forest Land Converted to Wetlands and Other Land Converted to Wetlands.

It is important to note that fluctuations in the area of lands converted to flooded land (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but rather reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (more than 10 years before the inventory year), whose areas are transferred out of the inventory. The reporting system does not encompass all reservoir areas in Canada.

6.7.2.3. Uncertainties and Time-Series Consistency

For Forest Land Converted to Wetlands, refer to the corresponding subheading in section 6.9, Forest Conversion. Annex 3.5 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in LULUCF estimation methodologies, it is not possible to fully monitor the fate of DOC and ensure that it is accounted for under the appropriate land category. The possibility of double counting in the Wetlands category is, however, limited to watersheds containing managed lands, which would exclude several large reservoirs in Taiga Shield East and Boreal Shield East reporting zones. Much of the DOC in these zones originates from unmanaged lands and is not subject to reporting.

6.7.2.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well. For Forest Land Converted to Wetlands, also refer to the corresponding subheading in section 6.9, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC, 2006), which assumes that all biomass C on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (immediate decay of all submerged biomass) that clearly is not verified.

6.7.2.5. Recalculations

Very small recalculations occurred in this source category (-1.7 kt in 2018) due to the indirect impact on the estimate of quantities of C stocks in lands deforested for hydro-reservoirs after revisions to the CBM-CFS3 (see section 6.3.1.5 for more details).

6.7.2.6. Planned Improvements

Further refining estimates of CO_2 emissions from the surface of reservoirs will partly depend on the ability to quantify lateral transfers of dissolved C from watersheds to reservoir systems. The monitoring of DOC as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities and will require long-term investments in research. Efforts to ensure that activity data are updated and validated will continue on an ongoing basis.

6.8. Settlements (CRF Category 4.E)

The Settlements category is very diverse and includes: all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial and industrial lands in urban and rural settings; and land used for resource extraction other than forestry (e.g., oil and gas, mining).

For the purpose of this inventory, the Settlements category is divided into Settlements Remaining Settlements (urban trees) and Land Converted to Settlements. Two types of land conversion to settlements were estimated: conversion from forested lands reported under Forest Land Converted to Settlements and conversion from non-forested lands in the Canadian North reported under Grassland Converted to Settlements. In 2019, 0.58 Mha of Land Converted to Settlements accounted for emissions of 6.6 Mt.

6.8.1. Settlements Remaining Settlements (CRF Category 4.E.1)

6.8.1.1. Sink Category Description

This category includes estimates of C sequestration by urban trees in Canada. Estimates of CO_2 removals from tree growth on other Settlement subcategories outside of urban areas are not included. Total annual removals from urban trees were relatively stable throughout the time series at around 4.3 Mt. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals in 2019 were in the Mixedwood Plains (1.6 Mt) and Pacific Maritime (1.5 Mt) reporting zones, which together accounted for 70% of total removals.

Emissions attributed to urban tree biomass transferred to the HWP pool and used for residential bioenergy accounted for 0.3 Mt per year of the total firewood emissions reported under the Harvested Wood Products category.

6.8.1.2. Methodological Issues

The CO_2 removals from urban trees were estimated using a Tier 2A crown cover methodology from the 2006 IPCC Guidelines (IPCC, 2006). Urban tree crown (UTC) cover estimates for 1990 and 2012 were developed for a significant portion of the total urban area using a point-based sampling approach. Sample points were interpreted manually and classed into broad categories of tree crown or non-crown, based on digital air photos or high-resolution satellite imagery. The total crown cover area was then estimated using UTC and total urban area estimates for each time period. The estimate of total crown cover area was then multiplied by a crown cover area growth rate (CRW) specific to its reconciliation unit (RU) to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The CRW values for 18 RUs (see Table A3.5-11) are derived as described in Steenberg et al. (2021). Growth and sequestration rates are applied to the 18 RUs and, as a result, estimates of urban tree crown cover area and the sequestration rate are the main driver of overall removal estimates. A more detailed description of this estimation methodology can be found in Annex 3.5.7.1.

6.8.1.3. Uncertainty and Time-Series Consistency

The uncertainty of the UTC estimates is assessed on the basis of the standard error associated with the sampling approach (0.2% for the national UTC estimate). Standard errors for the UTC estimates were low given the very high number of sampling points used. The uncertainty associated with the total urban area is estimated at 15% in 1990 and 10% in 2012. The uncertainty value for the national scale gross C sequestration (27%) was estimated using a Monte Carlo analysis associated with each RU for the urban tree field data collected in Canada. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 39% for 1990 and 2012. Annex 3.5.7.1 provides more information.

The same methodology and coefficients are used for the entire time series of emission estimates (1990–2019).

6.8.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well.

Estimates of regional UTC values used were compared with published UTC values for Canadian cities that were estimated from point-based sampling. In most cases, the UTC estimates correspond closely with an overall coefficient of determination (R^2) of 0.90 from linear regression analysis. In addition, at a national scale, UTC estimates were compared to those derived using a potential natural vegetation approach (IPCC, 2006) and, when weighted on the basis of urban area, were within 2%.

6.8.1.5. Recalculations

There were major recalculations in this category due to the updates made to residential bioenergy activity data, which include transfer of biomass resulting from harvest activities in urban forests to the HWP pool to be combusted as residential firewood. This change caused an annual decrease in C losses from Settlement Remaining Settlement and an increase in emissions reported in the Harvested Wood Products category (see section 6.4). As a result, there was an annual increase of net removals reported under Settlements Remaining Settlement of 0.3 Mt (around 7.5%), while the total contribution of the category to LULUCF considering the emissions from HWP remained virtually unchanged.

6.8.1.6. Planned Improvements

Continued work will focus on updating activity data estimates and the coefficients used to estimate gross and net removals. Updates are planned for 2005 and 2015 activity data that involve sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas around these years.

6

6.8.2. Land Converted to Settlements (CRF Category 4.E.2)

In 2019, emissions from Land Converted to Settlements amounted to 6.6 Mt. While there are potentially several land categories converted to Settlements, including Forest Land, there are currently insufficient data to quantify areas or associated emissions for all types of land-use change. Significant efforts were invested in quantifying the areas converted from forest to settlements, as this has been the leading forest conversion type since 2000. On average, during the 1990–2019 period, 26 kha of forest land were converted annually to settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime, Mixedwood Plains and Montane Cordillera reporting zones. Forest land conversion accounts for nearly 100% of emissions reported under this category. A consistent methodology was developed for all forest conversion and is outlined in section 6.9.

The remainder of this section covers non-forest land conversion to settlements, which includes land-use changes in the Canadian North reported under Grassland Converted to Settlements as well as land conversion occurring in the agricultural regions of Canada reported under Cropland Converted to Settlements.

6.8.2.1. Cropland Converted to Settlements (CRF Category 4.E.2.2)

6.8.2.6.1. Source Category Description

Urban and industrial expansion for resource extraction has been the main driver of conversion of cropland to settlements in Canada. On average, during the 1990–2000 and 2000–2010 periods, 18 kha and 11 kha of Cropland were converted annually to Settlements, predominantly in the Mixedwood Plains, Subhumid Prairies and Atlantic Maritime reporting zones. Emissions are not estimated at this point, but are part of the improvement plans for this category.

6.8.2.6.2. Methodological Issues

Areas of cropland converted to settlements were estimated from land-use maps from 1990, 2000 and 2010 by Huffman et al. (2015a) using the methods described in Annex 3.5.7.2. Annual conversion rates were estimated by calculating total areas of land converted between of these three years and dividing them by the time range, assuming a constant conversion rate from year to year. Annual conversion rates were extrapolated using a constant conversion rate after 2010.

6.8.2.6.3. Uncertainties and Time-Series Consistency

The uncertainty in land-use change areas was quantified using 457 points over the five main census metropolitan areas (i.e., Toronto, Hamilton, Oshawa, Montreal and Edmonton), which encompass over 45% of the total area changed. The overall accuracy in detecting areas of true change was above 80% and concurs with the values found by Huffman et al. (2015a) on the accuracy of each individual land-use map.

6.8.2.6.4. Quality Assurance / Quality Control and Verification

Polygons from the 2011 census were used to define the boundary of each census metropolitan area, and Landsat imagery from the Global Land Survey products from ArcGIS Online was obtained for each area for 1990, 2000 and 2010.[13] Over 200 points were used to verify land

13 https://www.arcgis.com/home/item.html?id=3db133ce90d548948fef4e9ff244ef8b

cover/land-use change for each time period, using visual interpretation. The points were defined using stratified random sampling, 50% on areas of change from Cropland to Settlements and 50% on areas of no change, separated by a minimum distance of 1 km, to avoid statistical bias.

6.8.2.6.5. Recalculations

There were no recalculations for this source category.

6.8.2.6.6. Planned Improvements

Future efforts to develop estimates for this category will focus on estimating emissions associated with the areas of change by determining above-ground biomass during pre-conversion as well as soil C loss.

6.8.2.2. Grassland Converted to Settlements (CRF Category 4.E.2.3)

6.8.2.6.1. Source Category Description

Resource development is the dominant driver of land-use change in Canada's Arctic and sub-Arctic regions. In 2019, the conversion of Grassland to Settlements in the Canadian North accounted for emissions of 19 kt, down from 48 kt in 1990. The major source of emissions in this category over the time series is associated with conversion of Grassland to Settlements in the Taiga Shield East, Taiga Plains and Boreal Cordillera (reporting zones 4, 13 and 16).

6.8.2.6.2. Methodological Issues

An accurate estimation of this direct human impact in Northern Canada requires that activities be geographically located and that the vegetation present prior to conversion is known—a significant challenge, considering that the area of interest extends over 560 Mha, intersecting with 11 reporting zones (1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18). Land-use change areas were estimated using mapping based on image interpretation for the years 1990, 2000 and 2010, as described in Annex 3.5.7.2.

Biomass factors were based on field sampling and cross-checked with values in the literature for the Canadian North (Annex 3.5.7.2).

Emissions include only C stock changes in pre-conversion above-ground biomass. In spite of field campaigns and comparison with existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

6.8.2.6.3. Uncertainties and Time-Series Consistency

An error propagation approach described in Annex 3.5 was used to estimate uncertainty for this category. The uncertainty estimate for this category varies between 78% and 87% for the different reporting zones due to the difficulty in the collection of ground data to estimate above-ground biomass and the variability of vegetation and climate conditions over this vast area.

6.8.2.6.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well.

6.8.2.6.5. Recalculations

There were no recalculations for this source category.

6.8.2.6.6. Planned Improvements

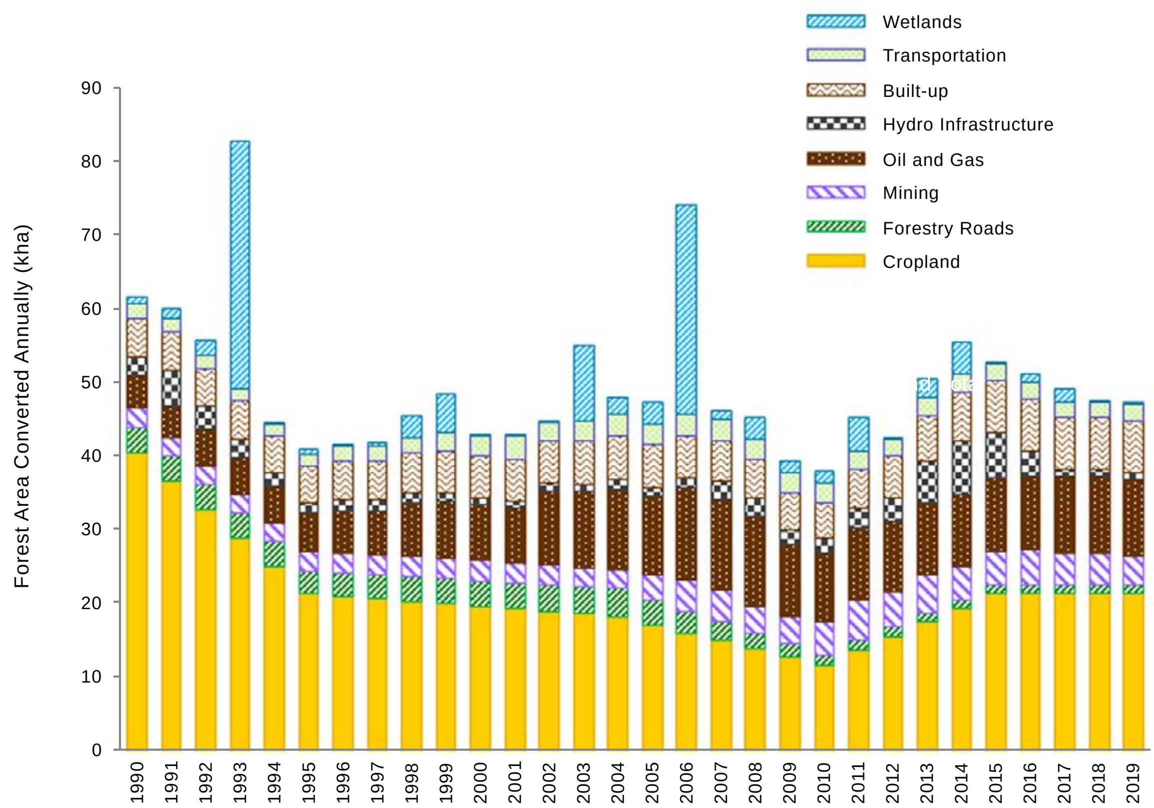
Future efforts to improve estimates for this category will focus on gathering data and compiling domestic science to estimate emissions from the soil pool as well as improving estimates of the pre-conversion above-ground biomass by adjusting the biomass factors used for each reporting zone with image-based vegetation indices and more ground data.

6.9. Forest Conversion

Forest conversion is not a reporting category, since it overlaps with the Cropland Remaining Cropland, Land Converted to Cropland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. This section will briefly discuss methodological issues specific to this type of land-use change and outline the general approach taken to estimate its extent, location and impact. A consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2019, conversion of forest land to cropland, wetlands and settlements resulted in total immediate and residual emissions of 13 Mt, down from 18 Mt in 1990. This decline includes a 4.7-Mt decrease in immediate and residual emissions from forest conversion to cropland and a 1.4-Mt decrease in emissions from forest conversion to wetlands (reservoirs). There was also an increase of 0.1 Mt in immediate and residual emissions from forest conversion to settlements. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs and 1 year for peat extraction) that are reported under the "land remaining" categories, such as Cropland Remaining Cropland or Wetlands Remaining Wetlands. Additional emissions associated with this source include those that result from the use and disposal of HWP manufactured from wood coming from forest conversion activities since 1990, which are included in the estimates of CO_2 reported in CRF Table 4.G and which amounted to 3.5 Mt in 2019, up from 2.4 Mt in 1990 (see section 6.4 for more details).

Figure 6–7 **Annual Forest Conversion Areas per End Land Use**



Care should be taken to distinguish annual forest conversion rates (64 kha in 1990 and 49 kha in 2019) from the total area of forest land converted to other land uses as reported in the CRF tables for each inventory year. The values in the CRF encompass all forest land conversion for 20 years, including the current inventory year (10 years for reservoirs and 1 year for peat extraction), and are therefore significantly higher than the annual rates of forest conversion to other land use.

It is also important to note that immediate emissions from forest conversion, which occur at the time of the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year. In 2019, immediate emissions (2.5 Mt) represented only 20% of the total reported land emissions due to forest conversion events; the balance is accounted for by residual emissions due to current and prior events. Decay rates for dead organic matter are such that residual emissions continue beyond 20 years (10 years for reservoirs and 1 year for peat extraction), after which they are reported in the C stock changes in Cropland Remaining Cropland and Wetlands Remaining Wetlands.

The primary drivers of forest conversion are agricultural expansion and resource extraction, accounting for 42% and 30%, respectively, of the cumulative area of forest conversion since 1990. Annual rates of forest conversion to cropland show a steady decrease over the 1990–2010 period. Since 2010, however, annual rates have increased to around 22 kha—the levels observed in mid-1990s—due to a more recent agricultural expansion mostly in the Boreal Plains, Subhumid Prairies and Mixedwood Plains (Figure 6–7).

By contrast, annual rates of forest land conversion to settlements for a range of end land uses, including forestry roads, mining, oil and gas, hydro infrastructure, transportation and built-up lands, increased from 21 kha in 1990 to peaks of 31 kha in 2007 and 33 kha in 2014 and then dropped to 27 kha in 2019 (Figure 6–7). Since 2000, the settlements land use has become the main driver of forest conversion, accounting on average for 60% of the total area converted annually, except for the years 2003 and 2006, when forest was cleared for important hydro development projects (Figure 6–7). This trend is reflective of resource development (e.g., forestry roads, hydro infrastructure, mining, oil and gas, and transportation), especially in the Boreal Plains region, which reached an annual rate of 15 kha in the years 2006, 2007 and 2008. Forest conversion for resource development in this region has decreased since, but still contributes to 24% of the total forest area lost nationally in 2019.

The occasional impoundment of large reservoirs (e.g., La Forge-1 in 1993 and Eastmain-1 in 2006) may also convert large forest areas to Wetlands (Figure 6–7).

However, because much of the pre-conversion C stocks are flooded, these episodic events may not release commensurate quantities of greenhouse gases.

Forest conversion affects both managed and unmanaged forests. Losses of unmanaged forests occur mainly in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East) and are caused mostly by reservoir impoundment. They also occur to a lesser extent in reporting zones 9 (Boreal Shield West) and 8 (Hudson Plains).

6.9.1. Methodological Issues

Forest conversion to other land categories has occurred in the past at high rates, but is a declining practice in Canada. It is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic activities causing forest losses are diverse; they result in heterogeneous spatial and temporal patterns of forest conversion, which have been systematically documented in recent decades. The challenge has been to develop an approach that integrates a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlap.

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: (1) systematic or representative sampling of remote sensing imagery, (2) records, and (3) expert judgement (Dyk et al., 2011, 2015). The core method involves mapping of forest conversion on samples from remotely sensed Landsat images dated circa 1975, 1990, 2000, 2008, 2013 and 2018. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns on the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. When the remote sensing sample was insufficient, expert opinion was called upon to resolve differences among records and remote sensing information and to resolve apparent discrepancies across the 1975–1990, 1990–2000, 2000–2008, 2008–2013 and 2013–2018 area estimates. A more detailed description of the approach and data sources is provided in Annex 3.5.2.5.

All estimates of emissions from biomass and dead organic matter pools due to forest conversion were generated using the CBM-CFS3 (section 6.3.1.2), except when forests were flooded without prior clearing. Emissions from the soil pool were estimated in different modelling frameworks, except for the Land Converted to Settlements subcategory, for which CBM-CFS3 decay rates were used. Hence, methods are generally consistent with those used in the Forest Land Remaining Forest Land subcategory. Annex 3.5 summarizes the estimation procedures.

6.9.2. Uncertainties and Time-Series Consistency

An overall uncertainty estimate of ±30% bounds the estimate of the total forest area converted annually in Canada (Leckie, 2011), placing with 95% confidence the true value of this area for 2019 between 34 kha and 64 kha per year. Care should be taken not to apply the 30% range to the cumulative area reported in the CRF tables for Forest Land converted to another land category over the last 20 years (10 years for reservoirs). Annex 3.5 describes the main sources of uncertainty associated with area estimates derived from remote sensing.

6.9.3. Quality Assurance / Quality Control and Verification

General QA/QC procedures are implemented as outlined in section 1.3 of Chapter 1. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development procedures, involving documented QC of imagery interpretation, field validation, cross-calculations and detailed examination of results (Dyk et al., 2011, 2015). The calculations, use of records data and expert judgement are traceable through the compilation system and documented. More information is available in Annex 3.5.2.5.

6.9.4. Recalculations

There were significant changes in the estimated annual areas of forest conversion to cropland and to settlements due to the implementation of a new time period of deforestation mapping for 2013–2018 that increased the total area of forest cleared for agriculture by 61 kha and for settlement by 31 kha. In addition, changes implemented in the forest ecosystem model and updates made to the bioenergy activity data indirectly impact the amounts of biomass removed from deforested lands. These changes resulted in adjustments of forest conversion estimates mainly in recent years. In 2018, they increased land emissions by 2.0 Mt (+13%) and the associated HWP emissions by 0.9 Mt (36%).

6.9.5. Planned Improvements

The development of new mapping data, parameters and processes for forest conversion is part of the continuous improvements of LULUCF estimates. In the medium-term, improvements include: (1) revision of 1970 to 2010s deforestation activity data used that will lead to improved estimates for earlier time periods; (2) northern RU deforestation mapping to improve alignment with non-forested northern land-use change; and (3) update assumptions of proportions of types of forest that existed previous to deforestation events.

CHAPTER 7

WASTE (CRF SECTOR 5)

7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including Solid Waste Disposal (Landfills), Composting and Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

7.1.1. Emissions Summary

Sources and gases from the Waste sector include methane (CH_4) from Solid Waste Disposal (Landfills) and Industrial Wood Waste Landfills; CH_4 and nitrous oxide (N_2O) from the Biological Treatment of Solid Waste; carbon dioxide (CO_2), CH_4 and N_2O from Incineration and Open Burning of Waste; and, CH_4 and N_2O from Wastewater Treatment and Discharge.

In 2019, greenhouse gas (GHG) emissions from the Waste sector accounted for 27.6 Mt of total national emissions, compared with 26 Mt for 1990—an increase of 1.6 Mt or 5.8% (Table 7–1). The emissions from this sector represented 4.3% and 3.7% of total Canadian GHG emissions in 1990 and 2019, respectively.

The chief contributor to the Waste sector emissions was Solid Waste Disposal (Landfills) which, in 2019, accounted for 23 Mt CO_2 eq or 83% of the Waste sector emissions (Table 7–1).

When the waste treated or disposed of is derived from biomass, CO_2 emissions attributable to such waste are reported in the inventory as a memo item. CO_2 emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO_2 uptake is not reported in the inventory (e.g., annual crops). In this latter case, emissions are not included in the inventory emission totals, since the absorption of CO_2 by the harvested vegetation is not estimated and thus the inclusion of these emissions in the Waste sector would result in an imbalance. Also, CO_2 emissions from wood and wood products are reported in the Land Use, Land-use Change and Forestry (LULUCF) sector. In contrast, CH_4 emissions from anaerobic decomposition of wastes are included in the inventory totals as part of the Waste sector.

The majority of changes relative to previous inventory submissions are from recalculations and updates to activity data (Table 7–2). Detailed descriptions of the recalculations and activity data updates are provided in the recalculation section for each source in this chapter and in Chapter 8.

Table 7–1 **Waste Sector GHG Emissions Summary, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)						
	1990	2005	2015	2016	2017	2018	2019
Waste	**26.0**	**31.0**	**26.7**	**26.7**	**26.9**	**27.2**	**27.6**
Solid Waste Disposal (Landfills)	21.0	25.1	21.8	21.9	22.2	22.5	23.0
Biological Treatment of Solid Waste	0.1	0.2	0.3	0.3	0.3	0.4	0.4
Wastewater Treatment and Discharge	0.8	0.9	1.0	1.0	1.0	1.0	1.0
Incineration and Open Burning of Waste	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Industrial Wood Waste Landfills	3.8	4.4	3.4	3.3	3.2	3.1	3.0

Note: Totals may not add up due to rounding.

Table 7–2 **Summary of Recalculations in the Waste Sector for Selected Years (Mt CO_2 eq)**

Sector	1990	2000	2005	2014	2015	2016	2017	2018
Biological Treatment of Solid Waste								
Previous (2020) inventory submission	0.06	0.18	0.29	0.46	0.45	0.45	0.45	0.45
Current (2021) inventory submission	0.07	0.19	0.24	0.31	0.31	0.31	0.32	0.37
Net change in emissions	0.02	0.01	-0.06	-0.15	-0.15	-0.13	-0.12	-0.07
Incineration and Open Burning of Waste								
Previous (2020) inventory submission	0.47	0.65	0.58	0.36	0.40	0.39	0.39	0.39
Current (2021) inventory submission	0.27	0.37	0.34	0.17	0.20	0.20	0.19	0.18
Net change in emissions	-0.20	-0.28	-0.24	-0.19	-0.20	-0.18	-0.20	-0.21
Industrial Wood Waste Landfills								
Previous (2020) inventory submission	3.85	4.46	4.28	3.70	3.62	3.55	3.47	3.40
Current (2021) inventory submission	3.85	4.53	4.37	3.46	3.37	3.27	3.18	3.09
Net change in emissions	0.00	0.08	0.09	-0.23	-0.26	-0.28	-0.30	-0.31
Solid Waste Disposal (Landfills)								
Previous (2020) inventory submission	15.42	13.38	13.74	11.80	12.32	12.43	12.49	12.27
Current (2021) inventory submission	20.98	24.69	25.09	21.67	21.83	21.89	22.22	22.54
Net change in emissions	5.56	11.31	11.35	9.87	9.51	9.46	9.72	10.26
Wastewater Treatment and Discharge								
Previous (2020) inventory submission	0.92	0.97	1.00	1.16	1.15	1.14	1.13	1.14
Current (2021) inventory submission	0.83	0.89	0.94	1.02	1.00	1.00	1.00	1.01
Net change in emissions	-0.09	-0.08	-0.07	-0.13	-0.15	-0.14	-0.13	-0.13

Note: Totals may not add up due to rounding.

7.2. Solid Waste Disposal (Landfills) (CRF Category 5.A)

7.2.1. Source Category Description

The Solid Waste Disposal (Landfills) category provides a quantification of CH_4 emissions resulting from the decay of waste deposited in municipal landfills. Municipal solid waste (MSW) encompasses waste from the residential sector, the industrial, commercial and institutional (ICI) sector and the construction and demolition (C&D) sector, as well as sewage sludge.

Industrial wood waste (i.e., waste from sawmill operations, pulp and paper production and other forest industry processes) is often deposited in small landfills at or near the originating facility. Because of the unique composition (wood) and distinct locations and practices of wood waste landfills, they are reported as a separate category (section 7.3).

In Canada, most waste disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites still exist in Canada. The disposal of MSW is regulated by provinces and territories, but is typically managed by municipal or regional authorities. While regulations vary across the country, common regulatory requirements include landfill gas capture and landfill covers. Furthermore, many provinces are implementing, or already have in place, specific waste reduction targets, such as organic bans on landfilled waste, or per capita waste generation goals.

Emissions from waste disposal are generated by the anaerobic decomposition of buried organic waste in the landfill. While CO_2 is also produced, it is of biogenic origin from the same year as emission and is therefore not reported as part of the total emissions of this sector. Emissions of N_2O are considered negligible.

MSW disposal is the dominant contributor of emissions from the Waste sector. This category accounted for 81% of the Waste sector emissions in 1990, 81% in 2005 and 83% of Waste sector emissions in 2019 (Table 7–1).

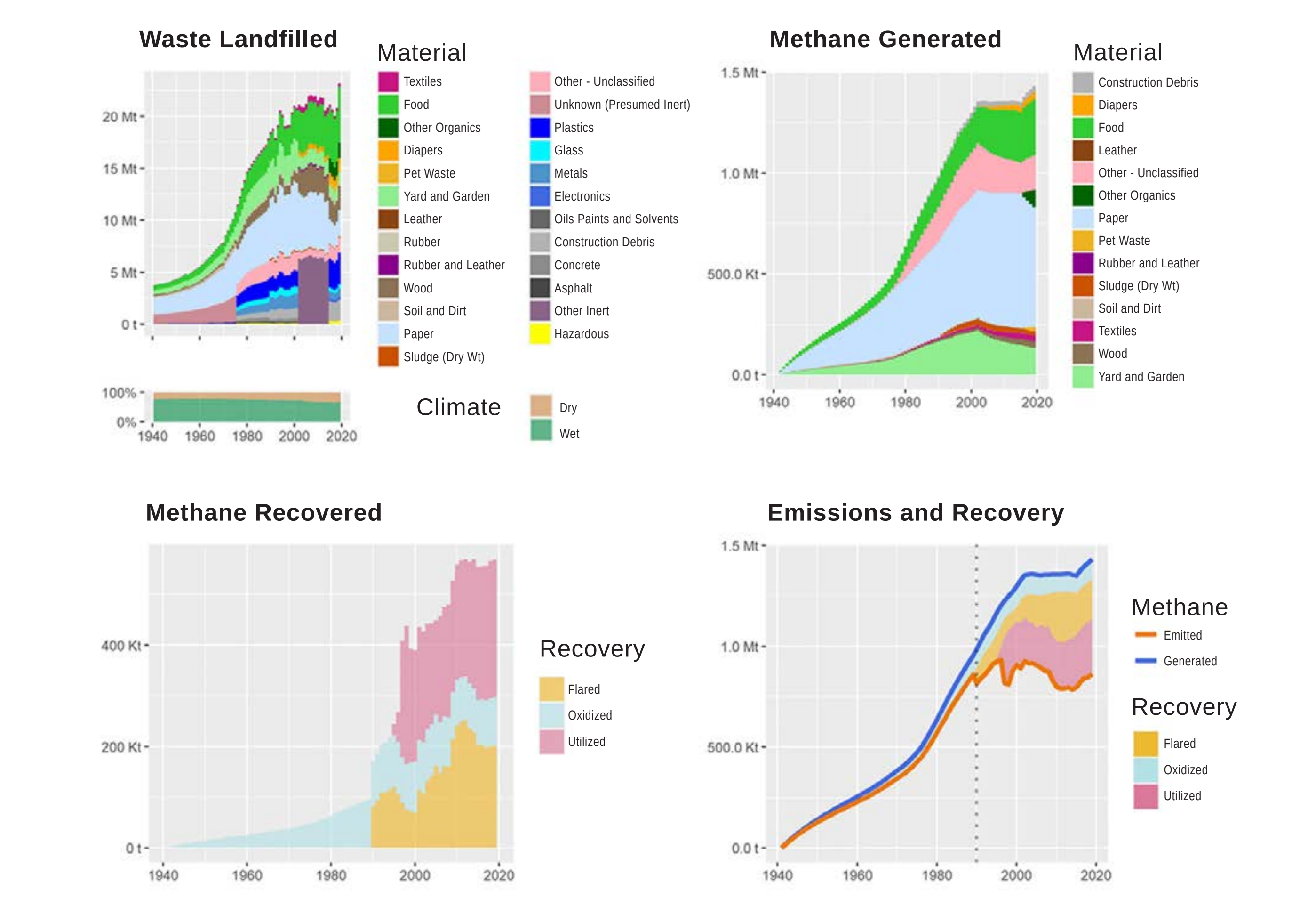
Factors influencing emissions from MSW landfills over time include population growth and waste management practices (Figure 7–1). As the population increases, more waste is generated. Methane production is closely tied to the composition of the material that was landfilled. Waste diversion practices and landfill gas capture have been increasing over time and offset the amount of waste landfilled.

7.2.2. Methodological Issues

Waste disposal emissions in Canada are estimated using the first-order decay methodology from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), with parameters from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). The same methodology—but with different parameters—is used for Solid Waste Disposal and Industrial Wood Waste Landfills (discussed in section 7.3.2).

7

Figure 7–1 **Waste Landfilled, Methane Generated (by Source Material), Recovered and Emitted**



Landfill gas, which is composed mainly of CH_4 and CO_2, is produced by the anaerobic decomposition of organic wastes. The decomposition process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH_4 and CO_2 gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton, 1991).

A consistent source of data on the amount of waste landfilled is not currently available. Instead, the total amount of waste disposed (landfilled, exported and incinerated) in each province forms the basis of the emission calculations. Data are available on the amount of waste exported and incinerated and so are used to derive the amount of waste landfilled.

A number of factors contribute to the generation of gases within a landfill. One of the most important factors is the composition of the waste entering the landfill. As consumer habits and waste management practices change over time, so do the types of waste disposed of in MSW landfills. Another important factor influencing the production of CH_4 emissions within a landfill is moisture content. Moisture is considered to be a limiting factor in CH_4 generation. It is assumed that it is the major factor affecting moisture content within the landfill, and it is captured by climate region (wet or dry). While there are a number of other factors affecting CH_4 generation in landfills, such as pH and nutrient availability, they are not represented in the model.

Not all CH_4 generated within a landfill will be released into the atmosphere. To determine the amount of CH_4 released, the amount captured through landfill gas capture technology and the proportion of CH_4 oxidized in landfill covers are accounted for. Landfill gas capture on managed landfill sites is an increasingly popular activity in Canada. Methane from landfill gas can be used to generate electricity or heat or is flared to reduce the GHG potential of emitted gases.

Oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill covers is accounted for by applying an oxidation factor to the emissions estimated to be generated in the landfill, after landfill gas capture is accounted for. Every province/territory in Canada requires managed landfills of a certain size to have daily cover material in place to bury waste. There are also annual cover requirements, as well as more robust cover material for closed landfills.

7.2.3. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH_4 emissions from Solid Waste Disposal was estimated to be ±76% for CH_4 based on defaults available in the IPCC 2006 Guidelines (IPCC, 2006).

7.2.4. QA/QC and Verification

The annual quality control process consisted in verifying that all activity data and methodological updates had been incorporated into the model. Expected changes in emission estimates from individual methodological updates and regular data updates were compared against the total actual changes in emissions to verify that all recalculations had been incorporated correctly. Inter-annual emissions were compared to identify any unexpected changes in emissions at the regional and national level. Standard quality assurance checks were run, such as confirming that records for all years and regions had been included in final estimates and that national totals matched the sum of regional totals.

7.2.5. Recalculations

Emission estimations from MSW landfills were recalculated over the 1990–2019 time series to account for the following:

- Decomposition is now calculated by material. In previous inventories, all waste was modelled as a homogenous "bulk" mass, with parameters taken as weighted averages or IPCC 2006 Guidelines default values. The key benefit of modelling decay by material is that material-specific decay rates can be applied. Decay rates can vary considerably between materials. Degradability and fractions of waste that do decompose in landfills are now also modelled as material-specific parameters based on the 2019 Refinement (IPCC, 2019).
- IPCC 2006 Guidelines decay rates are used. The decay rates used in previous inventories were based on erroneous methods (Table 7–3). The decay rates were underestimated in dry regions (provinces with low precipitation). The new decay rates, in addition to being material specific, are higher than the previous rates and are now in line with other IPCC Guidelines methods and those used by other countries. Decay rates are now based on climate region as defined by the mean annual precipitation (MAP) and potential evapotranspiration (PET): wet is MAP > PET, dry is MAP < PET. Previously, decay rates were calculated as a single value (varying with time). for each province based on precipitation near the largest landfill(s).
- The disposal time series has been updated and refined. Disposal quantities in the 1980s were previously taken from Levelton (1991), but the values in that report were an extrapolation. Interpolation methods used to fill the time series of waste disposal have been updated. Disposal quantities for the 1980s and early 1990s are now interpolated by linear interpolation of per-capita disposal rates between the nearest known values. This is now consistent with the disposal estimates from 1941 to 1980, which are based on per-capita disposal rates linearly interpolated between data points at 5- or 10-year intervals. Waste disposal estimates for the territories are now entirely based on per-capita disposal rates. They were previously taken as the remainder after accounting for the Canadian total and provincial totals (Statistics Canada, n.d.[c]) and data received directly from the province of PEI), the result of which was that any error, including rounding error, resulted in wild swings in estimates for the territories, which have comparatively small disposal amounts.

Table 7–3 **Updates to Decay Rates from Provincial Bulk Averages to Material and Climate-Specific Values**

Previous Inventory (averaged, bulk waste)			Current Inventory and IPCC 2006 Guidelines (material-specific)				
Province	k	half-life (yr)		Climate Zone Decay Rate (yr^{-1})		Half-Life (yr) by Climate	
			Material	Dry	Wet	Dry	Wet
NL	0.08	8.7					
PE	0.059	11.7	Food	0.06	0.185	11.6	3.7
NS	0.08	8.7	Paper	0.04	0.06	17.3	11.6
NB	0.062	11.2	Textiles	0.04	0.06	17.3	11.6
QC	0.056	12.4	Wood	0.02	0.03	34.7	23.1
ON	0.045	15.4	Yard and Garden	0.05	0.1	13.9	6.9
MB	0.017	40.8	Other Organics	0.05	0.1	13.9	6.9
SK	0.012	57.8	Leather	0.01	0.01	69.3	69.3
AB	0.01	69.3	Rubber and Leather	0.01	0.01	69.3	69.3
BC	0.04	17.3	Diapers, Pet Waste	0.06	0.185	11.6	3.7
NT	0.005	138.6	Construction Debris	0.02	0.03	34.7	23.1
NU	0.005	138.6	Sewage Sludge	0.06	0.185	11.6	3.7
YT	0.003	231	Default (Bulk)	0.05	0.09	13.9	7.7

7.2.6. Planned Improvements

Opportunities for more refined data on amounts and types of waste landfilled in provinces are being investigated. Increased collaboration with provincial and other regional authorities may result in higher quality data that can be integrated directly into the waste model or used to verify current estimates.

7.3. Industrial Wood Waste Landfills (CRF Category 5.A.2)

7.3.1. Source Category Description

Industrial Wood Waste Landfills are mostly privately owned and operated by forest industries, such as sawmills and pulp and paper mills. These industries use landfills to dispose of surplus wood residue, including sawdust, wood shavings, bark and sludge. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as waste is now being processed as a value-added product—e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particleboard.

Wood waste landfills are reported as unmanaged landfills in the CRF. Industrial wood waste disposal accounts for 15% (3.8 Mt) of the emissions from waste in 1990, 14% (4.4 Mt) in 2005, and 11% (3.0 Mt) in 2019.

7.3.2. Methodological Issues

Industrial Wood Waste Landfills are dedicated lots for the disposal of wood waste from the pulp and paper and solid wood industries. There is limited data available on the amount of waste sent to these lots. It is assumed that the amount of waste disposed of in wood waste landfills is rapidly decreasing as repurposing of wood waste becomes increasingly popular. As of 2010, landfilling of sawmill residues in private lots is believed to be negligible. In contrast, several pulp and paper facilities are continuing to landfill process waste.

It is assumed that no LFG recovery (flaring or use for energy) occurs at wood waste landfills. Wood waste landfills are assumed to be unmanaged. It is unknown whether landfill covers are installed. However, shallow wood waste is assumed to be an appropriate medium for the methanotrophic bacteria that oxidize CH_4 generated deeper in the landfill.

7.3.3. Recalculations

Emissions from wood waste landfills come from two different industries: the solid wood industry and the pulp and paper industry. Emissions from these industries were previously calculated together, but this year these industries have been calculated separately, with updates to activity data. The introduction of a new data source has resulted in a recalculation for previous years resulting in an overall reduction of emissions by 0% in 1990, 2% in 2005 and 9% in 2018.

7.3.4. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH_4 emissions from MSW landfills and wood waste landfills combined was estimated to be in the range of ± 190% for CH_4.

7.3.5. Planned Improvements

The oxidation factor used for wood waste landfills is under review. While Industrial Wood Waste Landfills are considered to be unmanaged sites, the managed landfill default oxidation factor of 0.1 has been used due to the assumption that wood acts as a bio-cover for the sites. Further, waste landfill parameters specific to the pulp and paper sector will be explored, along with those of the 2019 Refinement (IPCC, 2019).

7.4. Biological Treatment of Solid Waste (CRF Category 5.B)

7.4.1. Source Category Description

This source category includes emissions from composting and anaerobic digestion at biogas facilities. Many municipalities in Canada utilize centralized composting facilities and some are establishing centralized anaerobic digestion facilities to reduce the quantity of organics sent to landfill. Additionally, a number of municipalities across Canada are considering or have already established organic waste bans on landfills in their jurisdiction to further divert organic waste to biological treatment. These practices have contributed to a large increase in the quantity of organic waste diverted in Canada since 1990.

GHG emissions from composting are affected by the moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions. Anaerobic digestion of organic waste accelerates the natural decomposition of organic material without oxygen by maintaining optimal conditions for the process. Both biological treatment processes result in the production of

CO_2, CH_4 and N_2O emissions. However, CO_2 emissions are not included in the national inventory total as the carbon is considered to be of biogenic origin and accounted for under the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006).

In 2019, the Biological Treatment of Solid Waste category contributed 381 kt of CO_2 eq or 1% of total emissions to the Waste sector and 0.05% to Canada's total. Emissions were 308 kt (421%) above the 1990 levels of 73 kt.

7.4.2. Methodological Issues

The estimation of CH_4 and N_2O emissions from the biological treatment of waste in Canada is carried out by using a Tier 3 method. Facility-level data is available for both anaerobic digestion and composting facilities in Canada. This data has been collected with industry associations, online literature searches and annual reports as well as other in-house contracts led by Environment and Climate Change Canada. Composting emissions are calculated based on the waste type accepted in wet tonnes at the facility-level in Canada. The emission factors by waste type have been developed through a in-house literature review that compiled information from primary literature sources (ECCC, 2020a).

Under the Biological Treatment of Solid Waste category, anaerobic digestion emissions are only calculated for industrial or municipal facilities. Emissions are calculated as the percent of methane lost from the total biogas produced at the facility level. This percentage was developed based on primary literature and/or facility-based insight and compiled through an in-house literature review (ECCC, 2020b). Some gaps exist in the activity data for both composting and anaerobic digestion, including a lack of data prior to the year 1992 for composting. In order to fill the data gaps throughout the time series, the earliest available data point is carried back to 1990 for facilities that were known to be open at that time. Otherwise, the last available data point is carried forward to the next available data point through time. For anaerobic digestion, there were no facilities in the industrial/municipal sector that were in operation in 1990. Therefore, the earliest data point available for the facility is carried back to its opening year and is also carried forward until the next data point for the facility becomes available. For additional quality assurance, composting and anaerobic digestion activity data totals were compared against Statistics Canada's Waste Management Industry Survey: Business and Government Sectors (CANSIM 153-0043) (Statistics Canada, n.d.[b]). The Statistics Canada data set includes waste diverted as a single tonnage to both composting and anaerobic digestion.

7.4.3. Uncertainties and Time Series Consistency

The combined uncertainties for emissions of CH_4 and N_2O from composting and anaerobic digestion were calculated by waste type for composting and by the fugitive loss percentage for CH_4 for anaerobic digestion. Uncertainty range is from a high of ±176% down to ± 99% for CH_4 and ± 136% down to ± 65% for N_2O based on waste type for composting and ± 79% for CH_4 for anaerobic digestion fugitive loss. This is based on emission factors collected through primary literature and compiled in an in-house literature review. Activity data uncertainty was not calculated, given that it is based on direct facility data.

7.4.4. QA/QC and Verification

The quality control process for the Biological Treatment of Solid Waste category consisted of verifying all aspects of the emission estimate calculations, including:

- downloaded and manually inputted activity data
- calculations to carry forward or backward activity data to bridge data gaps in the time series
- inputted emission factors
- unit conversions and emission calculations

The final activity data and emission trends were plotted to identify any outliers. The recalculated emission estimates were also compared with the previous inventory's estimates to ensure that the changes in emission levels made sense.

7.4.5. Recalculations

The recalculations made for this category are based on applying a new methodology and including a new source of activity data for this source category. Please note that prior to the 2021 inventory, anaerobic digestion emissions for municipal and industrial facilities were not included.

7.4.6. Planned Improvements

Opportunities for acquiring more refined data on the amounts of waste being composted and/or anaerobically digested in the provinces and territories will continue to be investigated. Increased collaboration with provincial and other regional authorities may result in a more complete data set and higher quality data that could be used to improve or verify the current emission estimates.

7.5. Incineration and Open Burning of Waste (CRF Category 5.C)

7.5.1. Source Category Description

This category includes emissions from the incineration of waste. There are 36 incinerators currently in operation in Canada. Incinerators are classified by the source of their primary feed material: MSW, hazardous waste, sewage sludge or clinical waste. Some municipalities in Canada use incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application. Incineration can also be used for energy recovery from waste, and emissions from these facilities are reported in the Energy sector. GHG emissions from open burning of waste are assumed to be negligible, representing less than the reporting threshold of 500 kt CO_2 eq and 0.05% of national GHG total emissions.

Emissions from waste incineration include CO_2, CH_4 and N_2O. In accordance with the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. The only CO_2 emissions detailed in this section are from fossil fuel-based carbon waste, such as in the form of plastics, rubber, inorganics, and fossil liquids. CH_4 and N_2O emissions are estimated from all incinerated waste.

GHG emissions from incinerators vary with the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste and the facilities' operating conditions. Emissions are derived from the quantities of waste incinerated that were provided directly by facilities in a series of surveys conducted by Environment and Climate Change Canada (ECCC, 2020c), as well as additional reports which provide quantities of clinical waste incinerated for the early years in the time series (Chandler, 2006; RWDI AIR Inc., 2014).

Incineration of MSW is not a common practice across most of Canada. Approximately 5% of Canada's total MSW is incinerated, mostly in energy-from-waste facilities. The vast majority of Canada's incinerated MSW is processed in large, highly regulated facilities. However, there are still a small number of remote communities that rely on rudimentary incinerators to dispose of their MSW. There are currently four incinerators in operation in Canada that are classified as hazardous waste incinerators, all located in Ontario and Alberta. Two different types of sewage sludge incinerators exist in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially dewatered prior to incineration. The dewatering is typically done using a centrifuge or a filter press. There are currently two major centralized clinical waste incinerators in Canada, one in Ontario and the other in Alberta. They accounted for nearly 80% of the GHG emissions from clinical waste incineration.

The remaining 20% of GHG emissions are from a number of small hospital-based incinerators and incinerators operated by the Government of Canada.

The Incineration and Open Burning of Waste category contributed 187 kt CO_2 eq (0.68%) of total emissions to the Waste sector or 0.03% of Canada's total emissions in 2019. Emissions from this category are 31% below the 1990 level of 272 kt CO_2 eq.

7.5.2. Methodological Issues

The emission estimation methodology depends on type of waste incinerated and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.6.

Given the relatively small number of incinerators in Canada, emissions from incineration can be estimated at the facility level. Most facilities are required to report emissions to Environment and Climate Change Canada on an annual basis through the Greenhouse Gas Reporting Program (GHGRP). These publicly available data represent a significant portion of emissions from this sector.

In-house estimates for smaller facilities that are not required to report to the GHGRP are generated by ECCC using Tier 3 methodology and activity data from a biennial survey of incinerators across Canada. Please see Annex 3.6 for details. In-house estimates are also derived for historical emissions for those facilities operating before the GHGRP was put in place in 2004. This includes currently operating facilities that operated prior to 2004 and those that closed before the program began.

The in-house estimates are developed using the IPCC default values for carbon content of waste and fossil carbon as a percentage of total carbon (IPCC, 2006). N_2O and CH_4 emissions are estimated based on the type of waste being incinerated as well as the facilities specific incineration technology. IPCC default factors were used, except for hazardous waste, for which emission factors were derived from site-specific data provided by a facility, which were deemed more representative than IPCC default values. As the IPCC 2006 Guidelines do not contain default emission factors for clinical waste incineration, the IPCC 2006 Guidelines default emission factors for MSW incineration were used in accordance with the IPCC 2000 Good Practice Guidance, which recommends using MSW emission factors when specific clinical emission factors are not available.

Facilities are distinguished as either energy-from-waste (EFW) facilities or non-EFW facilities, depending on whether they produce energy and/or heat from the incineration process. Emissions from EFW facilities are reported under the Energy sector, while emissions from non-EFW facilities are reported under the Waste sector. See Annex 3.6 for details.

7.5.3. Uncertainties and Time Series Consistency

IPCC default values are used to quantify uncertainty for the incineration sector. The activity data uncertainty is ±5%, while the CO_2, CH_4 and N_2O emission factor uncertainties are ±40%, ±100%, and ±100%, respectively.

7.5.4. QA/QC and Verification

The quality control process consisted of verification in the model that all activity data updates were made, that all links were valid, and that the cells addressed by those links were populated. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data manipulation error. The emissions trend has been reviewed for the entire time series.

7.5.5. Recalculations

This year, the various different incineration categories were adjusted so that the same method of calculating waste at the facility level could be used rather than aggregating numbers and calculating at the provincial level. Some incinerators treat more than one type of waste and they were classified by their primary feed type. At this time, all energy-from-waste facilities primarily incinerate MSW. That allowed for the use of GHGRP data for four additional incinerators, two of which are classified as sewage sludge and the other two as hazardous waste incinerators.

As there are two types of sewage sludge incinerators in Canada; fluidized bed and multiple hearth, the emission factor previously used was a combination of the two technologies. This emission factor was applied to the provincial totals of sewage sludge incinerated. This year, since emissions are calculated at the facility level across all categories of incineration, a combined emission factor is no longer necessary and facility-specific factors were applied.

7.5.6. Planned Improvements

No planned improvements are scheduled for the Incineration and Open Burning of Waste category.

7.6. Wastewater Treatment and Discharge (CRF Category 5.D)

7.6.1. Source Category Description

In Canada, most wastewater from domestic and industrial sources is treated in centralized municipal wastewater treatment plants. However wastewater can also be treated by private and occasionally communal septic systems, notably in rural areas. In some coastal areas, untreated wastewater is discharged directly to the sea. Most industrial facilities discharge their wastewater to municipal treatment systems. Several large industrial facilities treat or pre-treat their wastewater on-site before discharging it to the environment or to municipal wastewater treatment systems for further treatment.

Wastewater treatment involves the removal of organics, measured as biological oxygen demand, or BOD_5, and nutrients. The treatment process results in emissions of CO_2, CH_4 and N_2O.

Centralized treatment systems can encompass a number of technologies, often classified by the degree of solids removal, the reduction in organic matter content (measured as BOD_5) and nutrient removal. The treatment level is classified as primary (solids removal only), secondary (solids removal, biological treatment and sometimes nutrient removal) and tertiary (advanced biological treatment and nutrient removal with additional disinfection).

The most common types of treatment systems in Canada are primary and secondary centralized treatment systems, aerobic and facultative lagoons, and septic systems. Discharge of untreated sewage to sea has been declining, but is still carried out in some coastal regions. Wetland treatment systems, sequence batch reactors, anaerobic lagoons and some other treatment types are also in use in Canada. Many of the largest systems in Canada have tertiary level treatment.

Wastewater treatment produces varying amounts of CH_4, depending on the organic load (BOD_5)—determined by the population—and treatment type. CH_4 is produced from certain treatment processes, steps, or areas in the treatment systems that are anaerobic. For example, primary and secondary treatment and aerobic lagoons produce little or no CH_4 emissions, whereas anaerobic steps in sequence batch reactors, anaerobic lagoons and septic systems produce relatively higher amounts of CH_4. Facultative lagoons have both naturally aerated and anaerobic layers and produce CH_4, but less than a fully anaerobic lagoon.

Centralized wastewater treatment plants with secondary or tertiary levels of treatment often include anaerobic sludge digestion, which produces CH_4 in the form of biogas or digester gas. The CH_4 generated in these systems is typically contained and combusted.

Wastewater treatment generates N_2O through the nitrification and denitrification of sewage nitrogen at treatment facilities. N_2O emissions are also considered to occur from the receiving body of discharged effluent, whether treated or untreated.

CO_2 is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in section 7.1, CO_2 emissions originating from the decomposition of organic matter are not included with the national total estimates in the Waste sector.

The Wastewater Treatment and Discharge category accounted for 1021 kt CO_2 eq, or 3.7%, of the total emissions of the Waste sector and 0.14% of Canada's total in 2019. Wastewater Treatment and Discharge emissions in 2019 were 194 kt CO_2 eq (23%) above the 1990 level of 827 kt.

Emissions from wastewater treatment show an increasing trend over time that roughly follows the trend in population growth. Changes in treatment technology have impacts on emission trends at the provincial level. For example, the growing percentage of the population using septic systems in several provinces results in increases in total emissions, whereas upgrades of several major wastewater systems from untreated discharge to sea to primary treatment in other provinces decreases emissions. On the whole, the increasing trend in emissions is fairly steady, with a slight acceleration in 2010 and 2011, largely due to an increase in the estimated population using septic systems in many provinces around that time. Overall, population growth is the most important factor in the emissions trend for Wastewater Treatment and Discharge. In part, this is because of assumed constant per-capita organics loading (BOD_5) and reasonably steady per-capita protein consumption rates (increasing from 66.17 g per person per day in 1991 to 69.85 g per person per day in 2009, the earliest and latest data points available) (Statistics Canada, 2009).

7.6.2. Methodological Issues

Annex 3.6 provides additional information on the methodologies used for various categories covered by this category.

The approach used to estimate CH_4 emissions from municipal wastewater treatment is based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH_4 in anaerobic treatment systems, according to IPCC 2006 Guidelines (IPCC, 2006; AECOM Canada, 2011).

Emission factors are treatment-type specific. These are obtained from the 2006 IPCC Guidelines (IPCC, 2006) and 2019 Refinement (IPCC, 2019), with a few exceptions for treatment types not detailed in the Guidelines. A methodological challenge is determining the number of people serviced by each wastewater treatment system type (e.g., septic, lagoon, untreated). The population served by septic systems was determined from an analysis of Statistics Canada's Households and the Environment Survey (Statistics Canada, n.d.[a]). The population served by each of the more than 3000 wastewater treatment or discharge systems in Canada was estimated on the basis of the relative regional volumes of wastewater treated by (or discharged through) that facility or system and the regional population, at the census metropolitan area level. A more complete description of the methodology is provided in Annex 3.6.

Emissions from on-site industrial wastewater treatment are estimated on a Tier 3, facility-by-facility basis. Environment and Climate Canada conducts facility-level surveys on a biennial basis to obtain methane emissions from industrial facilities that treat their effluent anaerobically on-site. The facilities surveyed were those identified by industry associations as having anaerobic wastewater treatment systems. Facility data have been updated (new data appended, existing data revised and corrected) with each successive biennial survey. The latest survey was conducted in 2016. Where actual measured facility data were not provided, design specifications particular to that site were used to estimate maximum emissions expected. A complete description of the methodology is provided in Annex 3.6. Currently estimates are based on 19 industrial facilities across the country. Expanding the list of facilities to survey and include in the industrial emissions estimates is a planned improvement.

The N_2O emissions are estimated based on nitrogen in the wastewater in accordance with the IPCC 2006 Guidelines (IPCC, 2006). The amount of nitrogen introduced to wastewater is estimated based on per-capita protein consumption. Protein consumption estimates, in kg/person/year, were obtained from an annual Food Statistics report published by Statistics Canada, adjusted to account for retail, household and cooking plate loss (Statistics Canada, 2009; AECOM Canada, 2012). A complete description of the methodology is provided in Annex 3.6.

7.6.3. Uncertainties and Time Series Consistency

The overall level of uncertainty associated with the Wastewater Treatment and Discharge category was estimated to be in the range of ±55% for CH_4 and ± 51% for N_2O based on IPCC 2006 default uncertainties and an estimated 20% uncertainty for the degree of utilization of each treatment type.

The updated activity data for municipal wastewater treatment and discharge will necessitate an updated uncertainty assessment. This is in progress and planned for the following inventory.

7.6.4. QA/QC and Verification

The quality control process consisted of following calculations step by step to ensure that equations, parameters and unit conversions were appropriate and that links were accurate. Emissions were plotted to observe trends for any unusual jumps or patterns that were inconsistent with changes in activity data over time. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data manipulation error.

7.6.5. Recalculations

Recalculations for this category involved updates to activity data, distinguishing different types of treatment technology, and inclusion of sludge removal and anaerobic digestion of sludge. Updates to activity data are a continuous process. There are over 3800 wastewater treatment systems in Canada, requiring extensive data gathering. Some ongoing activity data refinements include more information on the treatment technology employed at various facilities in the 1990s, more information on smaller facilities, particularly in Alberta, Saskatchewan and Manitoba, better data from the territories and updated data on volumes treated from 2013 to 2018 and private septic system use from for 2018. Attribution of population to wastewater systems was improved by using smaller geographic regions (see Annex 3.6).

The removal of organics from wastewater as sludge is now accounted for. In previous inventories, all organics in wastewater were implicitly assumed to be converted to gaseous emissions (CO_2 or CH_4). The sludge removal accounts for transfers of organics from wastewater to other sectors, such as landfill or land application, and removes a previous double-counting.

Anaerobic digestion of sludge on-site at wastewater treatment facilities is now accounted for. To date, 83 wastewater facilities have been identified as having on-site anaerobic digestion of sludge. It is assumed that all anaerobic reactors and sludge digesters have CH_4 recovery systems, with an assumed fugitive loss of 2.1%.

7.6.6. Planned Improvements

A planned improvement is to determine the degree to which CH_4 recovery from wastewater treatment and anaerobic digestion of sludge at wastewater treatment facilities is used for energy purposes and to refine and update the estimates of the efficiency of CH_4 capture and recovery.

Methods for estimating direct N_2O emissions from the 2019 Refinement to the 2006 IPCC Guidelines will be investigated as a possible improvement. Direct N_2O emissions from wastewater treatment are currently not included in the inventory.

The industrial wastewater treatment sub-category of the Wastewater Treatment and Discharge category will be thoroughly reviewed and updated. Planned improvements include developing a more comprehensive inventory of industrial sites with wastewater treatment facilities or processes and an updated inventory and/or modelling of methane production and recovery. Data submitted through the GHGRP will be used where possible.

CHAPTER 8

RECALCULATIONS AND IMPROVEMENTS

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions and improvements to maintain and enhance the completeness, consistency and accuracy of the reported information. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analyses by sector to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the major inventory improvements that were implemented this year can be found in section 8.2 and planned improvements for future inventories are described in section 8.3.

Further details on recalculations and improvements can be found within the individual chapters for each sector (Chapters 3–7).

8.1. Impact of Recalculations on Emission Levels and Trends

Continuous improvement is good inventory preparation practice. Environment and Climate Change Canada consults and works with key federal, provincial and territorial partners along with industry stakeholders, research centres and consultants on an ongoing basis to improve the quality of the underlying variables and scientific information used to compile the national inventory. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals.

As such, recalculations are expected to occur annually for any number of reasons, including the following:

- correction of errors detected by quality control procedures
- incorporation of updates to activity data, including changes in data sources
- reallocation of activities to different categories (this only affects subtotals)
- refinements of methodologies and emission factors
- inclusion of categories previously not estimated (which improves inventory completeness)
- recommendations from United Nations Framework Convention on Climate Change (UNFCCC) reviews

8.1.1. Estimated Impacts on Emission Levels and Trends

In this year's GHG inventory, total emissions were revised for all years. Overall, recalculations of previously reported 1990–2018 estimates have resulted in relatively small changes to national totals (i.e. < 5 Mt) for most years, except for 2005 to 2012 where the changes resulted in an increase between 7 Mt and 13 Mt (Figure 8–1).

The trend between 1990 and 2018 is now reported as a 21.1% increase in total GHG emissions since 1990 compared with an 20.9% increase reported in last year's NIR. There is a net upward recalculation of 9 Mt for the base year 2005 (Table 8–1).

8.1.2. Recalculations by Sector

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied across the time series (i.e. from 1990 to the most recent year reported). Methodological consistency across the time series avoids confounding a methodological change with an actual change in GHG emissions or removals.

Recalculations conducted this year have resulted in changes to previously reported emissions/removals for all Intergovernmental Panel on Climate Change [IPCC] sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources) and for all applicable years in the time series (1990–2018) (see Table 8–3 for more information).

These revisions are largely due to improved estimation methodologies as well as updated energy data. For 2018, the revisions that have the most significant changes are in Stationary Combustion (-6.1 Mt), Transport (-1.7 Mt), IPPU (-2 Mt) and Waste (+9.5 Mt). (See Table 8–2 for more information).

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2018 occurred in Residential (-2.7 Mt), Oil and Gas Extraction (-2.0 Mt), Manufacturing Industries (-1.7 Mt), Petroleum Refining Industries (-1.3 Mt) and Mining (+1.4 Mt). The downward recalculations for Residential are caused by decreased volumes of residential firewood and natural gas. Oil and Gas Extraction recalculations are due to

Figure 8–1 **Comparison of Emission Trends (2020 NIR vs 2021 NIR)**

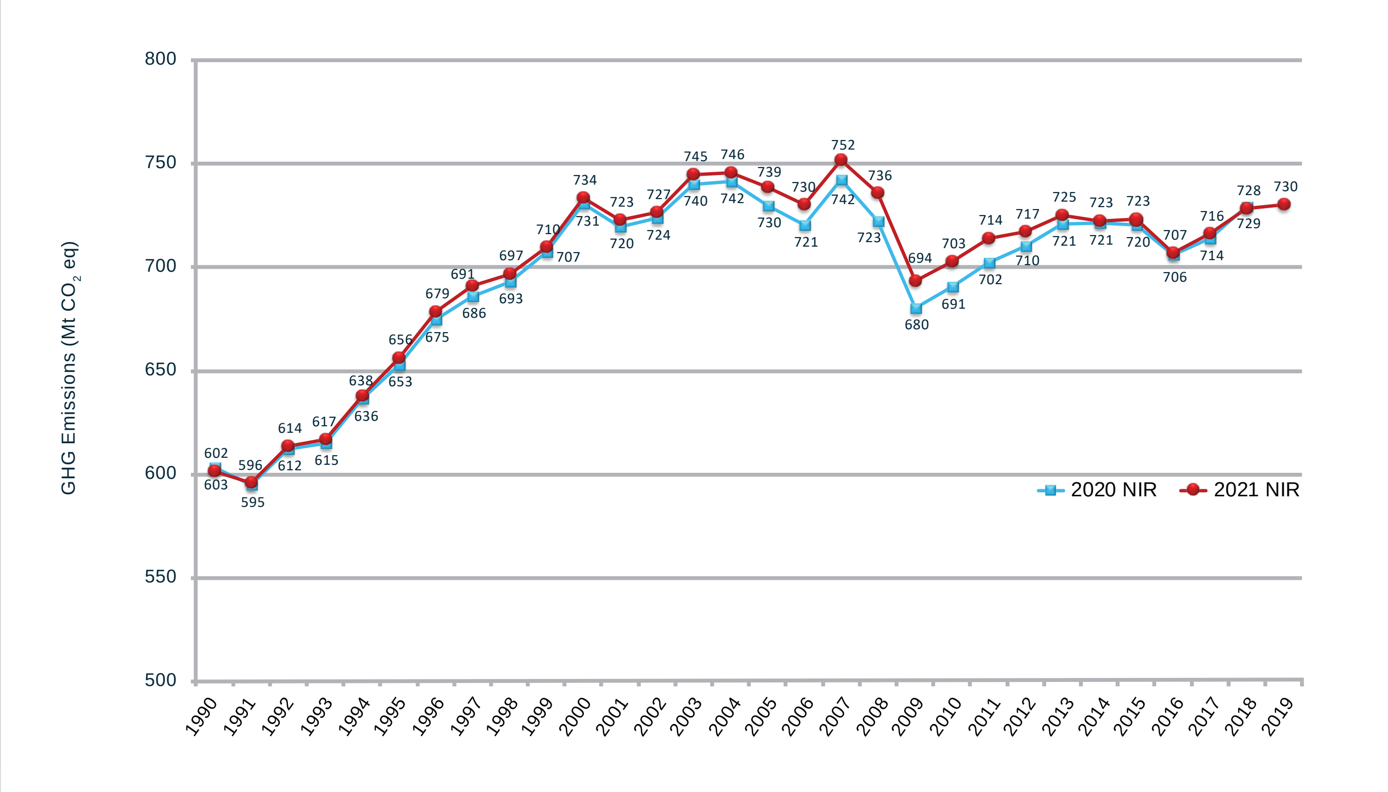


Table 8–1 **Summary of Recalculations in the 2021 National Inventory (excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2014	2015	2016	2017	2018	(1990–2018)	(2005–2018)
Previous Submission (2020 NIR)	603 222	730 682	729 746	721 354	720 378	706 194	713 837	729 348	20.9%	-0.1%
Current Submission (2021 NIR)	601 524	733 511	738 717	722 558	723 094	706 932	716 090	728 475	21.1%	-1.4%
Change in total emissions:	**-1 698**	**2 830**	**8 971**	**1 204**	**2 716**	**737**	**2 254**	**-873**	-	-
	-0.28%	**0.39%**	**1.23%**	**0.17%**	**0.38%**	**0.10%**	**0.32%**	**-0.12%**	-	-

Table 8–2 **Changes in Canada's GHG emissions from 729 Mt (for 2018, Previous Submission) to 730 Mt (for 2019, Current Submission)**

Sector	2018 to 2019 change (Mt CO_2 eq)	2018 change due to recalculations (Mt CO_2 eq)
Energy (Stationary Combustion)	1.2	-6.1
Energy (Transport)	1.6	-1.7
Energy (Fugitive)	-1.0	-0.7
Industrial Processes and Product Use	0.0	-2.0
Agriculture	-0.4	0.0
Waste	0.4	9.5
Total Change:	**1.8**	**-0.9**

Note: Totals may not add up due to rounding.

the updated CO_2 emission factor for producer-consumed natural gas in Alberta which caused a downward revision (-3.3 Mt) that was offset by increases to purchased natural gas consumption (+2.5 Mt). Additionally, revisions to the volumes of flared and vented gas in Saskatchewan and Alberta, which are subtracted from stationary combustion emission estimates in order to avoid double counting, resulted in a downward recalculation (-1.1 Mt). Downward recalculations for Manufacturing Industries (-1.7 Mt) are due to decreased volumes of natural gas combusted in the Chemical sector. For Petroleum Refining Industries, the change is a result of updated emission factors for petroleum coke and still gas. Finally, for Mining, increased volumes of coke combusted in Quebec (+0.6 Mt) and natural gas in Saskatchewan (+0.7 Mt) resulted in an upward revision in calculated emissions.

Energy (Transport)

Recalculations for the Transport sector were applied to the entire time series. The most notable of which is an emissions change of approximately -1.7 Mt (-0.8%) in 2018. The decrease is mainly due to the result of updates to preliminary motor gasoline and diesel fuel volume data used in the previous inventory. Recalculations for the rest of the time series are primarily driven by updates to the activity data in the marine consumption-based model and the aviation bottom-up model. In particular, the Marine Emission Inventory Tool (MEIT) was revised for the 2015 calendar year and new activity data for 2016, 2017 and 2018 were incorporated into the marine consumption-based model. For aviation, the aircraft performance data was updated, the aerodrome locations were redefined, and the aircraft movement statistics were refined.

Energy (Fugitives)

In the Fugitives subsector, Oil and Gas emission recalculations resulted in updated historical estimates for the entire time series. The methodology for estimating emissions from flaring and reported venting in Alberta were updated to incorporate new data sources. As a result, Alberta flaring emissions increased in 2010 and 2014–2018 with decreases in 2011–2013 ranging from -0.073 Mt CO_2 eq in 2012 to +0.064 Mt in 2017. Similarly, Alberta reported venting emissions emissions increased in 2010–2012 and decreased from 2013–2018, ranging from -0.761 Mt in 2016 to +0.372 Mt in 2010. Updated volumes of non-associated gas production in Alberta from 2012–2018 resulted in revisions to fugitive equipment leaks and unreported venting emissions in the Alberta Natural Gas Production subsector (ranging from -0.070 Mt to +0.028 Mt). Revisions to abandoned well counts in Saskatchewan, Alberta, British Columbia and New Brunswick resulted in minor recalculations

Table 8–3 **Summary of Recalculations by Sector**

	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2014	2015	2016	2017	2018	(1990–2018)	(2005–2018)
ENERGY (Stationary Combustion)										
Previous Submission (2020 NIR)	284 465	352 434	342 017	329 388	328 382	317 654	321 123	323 581	13.8%	-5.4%
Current Submission (2021 NIR)	277 722	344 748	340 523	322 634	323 997	311 116	315 717	317 502	14.3%	-6.8%
Change in Emissions	**-6 743**	**-7 686**	**-1 494**	**-6 753**	**-4 385**	**-6 538**	**-5 407**	**-6 079**	-	-
	2.4%	**2.2%**	**0.4%**	**2.1%**	**1.4%**	**2.1%**	**1.7%**	**1.9%**	-	-
ENERGY (Transport)										
Previous Submission (2020 NIR)	145 239	178 168	190 518	199 301	201 170	201 149	207 038	216 949	49.4%	13.9%
Current Submission (2021 NIR)	144 881	177 464	189 820	199 060	201 163	201 167	207 322	215 214	48.5%	13.4%
Change in Emissions	**-358**	**-704**	**-698**	**-241**	**-7**	**18**	**284**	**-1735**	-	-
	-0.2%	**-0.4%**	**-0.4%**	**-0.1%**	**0.0%**	**0.0%**	**0.1%**	**-0.8%**	-	-
ENERGY (Fugitive)										
Previous Submission (2020 NIR)	48 955	69 426	60 908	62 801	60 302	54 876	55 343	55 465	13.3%	-8.9%
Current Submission (2021 NIR)	48 956	69 495	60 904	62 621	59 484	54 133	54 767	54 799	11.9%	-10.0%
Change in Emissions	**1**	**69**	**-3**	**-180**	**-818**	**-743**	**-577**	**-666**	-	-
	0.0%	**0.1%**	**0.0%**	**-0.3%**	**-1.4%**	**-1.4%**	**-1.0%**	**-1.2%**	-	-
IPPU										
Previous Submission (2020 NIR)	56 912	54 005	56 553	54 736	54 338	55 226	54 015	56 319	-1.0%	-0.4%
Current Submission (2021 NIR)	57 020	54 114	56 612	53 934	53 491	54 473	53 041	54 345	-4.7%	-4.0%
Change in Emissions	**109**	**109**	**60**	**-802**	**-847**	**-753**	**-974**	**-1975**	-	-
	0.2%	**0.2%**	**0.1%**	**-1.5%**	**-1.6%**	**-1.4%**	**-1.8%**	**-3.5%**	-	-
AGRICULTURE										
Previous Submission (2020 NIR)	46 939	57 021	59 852	57 646	58 232	59 333	58 382	59 382	26.5%	-0.8%
Current Submission (2021 NIR)	46 940	57 021	59 884	57 672	58 257	59 366	58 341	59 427	26.6%	-0.8%
Change in Emissions	**1**	**-**	**32**	**26**	**25**	**33**	**-41**	**45**	-	-
	0.0%	**0.0%**	**0.1%**	**0.0%**	**0.0%**	**0.1%**	**-0.1%**	**0.1%**	-	-
WASTE										
Previous Submission (2020 NIR)	20 711	19 628	19 898	17 481	17 953	17 957	17 934	17 652	-14.8%	-11.3%
Current Submission (2021 NIR)	26 004	30 669	30 972	26 636	26 702	26 677	26 903	27 188	4.6%	-12.2%
Change in Emissions	**5 293**	**11 041**	**11 075**	**9 155**	**8 748**	**8 721**	**8 969**	**9 536**	-	-
	25.6%	**56.3%**	**55.7%**	**52.4%**	**48.7%**	**48.6%**	**50.0%**	**54.0%**	-	-
LULUCF										
Previous Submission (2020 NIR)	-59 627	-31 791	-12 706	-24 721	-18 154	-18 528	-16 414	-12 861	-78.4%	1.2%
Current Submission (2021 NIR)	-56 816	-21 741	8 189	-3 494	4 014	95	696	8 411	-114.8%	2.7%
Change in Emissions	**2 810**	**10 050**	**20 895**	**21 226**	**22 168**	**18 623**	**17 110**	**21 272**	-	-
	-4.7%	**-31.6%**	**-164.5%**	**-85.9%**	**-122.1%**	**-100.5%**	**-104.2%**	**-165.4%**	-	-

from 1990–2018 (ranging from -0.0007 Mt to +0.0043 Mt). The total number of operating wells in Alberta and Manitoba were revised, causing an increase in surface casing vent emission estimates with the largest increase in 2017 of +0.145 Mt. Other minor activity data changes resulted in additional minor revisions.

Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2018), ranging from -2.0 Mt to +0.12 Mt. A large contributor of recalculated emission values was a correction made to the Nitric Acid Production category for years 2008 to 2018. Emissions for a nitric acid production facility were recalculated using revised activity data and CEMS emission factor data to factor in N_2O abatement installations at two plants of this facility in 2008 and 2012–2013, respectively. These corrections ranged from -0.45 Mt in 2008 to -0.89 Mt in 2015.

Revisions to Statistics Canada's RESD data have resulted in recalculations for the Non-Energy Products from Fuels and Solvent Use category for the years 2011 to 2018, with 2018 observing the largest change of -0.56 Mt. For the Iron and Steel Production category, there was a method change introduced incorporating facility reported data, which resulted in recalculations for 2010–2018, ranging from -0.2 Mt in 2010 to -0.5 Mt in 2017. For the Cement Production category, there were updates to the emission factor for clinker production, the emission factor for total organic carbon in raw meal, the correction factor for cement kiln dust, and the incorporation of facility reported data. These resulted in recalculations for 1990 to 2018, ranging from 0.10 Mt in 2017 to -0.19 Mt in 2018.

Other minor recalculations include: revised 1990–2018 emission estimates (+0.016 to +0.034 Mt) for the Lime Production category to account for updates to the emission factor for high calcium lime, the emission factor for dolomitic lime, the correction factor for lime kiln dust, and the incorporation of facility reported data; revised 1990–2018 emission estimates (+0.022 to +0.030 Mt) for Ammonia Production category to correct for updated CO_2 emission factors for natural gas; revised 2013 to 2018 Other Uses of Urea emissions estimates (-0.0072 to 0.076 Mt) primarily due to updated fertilizer import and export data; revised 2011–2018 emission estimates (-0.026 Mt to +0.001 Mt) for the Product Uses as Substitutes for ODS category, specifically the consumption of HFCs, to account for updates in gross ouput data used in the data extrapolation process; revised 2009–2018 Integrated Circuit or Semiconductor emissions estimates (+0.000066 Mt to +0.038 Mt) mainly because of new activity data obtained from major gas distributors through a voluntary data survey conducted in 2019–2020; and revised 2010–2018 emission estimates (-0.00029 to +0.013 Mt) for the Magnesium Casting category to account for updates in gross output data used in data interpolations and inclusion of updated SF_6 use data provided by magnesium casting facilities.

Agriculture

Recalculations in the Agriculture sector were due to minor corrections to activity data for crop production and lime application, and minor modfications to the spatial distribution of livestock. As a result of these recalculations, agricultural emissions were revised upward by 1 kt in 1990, 32 kt in 2005, and 45 kt in 2018.

Waste

Recalculations in the Waste sector ranged from an increase of 5.2 Mt (25.6%) in 1990 to an increase of 11.7 Mt (60.1%) in 2003. By far the largest driver of recalculated emissions values was municipal solid waste (MSW) landfilling. This sector had model updates implemented that account for emissions from individual waste components, as opposed to calculations based on bulk (homogenous) waste. During the course of the update, it was discovered that previous decay rates were applied incorrectly, resulting in emissions below expected values, coupled with extremely long half-lifes of waste materials. These corrections to decay rates account for the majority of the recalculation. Other recalculations in MSW include the addition of sludge to the waste data and refinements on the waste disposal data over the time series.

In other waste sectors, the activity data for industrial wood waste was updated. Previously, the last data point was for 2004. Biological treatment of waste was updated for a Tier 1 method to Tier 3, allowing for the separatation of composting and anaerobic digestion to be estimated separately and at the facility level. For wastewater, a new sludge component was added to account for sludge in the wastewater model; wastewater effluent emissions, leaks for anaerobic digestion at wastewater facilities and other updates using the 2019 IPCC refinement were added. Lastly, in incineration, small corrections were made and one incineration facility's emissions were reallocated to the Energy sector. See Chapter 7, Table 7.2 for for recalculation values as well as Annex 3.6 for a detailed description of the waste methodologies.

Land-Use, Land-Use Change and Forestry

Recalculations also occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land and Harvested Wood Products categories. The most important recalculations were due to (i) the addition of new insect disturbances and corrections made to existing insect disturbances in the forest ecosystem model, (ii) updates made to bioenergy activity data, (iii) a correction in the list of excludable natural disturbances, and (iv) revisions to forest harvest activity data. Recalculations also occurred in estimates of woody biomass in Cropland Remaining Cropland mainly due to inclusion of an additional measurement point circa 2010 and the alignment with emissions of firewood sourced from Cropland but occurring in the Harvested Wood Products category. Other recalculations occurred in land categories associated with forest conversion, as a result of updates in forest conversion activity data for the period 2013–2018. The combined impact of these and other minor recalculations in the LULUCF sector decreased the estimates of net removals by 2.8 Mt for 1990, and switched the net sinks previously reported for 2005 and 2018 to net sources representing a total change of 21 Mt in both years.

Refer to Table 8–4 for more details on implemented improvements.

8.2. Inventory Improvements

Inventory improvements aim to improve the accuracy of GHG estimates or enhance components of the inventory preparation process, including the supporting institutional, legal and procedural arrangements. Improvements that involve a methodological change or refinement must be documented and reviewed prior to implementation. Improvements that lead to recalculations of estimates must be applied across the time series to maintain consistency.

This year, improvements to Canada's inventory resulted from recommendations from expert review teams (ERTs), continued implementation of the *2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (2006 IPCC Guidelines) or internal continuous improvement activities.

Table 8–4 provides additional information about the improvements implemented this year.

8.2.1. Expert Review Team Recommendations

Canada's inventory submission is typically reviewed annually by an ERT following agreed-upon UNFCCC review guidelines[1] as adopted in Decision 13/CP.20 at COP 20 in Lima in 2014. Reviews are coordinated by the UNFCCC Secretariat, and the ERT is composed of inventory experts from developed and developing countries. The purpose of the review is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to the UNFCCC Reporting Guidelines. At the end of the review, the ERT provides technical feedback on any methodological and procedural issues encountered. The ERT will focus on instances where the guiding principles of transparency, consistency, comparability, completeness and accuracy of the inventory could be improved. The outcome of the review is reflected in an annual review report (ARR) that is provided to the country under review and made public by the UNFCCC.

The recommendations from ERTs were taken into consideration when identifying potential improvements for this year. The latest review by the ERT can be found on the UNFCCC website.[2]

Methodological changes this year that addressed ERTs recommendations include the following:

- integration of recent afforestation activity data update for the province of Ontario
- updated CO_2 emission factors for Alberta producer consumption of natural gas

8.2.2. 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories

The 2006 IPCC Guidelines contain internationally agreed-upon methodologies for use by countries to estimate GHG emissions and to report to the UNFCCC (IPCC, 2006). These guidelines were developed by the IPCC at the invitation of the UNFCCC. The 2006 IPCC Guidelines encourage the use of country-specific refined methodologies for estimating emissions, including complex modelling approaches at higher tiers.

The 2006 IPCC Guidelines became the methodological reference in 2015, in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories for Annex I Parties (UNFCCC Reporting Guidelines), as adopted in Decision 24/CP.19 at COP 19 in Warsaw in 2013. Methodological changes made this year for consistency with the 2006 IPCC Guidelines include the following:

- inclusion of by-product C_2F_6 emissions from c-C_4F_8 use in semiconductor manufacturing

8.2.3. Continuous Improvements

The GHG inventory team also identifies improvements based on evolving science, quality assurance / quality control (QA/QC) and verification activities (in accordance with the QA/QC Plan), and new and innovative modelling approaches or new sources of activity data. Implementation of the improvements is prioritized by taking into consideration the outcomes of the key category and uncertainty analysis, the level of effort and the significance of the improvements. Examples of continuous improvement activities implemented in this year's inventory include:

- updated activity data for residential wood combustion
- updated activity data for the aviation bottom-up model
- updated method to calculate emissions from flaring and reported venting activities in the Alberta oil and gas industry

1 The Guidelines for the technical review of information reported under the Convention related to greenhouse gas inventories, biennial reports and national communications by Parties included in Annex I to the Convention can be found here: http://unfccc.int/resource/docs/2014/cop20/eng/10a03.pdf#page=3

2 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2019

- development of a facility-based oil sands emissions model to improve the allocation of IPCC sector to Economic sector for the Oil and Gas sector
- updated emission factors, correction factor and implemented Tier 3 methodology for the cement and lime production model
- improved activity data and model approach to estimate bioenergy emissions
- implemented deforestation new mapping 2013–2018
- improved estimates of uncertainty for the Harvested Wood Products category
- updated landfill waste model, implementing waste-specific parameters (as opposed to using bulk waste values); new waste decay rates based on wet and dry climate
- new facility level emissions estimates for composting and anaerobic digestion

8.3. Planned Inventory Improvements

Canada's planned improvements to the national GHG inventory are contained in an *Inventory Improvement Plan* that identifies and tracks planned improvements to emission estimates (including underlying activity data, emission factors and methodologies). The planned improvements are based on recommendations from internal sources and external review processes and on collaborative work between inventory sector experts and industry, other government departments and academia.

Planned improvement activities (Table 8–5) are prioritized by taking into consideration key category analysis, QA/QC activities, uncertainty assessments, the level of effort and the significance of the improvements. Although the quantification of uncertainty for the emission estimates (Annex 2) helps prioritize improvement activities for future inventories, uncertainty itself is not an indicator of potential future changes resulting from continuous improvement activities. The Inventory Improvement Plan is updated annually to track progress in implementing improvements to the inventory. Table 8–4 and Table 8–5 are updated as planned improvements are implemented each year.

Significant improvements to NIR estimates are anticipated in the 2022 edition of this report, following the implementation of a new fugitive emission model to estimate CO_2 and CH_4 emissions from pneumatic devices, compressor seals and equipment leaks in the upstream oil and gas industry.[3] The new model will use Canadian-specific studies and knowledge, will facilitate the adoption of new scientific data, and better capture the impact of improvements in technologies and industry practices on emissions.

3 See improvement "More adaptive method of estimating fugitive emissions from Oil and Natural Gas systems" for category Oil and Natural Gas – Fugitive (CRF 1.B.2) in the Energy sector in Table 8–5.

Table 8–4 **Improvements to Canada's 2021 NIR**

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Transport)	Domestic Aviation (CRF 1.A.3.a) Other Mobile (Military Aviation) (CRF 1.A.5.b) International Aviation (CRF 1.D.1.a)	Updated activity data for the aviation bottom-up model.	Updates to the activity data for the aviation bottom-up model were made. This includes updated aerodrome locations, aircraft descriptions, aircraft parameters, engine descriptions, engine parameters and flight distances.	Continuous improvement	Annex 3.1.4.2.2
	Marine Navigation (CRF 1.A.3.d) Fishing (CRF 1.A.4.c.iii) Other Mobile (Military Navigation) (CRF 1.A.5.b) International Navigation (CRF 1.D.1.b)	Updated activity data for marine consumption-based model.	Updated vessel activity data was incorporated into the marine model. The Marine Emission Inventory Tool (MEIT) updated their 2015 model and produced data for the 2016, 2017, 2018 calendar years.	Continuous improvement	Annex 3.1.4.2.3
Energy (Combustion)	Public Electricity and Heat Production (CRF 1.A.1.a) Petroleum Refining (CRF 1.A.1.b) Manufacturing Industries and Construction (CRF 1.A.2) Other Sectors (CRF 1.A.4)	Updated CO_2 emission factors and energy content for still gas and petroleum coke (excluding upgraders).	The emission factors for CO_2 taken from the Canadian Energy and Emissions Data Centre (CEEDC) were adjusted to better represent several refineries reporting to CEEDC. In addition, the energy content for still gas and petroleum coke was updated to use the annual values CEEDC produces, since it is based on information collected at the refinery level.	Continuous inventory improvement	Annex 6.1.2
	Residential (CRF 1.A.4.b)	Updated the activity data for residential fuelwood consumption for the entire time series (1990–2019).	A new time-series data set for quantity of wood combusted in the residential sector was created on a provincial level using Statistics Canada's Household and Environment Survey (HES) data from 2007, 2015, and 2017, along with Survey of Household Energy Use (SHEU) data from 1996 and 2003. HES 2017 collected detailed data on the quantity of wood, equipment used, and type of wood.	Continuous inventory improvement	Annex 3.1

Table 8–4 **Improvements to Canada's 2021 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
	Oil and Gas Extraction (CRF 1.A.1.c.ii)	Updated CO_2 emission factors for Alberta producer consumption of natural gas.	The Energy and Emissions Research Laboratory (EERL) at Carleton University analyzed over 400,000 raw gas samples obtained from the Alberta Energy Regulator (AER) to produce average gas compositions by Alberta Township. Annual volume-weighted CO_2 emission factors for 2010 to 2019 for raw natural gas consumed as fuel at oil and gas facilities are calculated using the new gas composition data and 2010 to 2019 Petrinex reported fuel gas volumes by township. As Petrinex data prior to 2010 is unavailable to ECCC, an average CO_2 emission factor for 1990 to 2009 has also been calculated.	UNFCCC ERT recommendation and Continuous inventory improvement	Annex 6.1.1
	Oil and Gas Extraction (CRF 1.A.1.c.ii)	Revised volumes of gas flared subtracted from stationary combustion in order to avoid double counting.	In order to avoid double counting, volumes of flared gas and associated emissions must be subtracted from Oil and Gas Extraction (CRF 1.A.1.c.ii) since flared volumes are included in Statistics Canada's producer consumption fuel data and flaring emissions are reported in Fugitive Emissions from Fuels – Venting and Flaring – Flaring (CRF 1.B.2.c). The flared gas volumes subtracted for the years 1990 to 2018 in Saskatchewan were revised based on an improved understanding of the data.	Continuous inventory improvement	Annex 3.2.2.7
Energy (Fugitive Emissions)	Fugitive Emissions from Fuels – Oil and Natural Gas – Venting and Flaring (CRF 1.B.2.c)	Updated method for estimating flaring and reported venting emissions in Alberta.	Alberta reported venting and flaring emissions are based on the Clearstone (2014) UOG study for the 2011 data year and extrapolated based on annual reported venting and flaring volumes. This method assumes a static gas composition based on the 2011 data year. The Energy and Emissions Research Laboratory (EERL) at Carleton University analyzed over 400,000 raw gas samples obtained from AER to produce average gas compositions by Alberta township. Emissions from flaring and reported venting are now calculated directly for the years 2010 to 2019 using the gas composition data by township and facility reported volumes of gas flared and vented from the Petrinex reporting system.	Continuous inventory improvement	Annex 3.2.2.1.2
Oil and Gas (Economic Sector)	Natural Gas Production and Processing Conventional Light Oil Production Conventional Heavy Oil Production Oil Sands (Mining, In-situ, Upgrading)	Refinements to allocation of IPCC sector to Economic sector emission estimates for Oil and Gas sector.	A new facility-based combustion model for Canada's Oil Sands was developed; including oil sands mining and extraction, crude bitumen upgrading and in-situ extraction (primary extraction, cyclic steam stimulation (CSS) and steam-assisted gravity drainage (SAGD)). This model provides emission estimates for all combustion sources, including stationary combustion, on-site transportation and cogeneration. It is used to allocate combustion emissions by IPCC sector, calculated using the Report on Energy Supply and Demand in Canada (RESD) data, to the Oil Sands sector as presented in the Economic Sector tables. It does not change national or provincial emission totals.	Continuous inventory improvement	Annex 10
IPPU	Cement Production (CRF 2.A.1)	Updated emission factors for clinker production (2015–2016) and for total organic carbon (TOC) (1990–2016), and the correction factor for cement kiln dust (CKD) (1990–2016). Updated clinker production capacities of cement production facilities for 2014–2016. Implemented Tier 3 methodology using GHGRP expanded cement data for 2017–2019.	1. The emission factor for TOC and the correction factor for CKD were previously averages that were kept constant throughout the time series, but have been updated to be year-specific. 2. Clinker production capacities of cement production facilities for 2014–2016 were previously assumed to stay constant at 2013 levels but have been updated based on data received from the Mining and Processing Division (MPD) of ECCC. 3. The emission factors for clinker production and TOC and the correction factor for CKD for 2015–2016 were previously assumed to stay constant at the 2014 values but have now been updated to be an average of the 2014 values calculated based on the data from the Cement Association of Canada and the 2017 values calculated based on the GHGRP expanded cement data. 4. The Tier 3 methodology uses all of the CO_2 emissions reported by Canadian cement production facilities under Schedule 9 of the GHGRP Notice to estimate the national and provincial territorial CO_2 emissions for 2017–2019.	Continuous Improvement	Chapter 4

Table 8–4 **Improvements to Canada's 2021 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
IPPU (cont'd)	Lime Production (CRF 2.A.2)	Updated calcining capacities of lime production facilities for 2009–2016. Updated 2009–2016 emission factors for high-calcium lime and for dolomitic lime. Updated 1990–2016 correction factor for lime kiln dust (LKD). Implemented Tier 3 methodology using GHGRP expanded lime data for 2017–2019.	1. Calcining capacities of lime production facilities for 2012–2016 (previously assumed to stay constant at 2011 levels) and those for 2009 and 2010 have been corrected and updated for based on data received from the Mining and Processing Division (MPD) of ECCC. 2. The emission factors for high-calcium lime and dolomitic lime for 2009–2016, previously assumed to stay constant at the 2008 values, have now been updated to be an average of the 2008 values calculated based on the data from the Canadian Lime Institute and the 2017–2019 values calculated based on the GHGRP expanded lime data. 3. The correction factor for LKD for 1990–2016, previously assumed to be the 2006 IPCC default value, has now been updated to be an average of the 2017–2019 correction factor for LKD calculated based on the GHGRP expanded lime data. 4. The Tier 3 methodology uses all of the CO_2 emissions reported by Canadian lime production facilities under Schedule 8 of the GHGRP Notice to estimate the national and provincial territorial CO_2 emissions for 2017–2019.	Continuous Improvement	Chapter 4
	Nitric Acid Production (CRF 2.B.2)	Corrections to Nitric Acid Production activity data and emission factors for the largest emitting facility.	Corrected activity data and emission factors for both plants at the largest emitting facility for years 2008–2018. Process-gas catalytic decomposition abatement catalysts were installed in 2008 at one plant, and 2012–2013 at the other. Plant-specific activity data and CEMS emission factors are used to recalculate N_2O emissions for this facility in the inventory.	Continuous improvement	Chapter 4
	Iron and Steel (CRF 2.C.1)	Update to activity data, carbon contents and emissions factors based on facility reported data provided through the GHGRP.	As assessment of facility reported data to the GHGRP for the years of 2017 to 2019 was completed validating previous activity data sources and to update static carbon content and emission factors. Emissions factors for coke use, electrode consumption in electric arc furnaces and basic oxygen furnaces were updated, as well as carbon contents of pig iron produced, pig iron used for steel making, crude steel produced in both the electric arc furnace and the basic oxygen furnace and scrap steel.	Continuous improvement	Chapter 4
	Semiconductor Manufacturing (CRF 2.E.1)	Collection of 2014 to 2019 NF_3, SF_6 and PFC intended use and sales data from major gas distributors and annual emission factors from the largest known semiconductor manufacturer.	Major gas distributors have provided annual distribution quantities and intended uses or customer lists for years 2014–2019. When customer lists and quantities sold were provided, semiconductor manufacturers were identified based on company research and cross-checked with a list of semiconductor and related product fabricators from a 2014 Cheminfo study. The largest known semiconductor manufacturer was surveyed to verify its use data and to provide information on its abatement technology use and the destruction efficiency. This information was provided for 2014–2019 and incorporated into the inventory estimates.	Continuous improvement	Chapter 4
	Semiconductor Manufacturing (CRF 2.E.1)	Inclusion of by-product C_2F_6 emissions from the use of c-C_4F_8 in semiconductor manufacturing.	By-product emissions of CF_4 have been included in past inventories, but the omission of by-product C_2F_6 emissions produced from the use of c-C_4F_8 was discovered from QA/QC procedures. No by-product C_3F_8 emissions are produced since C_4F_8O is not known to be distributed in Canada.	Continuous improvement	Chapter 4
	Product Uses as Substitutes for ODS – PFCs (CRF 2.F)	Collection of 2014 to 2019 PFC intended use and sales data from major gas distributors.	Major gas distributors have provided annual distribution quantities and intended uses or customer lists for years 2014–2019. The collected data indicates no intended use for PFCs as Substitutes for ODS, as all intended uses were attributed to Semiconductor Manufacturing (2.E.1) or as a Heat Transfer Medium, which is classified under PFC Emissions from Other Contained Product Uses (CRF 2.G.4).	Continuous improvement	Chapter 4
	PFC Emissions from Other Contained Product Uses (CRF 2.G.4)	Collection of 2014 to 2019 PFC intended use and sales data from major gas distributors.	Major gas distributors have provided annual distribution quantities and intended uses or customer lists for years 2014–2019. Activity data for intended PFC use as a heat transfer medium was included by one gas distributor. IPCC Tier 2 emission factors (IPCC 2000) are used for the inventory. There is no default emission factors in the 2006 IPCC GLs for this category.	Continuous improvement	Chapter 4

Table 8–4 **Improvements to Canada's 2021 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
LULUCF	Forest Land Remaining Forest Land (CRF 4.A.1)	Improved post-1990 insect disturbances.	Improved implementation of existing disturbance matrices for insects in QC and AB. Added several disturbance matrices and other relevant activity data for new insect time series in AB, BC, SK, MB, NWT and YT. Corrected list of excludable natural disturbances (impacted anthropogenic partition).	Continuous improvement	Chapter 6.3
	Forest Land Remaining Forest Land (CRF 4.A.1)	Correction to BC volume to biomass conversion.	Correction to previous improvement. Based on an external review by the government of British Columbia, another correction to the volume-to-biomass parameter update was implemented.	Continuous improvement	Chapter 6.3
	Forest Land Remaining Forest Land (CRF 4.A.1) Harvested Wood Products (CRF 4.G)	Update 1990–present forest activity data time series.	Captured revisions to National Forestry Database (NFD) harvesting, thinning and prescribed burning statistics. Set harvest efficiency parameter to 1 in all projects (to help extend shelf-life of current NFCMARS system).	Continuous improvement	Chapter 6.3 Chapter 6.4
	Forest Land Remaining Forest Land (CRF 4.A.1) Cropland Remaining Cropland (CRF 4.B.1) Settlements Remaining Settlements (CRF 4.E.1) Harvested Wood Products (CRF 4.G)	Bioenergy improvements	Revised firewood consumption statistics through improved collaboration with Statistics Canada, allowing updates to bioenergy activity data resulting from improved residential firewood data. Modified harvest routines for firewood supply sourced from FLFL (live and DOM), and sourced firewood from other land-use categories, CLCL (woody biomass on croplands), SLSL (urban trees) and HWP (pellets, manufactured logs). Corrected emission factors for industrial firewood through collaboration with the Energy Sector, Forest Products Association of Canada (FPAC) and the National Council for Air and Stream Improvements (NCASI). Allocation of un-combusted C to bioenergy emissions.	Continuous improvement	Chapter 6.3 Chapter 6.4 Annex 3.5.2 Annex 3.5.3
	Land Converted to Forest Land (CRF 4.A.2)	Afforestation activity data update for Ontario.	Thorough review of Forests Ontario to identify records appropriate for inclusion in NIR estimates. Planting activities added span 2007–2015, most (but not all) in southern Ontario. Yield curves developed and implemented.	UNFCCC ERT recommendation and Continuous improvement	Chapter 6.3
	Cropland Remaining Cropland (CRF 4.B.1)	Updates to woody biomass time series.	Addition of new observation data (2010) allowed a trend analysis and therefore, a time series data on the changes in woody biomass in Croplands was estimated. A thorough quality check on the procedure used to identify the woody biomass from the aerial photographs was conducted. This resulted in refinement of estimates. Furthermore, the woody biomass estimates were reconciled with the residential firewood estimates reported under Harvested Wood Products.	Continuous improvement	Chapter 6.5 Annex 3.5.4
	Land Converted to Cropland (CRF 4.B.2) Land Converted to Settlements (CRF 4.E.2) Harvested Wood Products (CRF 4.G)	Deforestation new mapping 2013–2018.	Result of standard protocol of updates to activity data. Completed mapping in 12 260 sample cells. New pivot point resulted in interpolation between 2010 and 2015.	Continuous improvement	Chapter 6.9 Annex 3.5.2.6
	Harvested Wood Products (CRF 4.G)	Improve uncertainty estimates.	Significant changes to the uncertainty estimation methodology for Harvested Wood Products (HWP) that include an update to the probability distributions for many HWP modelling parameters, as well as the coupling of uncertainty between forest modelling with CBM-CFS3 and HWP modelling.	Continuous improvement	Chapter 6.4 Annex 3.5.3
Waste	Solid Waste Disposal (CRF 5.A)	The waste model was updated to enable emissions calculations based on waste subcomponents, whereas previously emissions were calculated using bulk waste (averaged waste content). Additional refinements were also made (see description).	Estimations of methane emissions now use waste-specific parameters according to the type of waste: paper, food, plastic, etc. (as opposed to using bulk waste values). Decay Rates are now based on default IPCC 2006 climate approach (precipitation & evapotranspiration) and includes a new mapping of Provinces and Territories into "wet" and "dry" zones based on meteorological data. Sewage sludge landfilled is included in quantities landfilled and Disposal and Exports have been recalculated.	Continuous improvement	Chapter 7.2.5
	Biological treatment of Waste (CRF 5.B)	Addition of anaerobic digestion to estimates, update to composting model.	Updates include time series modifications to waste volumes sent to composting through the development of a facility-level inventory. Updates to emission factors for composting by input feedstock types. Canada now includes anaerobic digestion for Municipal and Industrial facilities under Biological Treatment of Waste as well, waste volumes sent to anaerobic digestion are developed through a facility-level inventory. Methane loss is based on onsite leakages of anaerobic digestion systems, developed through a literature review approach.	Continuous Improvement	Annex 3.6.2

Table 8–4 **Improvements to Canada's 2021 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Waste (cont'd)	Solid Waste Disposal (CRF 5.A.2)	Update to activity data.	Updating of activity data based on a survey of pulp and paper industries. In addition, a review of the solid wood industry (sawmills) determined that waste residues from this sector are no longer landfilled.	Continuous Improvement	Annex 3.6.1.3
	Municipal Wastewater Treatment/Discharge (CRF 5.D)	This method change includes: • Inclusion of industrial correction factor to domestic wastewater • Accounting for sludge • Anaerobic digestion of sludge at wastewater treatment plants • Emissions from organics in effluent in receiving waterbody	A number of updates were made to the wastewater sector, notably a more robust accounting for sludge removal, inclusion of anaerobic digestion fugitive losses and addition of emissions related to wastewater effluent. A number of parameters from the 2019 IPCC refinement were also added to the model.	Continuous improvement	Annex 3.6.4

Table 8–5 **Summary of Canada's Inventory Improvement Plan**

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Energy	General	Conversion of volumes of natural gas to energy units.	An investigation is underway to obtain current and historical activity data to allow volumes of natural gas to be converted to energy units, by the province in which they are consumed.	UNFCCC ERT recommendation	Data collection and analysis underway
	General	Natural gas fuel composition study. Update carbon and energy content for inventory use.	Canada is a producer, exporter and importer of natural gas, with varying composition across consuming regions. The objective of this project is to determine, develop and collect representative natural gas composition at key delivery points for each consuming province and territory to improve the accuracy of GHG emission estimates.	Continuous improvement	Data collection and analysis underway
	Oil and Natural Gas – Fugitive (CRF 1.B.2)	More adaptive method of estimating fugitive emissions from Oil and Natural Gas systems.	Work is underway to develop a method to estimate fugitive emissions from the oil and gas industry that more easily facilitates the adoption of new scientific data and properly captures the impact of technological improvements and/or regulations on emissions. The current method is dependent on comprehensive studies that occur approximately every 5 years with emission intensities remaining static between studies. Currently, emissions are estimated for intervening years based on changes to activity data such as production volumes, number of wells drilled, volumes of fuel flared and vented, etc.	Continuous improvement	Alternative methods being considered
	Oil and Natural Gas – Fugitive (CRF 1.B.2)	Analyze and incorporate raw gas composition data for the province of British Columbia into emission estimates.	The British Columbia Oil and Gas Commission (BCOGC) collects measured raw gas composition data for oil and gas wells drilled in the province and makes the data available on their website. The data will be analyzed to improve fugitive emission estimates from oil and gas facilities and the CO_2 emission factors used to estimate emissions from raw gas combustion at oil and gas facilities.	Continuous improvement	Data collection underway
	Oil and Natural Gas – Fugitive (CRF 1.B.2)	Incorporation of measurement data from accidental venting from well surface casing vents.	The Alberta Energy Regulator (AER) and British Columbia Oil and Gas Commission (BCOGC) track data on accidental venting from well surface casing vents, which accounts for a significant amount of oil and gas fugitive emissions. The current estimation method has high uncertainty while the new data is based on measurements and should increase accuracy and lower uncertainty.	Continuous improvement	Data analysis underway
	Off-Road Transportation (General)	Revamp of off-road emissions model inputs.	Work is underway to incorporate several major updates to off-road model inputs. These updates include implementing new off-road equipment population data for all reported calendar years, modifying the geographical distributions assigned to off-road equipment and updating the annual hours of use parameter for select off-road equipment types.	Continuous improvement	Data collection and analysis underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Energy (cont'd)	Off-Road Transportation (General)	Off-road emissions model update.	Work is underway to improve the already modified version of the United States Environmental Protection Agency's off-road emissions model NONROAD. As per an ERT recommendation, the improved model will include consumption and emissions of lube oils used in two-stroke gasoline engines. In addition, the improved model will have updated reference tables to ensure the inclusion of new off-road equipment types introduced since the last model update.	UNFCCC ERT recommendation	Verification and finalization of improvement
	Road Transportation (CRF 1.A.3.b)	Revamp of on-road emissions model inputs.	Work is underway to incorporate several major updates to on-road model inputs. These updates include implementing new on-road vehicle population data and utilizing more recent kilometer accumulation rates.	Continuous improvement	Data collection and analysis underway
	Road Transportation (CRF 1.A.3.b)	Transition to an improved on-road emissions model.	Subject to review, ECCC intends to adopt the United States Environmental Protection Agency's most recent motor vehicle emission simulator $MOVES_3$. Some benefits of transitioning from MOVES2014b to $MOVES_3$ are updated emission rates and adjusted modelling to better account for vehicle starts and long-haul truck hoteling.	Continuous improvement	Model review underway
Oil and Gas (Economic Sector)	Natural Gas Production and Processing Conventional Light Oil Production Conventional Heavy Oil Production Oil Sands (Mining, In-Situ, Upgrading)	Refine allocation of emissions from Total Mining and Oil and Gas Extraction to the various oil and gas industry segments (i.e. Light crude oil production, Natural gas production and processing, Oil sands mining, extraction and upgrading, etc.)	Statistics Canada reports fuel consumption data in the aggregated category "Total Mining and Oil and Gas Extraction" which includes all mining sectors (i.e. coal, metal mining, non-metal mining, oil sands mining) and oil and gas extraction. Work is underway to refine the model used to allocate fuel consumption and the subsequent emissions from the aggregated category to more discrete categories and sub-categories. Additional analysis is being done to refine the allocation of fugitive emissions between conventional heavy oil and primary oil sands production.	Continuous improvement	Data analysis underway
IPPU	Methanol Production (CRF 2.B.8.a)	Validate the applicability of EFs used.	The EFs used to estimate emissions from methanol production came from the 2010 Cheminfo study. The improvement plan is to assess the applicability of such EFs for years post-2010.	UNFCCC ERT recommendation	No significant progress made
	Iron and Steel Production (CRF 2.C.1)	Allocate natural gas and coal emissions associated with manufacturing with iron and steel manufacturing to Iron and Steel Production instead of the Energy sector's manufacturing, and IPPU sector's Non-Energy Products from Fuels and Solvent Use, respectively.	A part of the process CO_2 emissions associated with Iron and Steel Production originates from the use of reductants other than metallurgical coke; more importantly, natural gas and coal. Natural gas is used as a reductant in the Direct Reduced Iron (DRI) method of iron manufacturing and is currently reported as part of the Energy sector's CO_2 emissions associated with Iron and Steel Production. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Non-energy Products from Fuels and Solvent Use sub-category. It is planned to allocate the aforementioned emission to the Iron and Steel Production Category.	UNFCCC ERT recommendation	Data analysis underway
	Non-Energy Products from Fuels and Solvent Use (CRF 2.D)	Update emission factors for various non-energy petroleum products and natural gas.	Emission factors for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. There is a plan to evaluate whether these emissions factors are still valid and update if necessary.	UNFCCC ERT recommendation	No significant progress made
	Product Uses as Substitutes for ODS (HFCs, CRF 2.F)	Develop means to annually update in-item HFC use.	A data gap exists with the in-item data that is available up to 2010. To fill this gap, statistics and import/export data will be examined to determine a method to arrive at HFC quantities.	Continuous improvement	No significant progress made
	Electrical Equipment (CRF 2.G.1)	Reporting of CF_4 emissions.	SF_6 is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF_6 gas can be mixed with CF_4 gas. Currently, Canada only reports SF_6 from this source category and it is planned to report CF_4 emissions as well.	Continuous improvement	Initiated data collection / study
	Hydrogen Production	Include CO_2 emissions resulting from stand-alone hydrogen production facilities in Canada.	Collect hydrogen production activity data and estimate CO_2 emissions from this source using methods presented in the 2019 Refinements to the 2006 IPCC Guidelines.	Continuous improvement	Data collection underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU (cont'd)	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Resolve 2017–2019 activity data discrepancies and identify new activity data source (as necessary).	Potential discrepancies were observed in 2017–2019 data on limestone and dolomite use in various sectors, particularly for iron and steel, and ferrous foundry sectors. Investigations have been started and will be continued to determine if corrections are needed and if a new data source is needed.	Continuous improvement	Data analysis underway
	Product Uses as Substitutes for ODS – HFCs (CRF 2.F)	Update end-of-life emission factors for HFCs in refrigeration and air conditioning applications.	End-of-life emission factors for HFCs in refrigeration and air conditioning applications are currently from the 2006 IPCC guidelines. Information and data on HFC recovery at the end-of-life for refrigeration and air conditioning applications will be collected (e.g., from industry associations) and assessed to determine the feasibility of developing country-specific end-of-life emission factors.	Continuous improvement	No significant progress made
	Semiconductor Manufacturing – NF_3, SF_6, PFCs (CRF 2.E.1)	Collection of 2014–2019 activity data and emission factor information from end users.	The largest known semiconductor manufacturer in Canada was surveyed and provided validation information on their purchase of NF_3, SF_6, and PFCs (previously provided in gas distributor surveys). It also provided information on the emissions abatement technology utilization and efficiency for each gas used. Other known semiconductor manufacturers, who are also purchasers of NF_3, SF_6, and PFCs, will be contacted to confirm their purchase quantities and to collect data that can be used to develop facility-specific emission factors (where possible).	Continuous improvement	Data collection underway
	SF_6 and PFCs from other product use – SF_6 (CRF 2.G.2)	Data collection and significance assessment.	Collected 2014–2019 sales data from gas distributors from voluntary data surveys indicate that SF_6 may be used as a leak detector in certain military applications and for adiabatic applications – i.e. "other product use." Disaggregated 2.G.2 categories will be included in 2019–2020 gas distributor data surveys to ensure that major distributors can identify and report these categories as intended uses if they occur. A Tier 1 emission estimation will be performed for these years to assess the significance level of emissions coming this category. If the category is determined to be significant, efforts will be made to develop emission estimates for the whole time series.	UNFCCC ERT recommendation	Data collection underway
	N_2O Emissions from Medical Applications (CRF 2.G.3.a) and Propellant Usage (CRF 2.G.3.b)	Update N_2O sales patterns by application.	The N_2O sales pattern by application is based on 2005 data and has been assumed to be the same since. Work is underway to update the sales pattern by application.	Continuous improvement	Data collection underway
	Ammonia Production (2.B.1)	Update activity data.	Emissions from ammonia production are currently estimated based on "estimates" of natural gas use as feedstock. These estimates are obtained through multiplication of ammonia production values by ammonia-to-feed fuel conversion factors. Work is underway to assess the quality and accuracy of natural gas use as feedstock values reported by facilities. If the facility-reported data are determined to be accurate, they will be used as activity data in future inventories.	Continuous improvement	Data analysis underway
Agriculture	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/Agricultural Soils (CRF 3.D)	Integrate new information on animal nutrition.	Continued improvements to animal nutrition time series are being carried out based on the review and compilation of multiple data sources. Although priority is on the beef sector, minor refinements to the dairy and swine sectors will be carried out as required. Data have been collected and analyzed, but model development is not complete. Approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, are required, to be followed by database implementation.	Continuous improvement	Developing new parameters
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/Agricultural Soils (CRF 3.D)	Update dairy nutrition parameters.	A dairy nutrition time series is currently used to track changes in animal feed and characteristics for dairy cattle. Updates to the nutrition data for dairy cattle are being derived for years after 2010. Data have been acquired and are undergoing analysis. Approval and alignment with AAFC methodologies will be followed by database implementation.	Continuous improvement	Data analysis underway
	Manure Management (CRF 3.B)	Integrate new information on manure management systems.	Information from multiple surveys to attempt to develop a consistent representation of the changes in manure storage systems for beef over the reporting period, better capture changes in farm practices and improve the accuracy of emission estimates. Data have been collected and analyzed but require approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, followed by database implementation.	Continuous improvement	Developing new parameters

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Agriculture (cont'd)	Manure Management (CRF 3.B)	Revise methane conversion factors (MCFs).	Methane conversion factors (MCFs) obtained from the 2006 IPCC guidelines are currently used in the calculation of manure management methane emissions. For certain manure management systems, the default MCF is selected based on a relationship with the average annual temperature of the manure systems. An updated methodology has been provided in the 2019 refinement that uses monthly temperatures and retention time as predictors of methane loss, rather than an averaged annual temperature. Canada plans to implement the 2019 refinement approach as both a continuous improvement and to address an ERT recommendation to regarding the current averaged MCFs used.	UNFCCC ERT recommendation	Data collection underway
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating soil nitrous oxide emissions.	A compilation of soil N_2O flux data since 1990 collected mainly through published literature is on-going to identify key factors, including soil properties, climatic conditions, N sources and management practices in explaining N_2O emissions from agricultural soils in Canada, and to re-evaluate the empirical relationship between N_2O emission factors and the growing season precipitation and evapotranspiration.	Continuous improvement	Developing new parameters
	Agricultural Soils (CRF 3.D)	Integrate estimates of N_2O emissions from land application of compost.	Canada currently does not report N_2O emissions from the application of compost to agricultural soils, due to a lack of activity data. A contract is underway to collect information on land application of compost in Canada, after which the data will undergo analysis, approval, alignment and integration with the existing organic N fertilizer methodology.	UNFCCC ERT recommendation	Initiated data collection / study
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating soil nitrous oxide emissions from cultivation of histosols.	Revise estimates for Cropland on drainage of organic soils considering guidance from the IPCC Wetlands Supplement.	Continuous improvement	Data analysis underway
	Field Burning of Agricultural Residues (3.F)	Improve estimates of crop residue burning.	Data on crop residue burning are available from the Farm Environmental Management Survey (2011), but these data have not been updated for estimating emissions of GHGs. Survey data on field burning of agricultural residues will be extracted and incorporated into the database.	Continuous improvement	Data analysis underway
LULUCF	Cross-cutting	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Data collection underway
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not been undertaken due to resource limitations. Uncertainty estimates for new and updated categories have been included in recent submissions. Canada aims to develop a plan for estimating, updating and reporting uncertainties for all LULUCF subcategories.	UNFCCC ERT recommendation	Alternative methods being considered
	General: Land Transition Matrix (CRF 4.1)	Revise and improve the consistency and completeness of the land transition matrix.	Include in the next NIR any update on the status of implementation of the project to revise and improve the consistency and completeness of the land transition matrix.	UNFCCC ERT recommendation	Data analysis underway
	Forest Land Conversion FLCL, FLWL, FLSL (CRF 4.B.2, 4.D.2, 4.E.2)	Land-use change improvements – Update and improve forest conversion activity data, parameters and processes.	In the medium-term, improvements to: i) 1970 to 201X deforestation activity data used by CBM-CFS3 and others; ii) Northern RU Deforestation Mapping, improved alignment with non-forested northern land-use change; and iii) Update deforestation pre-type proportion assumptions.	Continuous improvement	Developing new parameters
	Forest Land (CRF 4.A)	Updates to Baseline data/processes/ parameters as input into the Carbon Budget Model.	Updates in the short-term include: i) Improved identification of the stand initiating disturbance in stands that were disturbed prior to 1990 disturbances; ii) Refinements to post-1990 insect disturbances activity data; iii) Refinements to forest management activity data time series; and in the medium-term include: iv) Improvements to the spatial distribution of harvest; v) Refinements to wildfire emissions estimates, incorporating variable fire intensity; vi) Refinements to regional estimates of slashburning activity; vii) Updates to volume-to-biomass coefficients for the province of Ontario; viii) Further updates to insect disturbance activity data in certain provinces; and ix) Improvements to nationwide estimates of controlled biomass burning.	Continuous improvement	Data analysis underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
LULUCF (cont'd)	Forest Land (CRF 4.A)	Science improvements.	Improve the representation of partial harvesting in CBM through explicit modelling of uneven-aged stands using the LANDIS-II / ForCS simulation platform.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A)	Validation analysis.	Independent EO-based validation dataset of forest carbon stocks for NIR in hardwood forests of Eastern Canada.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A) Cropland (CRF 4.B.1) Grassland (CRF 4.C.1)	Biomass burning improvements.	Refine estimates of C loss associated with controlled biomass burning. Integrate estimates into NIR, APEI and Black Carbon Inventory.	Continuous improvement	No significant progress made
	Cropland (CRF 4.B.1)	Develop methods for estimating changes in soil organic carbon stocks from the addition/removal of crop residues and manure application.	Refine estimates of C & N inputs from crop residues, taking into account crop residue baling based on the Farm Environmental Management Survey (FEMS) by Statistics Canada, and provide estimates of changes in soil organic carbon stocks from the addition/removal of crop residues and manure application.	Continuous improvement	Data analysis underway
	Wetlands converted to Cropland (CRF 4.B.2)	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE. Carbon loss from agricultural drainage of inland mineral wetland soils in the Prairie potholes region.	UNFCCC ERT recommendation	Data collection underway
	Flooded Land Remaining Flooded Land (CRF 4.D.1.2) Land Converted to Flooded Land (CRF 4.D.2.2)	Development of activity data, parameters and emission factors for methane in flooded lands.	Improved knowledge of methane emissions in flooded lands with updated activity data and emission factors	Continuous improvement	No significant progress made
	Settlements remaining Settlements (CRF 4.E.1.1)	Development of a new time series data point for 2005 and 2015 2020 for urban trees.	Update sampling point is planned for 2005 and 2015 activity data that involves sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas.	Continuous improvement	Data collection underway
	Land converted to Settlements (CRF 4.E.2)	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE. Carbon loss from Forest Land and Wetlands to Settlements conversion in the oil sands region and the North.	UNFCCC ERT recommendation	Data collection underway
	Cropland converted to Settlements (CRF 4.E.2.2)	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Data analysis underway
	Harvested Wood Products (CRF 4.G)	Improve uncertainty estimates, development of country-specific half-lives and expansion of temporal coverage.	Improvements are planned to enhance the uncertainty analysis of HWP estimates by considering the uncertainty inherent to the C inputs.	Continuous improvement	Developing new parameters
	Harvested Wood Products (CRF 4.G)	Development of country-specific half-lives.	Research is ongoing to develop country-specific half lives for a significant portion of Canada's HWP production that reflects much longer HWP residence times in housing than the IPCC default values.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Develop and implement HWP production and trade parameters for each province.	Research is ongoing to improve the regional differentiation of HWP production and trade, so that provincial/territorial summaries more accurately reflect regional conditions.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Estimate long-term emissions from solid waste disposal sites.	Research is ongoing to include the incorporation of the effects of wood and paper waste in solid waste disposal sites.	2006 IPCC guidelines / Continuous improvement	Data collection underway
	Harvested Wood Products (CRF 4.G)	Improve emission factors for residential firewood.	Research is ongoing to improve the accuracy of residential biomass burning emission factors.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Improve knowledge and characterization of industrial fuelwood.	Improve knowledge of industrial bioenergy chain (where the wood is coming from) and develop a better characterization of wood feedstock serving as wood fuel for the industry sector.	Continuous improvement	No significant progress made

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Waste	Solid Waste Disposal (CRF 5.A.2)	Review model parameters specific to industrial wood waste.	The project will review and update the model to be more specific to industrial wood waste landfilling.	Continuous Improvement	Initiated data collection / study
	Incineration of Solid Waste (CRF 5.C)	Refinement of sewage sludge moisture content.	Moisture content can range from 40% to 99% of the total mass of sewage sludge. Moisture content can also affect combustion efficiency and, as a result, emissions. Efforts to better quantify and incorporate moisture content will be developed.	Continuous Improvement	No significant progress made
	Wastewater Treatment and Discharge (CRF 5.D)	Update to industrial on-site wastewater treatment.	Revise and update estimates of emissions from industrial wastewater treatment.	Continuous improvement	Initiated data collection / study
	Wastewater Treatment and Discharge (CRF 5.D)	Update to N_2O from wastewater treatment to distinguish emissions from centralized modern treatment versus from receiving water bodies.	Update methods to estimate and distinguish N_2O emissions from centralized modern wastewater treatment.	Continuous improvement	Initiated data collection / study

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Chapter 1, Introduction

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NATIONAL INVENTORY REPORT 1990–2019: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

CANADA'S SUBMISSION TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

PART 2

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Cat. No.: En81-4E-PDF
ISSN: 1910-7064
EC8369

The Executive Summary of this report is available at: canada.ca/ghg-inventory

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Meteorological Service of Canada's **150th anniversary**
150e anniversaire du Service météorologique du Canada

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC	criteria air contaminant
CANSIM	Statistics Canada's key socioeconomic database
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
ECCC	Environment and Climate Change Canada
EF	emission factor
GDP	gross domestic product
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
HFC	hydrofluorocarbon
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Proccesses and Product Use
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
MSW	municipal solid waste
N/A	not available
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
NPRI	National Pollutant Release Inventory
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
POP	persistent organic pollutant
QA	quality assurance
QC	quality control
RESD	*Report on Energy Supply and Demand in Canada*
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Chemical Formulas

Al	aluminium
Al_2O_3	alumina
CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3 \cdot MgCO_3$)
CaO	lime; quicklime; calcined limestone
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene
C_6H_6	benzene
$CHCl_3$	chloroform
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HF	hydrogen fluoride
HNO_3	nitric acid
K_2CO_3	potassium carbonate
Mg	magnesium
$MgCO_3$	magnesite; magnesium carbonate
MgO	magnesia; dolomitic lime
N	nitrogen

N_2 .... nitrogen gas
Na_2CO_3 .... sodium carbonate; soda ash
Na_3AlF_6 .... cryolite
NF_3 .... nitrogen trifluoride
NH_3 .... ammonia
NH_4^+ .... ammonium
NH_4NO_3 .... ammonium nitrate
N_2O .... nitrous oxide
N_2O-N .... nitrous oxide emissions represented in terms of nitrogen
NO .... nitric oxide
NO_2 .... nitrogen dioxide
NO_3^- .... nitrate
NO_x .... nitrogen oxides
O_2 .... oxygen
SF_6 .... sulphur hexafluoride
SiC .... silicon carbide
SO_2 .... sulphur dioxide
SO_x .... sulphur oxides

Notation Keys

IE .... included elsewhere
NA .... not applicable
NE .... not estimated
NO .... not occurring

Units

g...................... gram
Gg .... gigagram
Gt .... gigatonne
ha .... hectare
kg .... kilogram
kha .... kilohectare
km .... kilometre
kt .... kilotonne
kWh................. kilowatt-hour
m .... metre
Mg .... megagram
Mha .... million hectares
mm .... millimetre
ML .... megalitre
Mt .... megatonne
MW.................. megawatt
PJ .... petajoule
t .... tonne
TWh .... terrawatt-hour

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ANNEX 1

KEY CATEGORIES

A1.1. Key Categories – Methodology

This annex presents the use of an IPCC Tier 1 key category analysis and results for Canada's inventory submission. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals" (IPCC, 2006); this term is used in reference to both source and sink categories.

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions expressed in CO_2 equivalent units according to standard global warming potentials (GWPs).
- A category should be identified for each gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas.
- Categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The IPCC Tier 1 quantitative approach is used to identify key categories from two perspectives: their contribution to the overall emissions and their contribution to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The trend assessment uses each category's relative contribution to the overall emissions, but assigns greater weight to the categories whose relative trend departs from the overall trend (with and without LULUCF). In this assessment, trends are calculated as the absolute changes between the base and most recent inventory years.

The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC, 2006). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key.

Level Assessment

Level contribution of each source or sink is calculated according to Equation A1–1, which follows IPCC (2006):

Equation A1–1 **for source/sink category level assessment**

$$L_{x,t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

$L_{x,t}$ = level assessment for source or sink x in latest inventory year (year t)

$|E_{x,t}|$ = the absolute value of emission or removal estimate of source or sink category x in year t

$\sum_y |E_{y,t}|$ = total contribution, which is the sum of the absolute values of emissions and removals in year t calculated using the aggregation level chosen by the country for key category analysis; because both emissions and removals are entered with positive sign, the total contribution/level can be larger than a country's total emissions less removals

Trend Assessment

The trend contribution of each source and sink is calculated according to Equation A1–2 and Equation A1–3 following IPCC (2006). Note that the use of Equation A1–3 only applies to source and sink categories where there are zero emissions in the base year.

Equation A1–2 **for source/sink category trend assessment**

$$T_{x,t} = L_{x,0} \bullet \left| \left[\frac{(E_{x,t} - E_{x,0})}{|E_{x,0}|} \right] - \left[\frac{(\sum_y E_{y,t} - \sum_y E_{y,0})}{|\sum_y E_{y,0}|} \right] \right|$$

$T_{x,t}$ = trend assessment of source or sink category x in year t as compared to the base year (year 0)

$L_{x,0}$ = the level assessment for source or sink category x in year 0 (derived in Equation A1–1)

$E_{x,t}$ and $E_{x,0}$ = real values of estimates of source or sink category x in years t and 0, respectively

$\sum_y E_{y,t}$ and $\sum_y E_{y,0}$ = total inventory estimates in years t and 0, respectively

A 1

Equation A1–3 **for source and sink category trend assessment with zero base year emissions**

$$T_{x,t} = \left|\frac{E_{x,t}}{\sum_y |E_{y,0}|}\right|$$

$T_{x,t}$ = trend assessment of source or sink category *x* in year *t* as compared to the base year (year 0)

$E_{x,t}$ = real values of estimates of source or sink category *x* in year *t*

$\sum_y |E_{y,0}|$ = total inventory estimates in year 0

The overall purpose of identifying key categories is the institution of best practices in greenhouse gas inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. In this analysis, sectors and major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes and Product Use (IPPU), Agriculture and Waste are in keeping with the common reporting format (CRF). Thus, while the UNFCCC CRF categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks has been made for the purpose of key category analysis. In general, the aggregation of categories has been performed when estimates are based on common emission factors and activity data. An exhaustive list of the aggregated categories as well as explanations regarding the rationale for category aggregation is presented in Table A1–1.

Summary Assessment

Key categories were assessed for the 2019 inventory year using level and trend criteria and for the base year using the level criterion only. There were 34 level key categories in 1990, while in 2019there were 30 with all combined criteria. Combined assessment results are presented in Table A1–2.

Table A1–1 **Aggregation of IPCC Categories**

Source Table	Aggregated IPCC Category	Categories Included in the Aggregated IPCC Categories	Rationale for Aggregation
1-A-1	Stationary Fuel Combustion – Energy Industries	Public Electricity and Heat Production	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-1 level for a Tier 1 approach (IPCC, 2006).
		Petroleum Refining	
		Manufacture of solid fuels and other energy industries	
1-A-2	Stationary Fuel Combustion – Manufacturing industries and construction	Iron and Steel	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-2 level for a Tier 1 approach (IPCC, 2006).
		Non-ferrous metals	
		Chemicals	
		Pulp, paper and print	
		Non-metallic minerals	
		Other	
1-A-3-b	Fuel Combustion – Road Transportation	Heavy-Duty Diesel Vehicles	Table 4.1 in Volume 1 : General Guidance and Reporting of the 2006 IPCC Guidelines suggest that road transportation be aggregated to the 1-A-3-b level for a Tier 1 approach (IPCC, 2006).
		Heavy-Duty Gasoline Vehicles	
		Light-Duty Diesel Trucks	
		Light-Duty Diesel Vehicles	
		Light-Duty Gasoline Trucks	
		Light-Duty Gasoline Vehicles	
		Motorcycles	
		Natural Gas Vehicles	
		Propane Vehicles	
		Urban Bus	
1-A-4	Stationary Fuel Combustion – Other Sectors	Commercial/institutional	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-4 level for a Tier 1 approach (IPCC, 2006).
		Residential	
		Agriculture/forestry/fisheries	
1-B-2-(a+c)	Fugitive Emissions – Oil	Oil	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-B-2-a level for a Tier 1 approach (IPCC, 2006).
		Venting – Oil	
		Flaring – Oil	
		Venting – Combined (split with 1-B-2-(b+c))	
		Flaring – Combined (split with 1-B-2-(b+c))	
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	Natural Gas	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-B-2-b level for a Tier 1 approach (IPCC, 2006).
		Venting – Natural Gas	
		Flaring – Natural Gas	
		Venting – Combined (split with 1-B-2-(a+c))	
		Flaring – Combined (split with 1-B-2-(a+c))	
2-B-8	Petrochemical and Carbon Black Production	Carbide Production (reported in $2B_5$ in the CRF, but with $2B_8$ for the purpose of key category analysis)	For simplicity and data confidentiality reasons, these categories are included in "Petrochemical and Carbon Black Production" for the purpose of key category analysis. Efforts will be made to disaggregate these categories in future inventories. See below for comments related to CO_2 emissions from certain petrochemical categories.
		Methanol Production	
		Ethylene Production	
		Ethylene Dichloride Production	
		Carbon Black Production	
		Styrene Production	
		Ethylene Oxide Production	
		Other (Other Uses of Urea) (reported in $2B_{10}$ in the CRF, but with $2B_8$ for the purpose of key category analysis)	

Table A1–1 **Aggregation of IPCC Categories** (cont'd)

Source Table	Aggregated IPCC Category	Categories Included in the Aggregated IPCC Categories	Rationale for Aggregation
2-C-1	Iron and Steel Production	Steel Production	Disaggregation of the reductant portion of steel production (i.e. metallurgical coke) is not available and therefore emissions have to be reported under category 2.C.1.b Pig Iron production.
		Pig Iron Production	
		Metal Industry – Ferroalloys Production	CO_2 emissions from Ferroalloys Production (CRF category 2.C.2) are included in CRF category 2.C.1.a Steel Production. Production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace prcess using reductants.
2-D-3	Non-energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2 emissions from Carbide Production, Carbon Black Production, Styrene Production, and Ethylene Dichloride and Vinyl Chloride Monomer Production	Disaggregation of national statistics to broader categories is currently not possible.
		Iron and Steel – Sinter production	
		Iron and Steel – Pellet production	
		Metal Industry – Lead Production	
		Metal Industry – Zinc Production	
		Non-energy Products from Fuels and Solvent Use – Other (Solvent use)	
		Non-energy Products from Fuels and Solvent Use – natural gas, solid fuels and liquid fuels (including lubricant and paraffin wax use)	
2-F	Product Uses as Substitutes for Ozone Depleting Substances	Refrigeration and Air conditioning	For simplicity reasons, these categories are included in "Product Uses as Substitutes for Ozone Depleting Substances" for the purpose of key category analysis. Efforts will be made to disaggregate these categories in future inventories.
		Foam Blowing Agents	
		Fire Protection	
		Aerosols	
		Solvents	
		Other Applications	
3-A	Agriculture – Enteric Fermentation	Cattle	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Sheep	
		Swine	
		Other Livestock	
3-B	Agiculture – Manure Management	N_2O and NMVOC Emissions – Cattle	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		N_2O and NMVOC Emissions – Sheep	
		N_2O and NMVOC Emissions – Swine	
		N_2O and NMVOC Emissions – Other Livestock	
		N_2O and NMVOC Emissions – Indirect N_2O Emissions	
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	Inorganic N Fertilizers	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Organic N Fertilizers	
		Urine and Dung Deposited by Grazing Animals	
		Crop Residues	
		Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	
		Cultivation of Organic Soils	
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	Atmospheric Deposition	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Nitrogen Leaching and Run-Off	
4-A-1	LULUCF – Forest Land remaining Forest Land	Forest Land remaining Forest Land	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Biomass Burning, Forest Land remaining Forest Land	
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Forest Land	
4-B-2	LULUCF – Land converted to Cropland	Land converted to Cropland	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization resulting from change of land use or management of mineral soils	
		Biomass Burning, Land Converted to Cropland	
4-C-1	LULUCF – Grassland Remaining Grassland	Grassland Remaining Grassland	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Biomass Burning, Grassland Remaining Grassland	
4-D-1	LULUCF – Wetlands remaining Wetlands	Emissions and removals from drainage and rewetting and other management of organic and mineral soils for Peat extraction lands (*only emissions associated to peat extraction remaining peat extraction)	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Flooded land remaining Flooded land	
4-D-2	LULUCF – Land converted to Wetlands	Land converted to Flooded land	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Peat extraction lands (*only emissions associated to Land converted to peat extraction)	
		Biomass Burning, Land converted to Wetlands	
4-E-2	LULUCF – Land converted to Settlements	Land converted to Settlements	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Biomass Burning, Settlements	
5-A-1	Waste – Solid Waste Disposal	Municipal Solid Waste Landfills	To organize the two landfill sectors together which use similar methodologies
		Wood Waste Landfills	

Table A1–2 **Key Category Analysis Summary, 2019 Inventory Year**

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2019)	Criteria 1990 / 2019 L: Level, T: Trend
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	Yes / Yes	L / L , T
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	No / Yes	T
1.A.1	Stationary Fuel Combustion – Energy Industries	N_2O	No / No	
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	Yes / Yes	L / L , T
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CH_4	No / No	
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	N_2O	No / No	
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	Yes / Yes	L / L , T
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	No / Yes	T
1.A.4	Stationary Fuel Combustion – Other sectors	N_2O	No / No	
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	Yes / Yes	L / L , T
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	Yes / Yes	L / L , T
1-A-3-a	Fuel Combustion – Domestic Aviation	CH_4	No / No	
1-A-3-a	Fuel Combustion – Domestic Aviation	N_2O	No / No	
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	Yes / Yes	L / L , T
1-A-3-b	Fuel Combustion – Road Transportation	CH_4	No / No	
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	Yes / Yes	L / T
1-A-3-c	Fuel Combustion – Railways	CO_2	Yes / Yes	L / L , T
1-A-3-c	Fuel Combustion – Railways	CH_4	No / No	
1-A-3-c	Fuel Combustion – Railways	N_2O	No / No	
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	No / Yes	L , T
1-A-3-d	Fuel Combustion – Domestic Navigation	CH_4	No / No	
1-A-3-d	Fuel Combustion – Domestic Navigation	N_2O	No / No	
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	Yes / Yes	L / L , T
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	No / Yes	T
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	N_2O	No / No	
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	Yes / Yes	L / L
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CH_4	No / No	
1-A-3-e-i	Fuel Combustion – Pipeline Transport	N_2O	No / No	
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	No / Yes	T
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	No / Yes	T
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	Yes / Yes	L / L , T
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	N_2O	Yes / Yes	L / T
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	CO_2	No / No	
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	CH_4	No / No	
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	N_2O	No / No	
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	Yes / Yes	L / L , T
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	Yes / Yes	L / L , T
1-B-2-(a+c)	Fugitive Emissions – Oil	N_2O	No / No	
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	Yes / Yes	L / L , T
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	Yes / Yes	L / L , T
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	N_2O	No / No	
1-C-1	CO_2 Transport and Storage – Pipelines	CO_2	No / No	
2-A-1	IPPU – Cement Production	CO_2	Yes / Yes	L / L
2-A-2	IPPU – Lime Production	CO_2	No / Yes	T
2-A-3	IPPU – Glass Production	CO_2	No / No	
2-A-4-b	IPPU – Other Uses of Soda Ash	CO_2	No / No	
2-A-4-c	IPPU – Other (Magnesite Use)	CO_2	No / No	
2-A-4-d	IPPU – Other (Limestone and Dolomite Use Other)	CO_2	No / Yes	T
2-B-1	IPPU – Ammonia Production	CO_2	Yes / Yes	L / T
2-B-2	IPPU – Nitric Acid Production	N_2O	No / Yes	T
2-B-3	IPPU – Adipic Acid Production	N_2O	Yes / Yes	L / T
2-B-7	IPPU – Soda Ash Production	CO_2	No / No	
2-B-8	IPPU – Petrochemical and Carbon Black Production	CO_2	Yes / No	L
2-B-8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	No / No	

Table A1–2 **Key Category Analysis Summary, 2019 Inventory Year** (cont'd)

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2019)	Criteria 1990 / 2019 L: Level, T: Trend
2-B-8	IPPU – Petrochemical and Carbon Black Production	N_2O	No / No	
2-B-9-a	IPPU – Fluorochemical Production	HFCs	No / Yes	T
2-C-1	IPPU – Iron and Steel Production	CO_2	Yes / Yes	L / L , T
2-C-1	IPPU – Iron and Steel Production	CH_4	No / No	
2-C-3	IPPU – Aluminium Production	CO_2	No / Yes	L , T
2-C-3	IPPU – Aluminium Production	PFCs	Yes / Yes	L / T
2-C-3	IPPU – Aluminium Production	SF_6	No / No	
2-C-4	IPPU – Magnesium Production	SF_6	No / Yes	T
2-C-7	IPPU – Other (Magnesium Casting)	SF_6	No / No	
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	Yes / Yes	L / L , T
2-D-3-b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	PFCs	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	SF_6	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	NF_3	No / No	
2-E-5	IPPU – Other Emissives Applications	PFCs	No / No	
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	No / Yes	L , T
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	No / No	
2-G-1	IPPU – Electrical Equipment	SF_6	No / No	
2-G-3-a	IPPU – Other (Medical Applications of N_2O)	N_2O	No / No	
2-G-3-b	IPPU – Other (Use of N_2O for Propellant)	N_2O	No / No	
2-G-4	IPPU – Other Contained Product Uses	PFCs	No / No	
3-A	Agriculture – Enteric Fermentation	CH_4	Yes / Yes	L / L , T
3-B	Agriculture – Manure Management	CH_4	No / Yes	L , T
3-B	Agriculture – Manure Management	N_2O	Yes / No	L
3-B-5	Agriculture – Indirect N_2O Emissions	N_2O	No / No	
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	Yes / Yes	L / L , T
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	No / Yes	L , T
3-F	Agriculture – Field Burning of Agricultural Residues	CH_4	No / No	
3-F	Agriculture – Field Burning of Agricultural Residues	N_2O	No / No	
3-G-1	Agriculture – Limestone $CaCO_3$	CO_2	No / No	
3-H	Agriculture – Urea Application	CO_2	No / Yes	T
3-I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	No / No	
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	Yes / Yes	L / L , T
4-A-1	LULUCF – Forest Land remaining Forest Land	CH_4	No / No	
4-A-1	LULUCF – Forest Land remaining Forest Land	N_2O	No / No	
4-A-2	LULUCF – Land converted to Forest Land	CO_2	No / No	
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	No / Yes	L , T
4-B-2	LULUCF – Land converted to Cropland	CO_2	Yes / Yes	L / T
4-B-2	LULUCF – Land converted to Cropland	CH_4	No / No	
4-B-2	LULUCF – Land converted to Cropland	N_2O	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	CO_2	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	CH_4	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	N_2O	No / No	
4-D-2	LULUCF – Land converted to Wetlands	CO_2	Yes / Yes	L / T
4-D-2	LULUCF – Land converted to Wetlands	CH_4	No / No	
4-D-2	LULUCF – Land converted to Wetlands	N_2O	No / No	
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	Yes / Yes	L / L , T
4-E-2	LULUCF – Land converted to Settlements	CO_2	Yes / Yes	L / L , T
4-E-2	LULUCF – Land converted to Settlements	CH_4	No / No	
4-E-2	LULUCF – Land converted to Settlements	N_2O	No / No	
4-C	LULUCF – Grassland	CH_4	No / No	
4-C	LULUCF – Grassland	N_2O	No / No	
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	Yes / Yes	L / L , T
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	Yes / Yes	L / L , T
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	Yes / Yes	L / T
5-B	Waste – Biological Treatment of Solid Waste	N_2O	No / No	
5-B	Waste – Biological Treatment of Solid Waste	CO_2	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	N_2O	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	CH_4	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	CH_4	No / No	
5-D-1	Waste – Wastewater Treatment and Discharge	CH_4	No / No	
5-D-1	Waste – Wastewater Treatment and Discharge	N_2O	No / No	

Notes: L = key category by level (for an individual year), T = key category by trend (between the base year and the current year)

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A1.2. # Key Category Tables

A1.2.1. ## Level Assessment With and Without LULUCF

Table A1–3 shows the 1990 key categories identified from level assessment with and without LULUCF.

Table A1–4 shows the 2019 key categories identified from level assessment with and without LULUCF.

Table A1–3 **1990 Key Categories by Level Assessment With and Without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2019	without LULUCF	with LULUCF	without LULUCF	with LULUCF
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	NA	0.209	NA	0.209
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.234	0.146	0.234	0.356
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	NA	0.136	NA	0.491
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.134	0.084	0.368	0.575
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.116	0.072	0.484	0.647
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.103	0.064	0.586	0.711
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.037	0.023	0.623	0.735
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.035	0.022	0.658	0.757
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.029	0.018	0.687	0.775
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.028	0.017	0.715	0.792
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.026	0.016	0.741	0.808
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.024	0.015	0.765	0.823
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.017	0.011	0.782	0.834
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.017	0.011	0.799	0.845
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.016	0.010	0.816	0.855
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.015	0.009	0.831	0.864
4-B-2	LULUCF – Land converted to Cropland	CO_2	8 980	3 414	NA	0.009	NA	0.874
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.013	0.008	0.843	0.882
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.012	0.007	0.855	0.889
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.011	0.007	0.867	0.896
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.010	0.006	0.877	0.903
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.010	0.006	0.887	0.909
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	NA	0.006	NA	0.915
2-A-1	IPPU – Cement Production	CO_2	5 823	7 177	0.010	0.006	0.897	0.921
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.010	0.006	0.907	0.927
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.009	0.006	0.916	0.933
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	NA	0.004	NA	0.937
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.006	0.004	0.922	0.941
4-D-2	LULUCF – Land converted to Wetlands	CO_2	3 830	185	NA	0.004	NA	0.945
2-B-8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.006	0.003	0.928	0.949
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.005	0.003	0.938	NA
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.005	0.003	0.942	NA
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.005	0.003	0.947	NA
3-B	Agriculture – Manure Management	N_2O	3 062	3 348	0.005	0.003	0.933	NA

Note: NA = Not Applicable

Table A1–4 **2019 Key Categories by Level Assessment With and Without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2019	without LULUCF	with LULUCF	without LULUCF	with LULUCF
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.253	0.179	0.25	0.18
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.206	0.146	0.46	0.32
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	NA	0.138	NA	0.46
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	NA	0.129	NA	0.59
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.107	0.076	0.57	0.67
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.067	0.047	0.63	0.72
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.033	0.023	0.67	0.74
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.031	0.022	0.70	0.76
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.028	0.020	0.73	0.78
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.026	0.019	0.75	0.80
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.024	0.017	0.78	0.82
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.019	0.014	0.79	0.83
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.017	0.012	0.81	0.84
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.016	0.011	0.83	0.85
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/ Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.015	0.011	0.84	0.86
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.015	0.010	0.86	0.87
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.011	0.008	0.87	0.88
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.011	0.008	0.88	0.89
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.011	0.008	0.89	0.90
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	-1 902	-7 827	NA	0.008	NA	0.91
2-A-1	IPPU – Cement Production	CO_2	5 823	7 177	0.010	0.007	0.90	0.91
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.009	0.007	0.91	0.92
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	NA	0.006	NA	0.93
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.007	0.005	0.92	0.93
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.006	0.005	0.92	0.93
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.006	0.005	0.93	0.94
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	NA	0.004	NA	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.006	0.004	0.94	0.95
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.006	0.004	0.94	NA
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.005	0.004	0.95	NA

Note: NA = Not Applicable

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A1.2.2. **Trend Assessment With and Without LULUCF**

Table A1–5 and Table A1–6 show the key categories indicated from the trend assessment without and with LULUCF, respectively. These tables also show the contribution of the key categories to the trend assessment.

The integration of the LULUCF sector introduces additional key categories and alters the categories' relative contributions and overall trends, which causes a rearrangement in the ranking of key categories. For example, a single LULUCF category, Forest Land Remaining Forest Land (CO_2), is ranked as the second highest contributor in the trend assessments.

The trend assessment without LULUCF identifies 40 key categories, while the same analysis with LULUCF results in 44 key categories, including seven categories from the LULUCF sector.

Table A1–5 **Key Categories by Trend Assessment without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2019			
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.087	0.243	0.24
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.043	0.120	0.36
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.023	0.065	0.43
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.023	0.065	0.49
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.021	0.058	0.55
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.021	0.058	0.61
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.014	0.040	0.65
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.011	0.029	0.68
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.008	0.021	0.70
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.007	0.021	0.72
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.007	0.018	0.74
2-C-4	IPPU – Magnesium Production	SF_6	2 738	0	0.006	0.015	0.75
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.005	0.015	0.77
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.005	0.014	0.78
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/ Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.005	0.014	0.80
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.005	0.014	0.81
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.004	0.012	0.82
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.004	0.010	0.83
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.004	0.010	0.84
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	2 824	1 391	0.003	0.010	0.85
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.003	0.009	0.86
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.003	0.008	0.87
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.002	0.007	0.88
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.002	0.007	0.88
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.002	0.006	0.89
3-H	Agriculture – Urea Application	CO_2	754	2 191	0.002	0.006	0.89
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	2 202	1 456	0.002	0.006	0.90
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	1 235	285	0.002	0.006	0.91
2-B-9-a	IPPU – Fluorochemical Production	HFCs	971	0	0.002	0.005	0.91
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.002	0.004	0.92
2-B-2	IPPU – Nitric Acid Production	N_2O	973	258	0.002	0.004	0.92
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.001	0.004	0.92
2-A-2	IPPU – Lime Production	CO_2	1 813	1 339	0.001	0.004	0.93
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	1 520	2 701	0.001	0.004	0.93
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.001	0.004	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.001	0.004	0.94
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.001	0.003	0.94
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	236	1 168	0.001	0.003	0.95
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.001	0.002	0.95
2-A-4-d	IPPU – Other (Limestone and Dolomite Use Other)	CO_2	449	101	0.001	0.002	0.95

Table A1–6 **Key Categories by Trend Assessment with LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2019			
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.055	0.192	0.19
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	0.028	0.097	0.29
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.026	0.090	0.38
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.016	0.056	0.44
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	0.015	0.052	0.49
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.014	0.050	0.54
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.013	0.045	0.58
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.013	0.045	0.63
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.009	0.031	0.66
4-B-2	LULUCF – Land converted to Cropland	CO_2	8 980	3 414	0.008	0.027	0.68
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	-1 902	-7 827	0.007	0.023	0.71
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.006	0.020	0.73
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.005	0.017	0.74
4-D-2	LULUCF – Land converted to Wetlands	CO_2	3 830	185	0.005	0.016	0.76
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.005	0.016	0.77
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.004	0.014	0.79
2-C-4	IPPU – Magnesium Production	SF_6	2 738	0	0.003	0.012	0.80
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.003	0.011	0.81
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.003	0.011	0.82
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.003	0.011	0.83
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.003	0.010	0.84
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.002	0.008	0.85
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.002	0.008	0.86
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.002	0.007	0.87
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.002	0.007	0.87
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	2 824	1 391	0.002	0.007	0.88
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.002	0.006	0.89
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.002	0.005	0.89
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.001	0.005	0.90
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.001	0.005	0.90
3-H	Agriculture – Urea Application	CO_2	754	2 191	0.001	0.005	0.91
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	1 235	285	0.001	0.004	0.91
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	2 202	1 456	0.001	0.004	0.92
2-B-9-a	IPPU – Fluorochemical Production	HFCs	971	0	0.001	0.004	0.92
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	0.001	0.004	0.92
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.001	0.003	0.93
2-B-2	IPPU – Nitric Acid Production	N_2O	973	258	0.001	0.003	0.93
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.001	0.003	0.93
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	1 520	2 701	0.001	0.003	0.94
2-A-2	IPPU – Lime Production	CO_2	1 813	1 339	0.001	0.003	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.001	0.003	0.94
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.001	0.003	0.94
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	0.001	0.002	0.95
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	236	1 168	0.001	0.002	0.95

UNCERTAINTY

A2.1. Introduction

All Annex I Parties to the United Nations Framework Convention on Climate Change are required to report estimated uncertainties associated with both annual estimates of emissions and emission trends over time in their respective national inventory reports. Uncertainty analysis helps to prioritize improvements of future inventories and to guide decisions on methodological choice (IPCC, 2006).

In this submission, Canada used the error propagation method (Approach 1) for combining uncertainties, as outlined in Volume 1 (Chapter 3) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), to assess the uncertainty in emission estimates for the latest year. Uncertainty estimates were combined by completing Table 3.3 at the source category level. Uncertainty estimates for each source/sink category were either retained from previous studies (e.g. a comprehensive Monte Carlo analysis (Approach 2) conducted in 2003/2004), improved upon on the basis of these studies, or derived independently as in the Agriculture (methane and nitrous oxide), Energy (some fuel combustion categories and fugitive emissions), Industrial Processes and Product Use (IPPU) and Land Use, Land-Use Change and Forestry (LULUCF) sectors. For details on uncertainty related to specific sectors, refer to the uncertainty sections throughout Chapters 3 to 7.

A2.2. Interpretation of Uncertainty about Inventory Estimates

Often uncertainty about GHG estimates is incorrectly interpreted as a measure of accuracy or reliability. In fact, accuracy (or its inverse, bias) can only be quantified by measuring departure from the truth. Uncertainty estimation for inventories is not designed as a measure of accuracy, rather in the context of national inventories, the process of uncertainty estimation mostly aims to quantify precision. High uncertainty about a category estimate suggests it would be difficult to obtain agreement among repeated measurements. This can arise from many factors, including true heterogeneity over time and space: variability is an inherent property of many systems, including nature.

In IPCC good practice guidance, uncertainty information is primarily a "means to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice, …" (IPCC, 2006 vol 1, chapter 3). Minimizing bias and obtaining reliable estimates are better achieved by implementing good practice in estimate development.

A2.3. Uncertainty Assessment on 2019 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2019 national emission estimate (not including the LULUCF sector) of 730 Mt CO_2 eq lies within an uncertainty range of 708 Mt CO_2 eq to 753 Mt CO_2 eq (±3%) (Table A2–1). The Energy sector has the lowest uncertainty, at ±2%, while the Waste sector has the highest uncertainty, at ±66%. The IPPU sector and the Agriculture sector have uncertainties of ±5, and ±47%, respectively. The five emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Direct Agriculture Soils, N_2O
3. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites –Wood Waste Landfills, CH_4
4. Agriculture – Enteric Fermentation, CH_4
5. Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2

The 2019 national emission estimate, including LULUCF emissions and removals, of 740 Mt CO_2 eq, lies within an uncertainty range of 675 Mt CO_2 eq to 806 Mt CO_2 eq (±9%) (Table A2–2). The top five contributors influencing the national uncertainty when LULUCF is included were:

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. LULUCF – Harvested Wood Products (HWP), CO_2
3. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
4. Agriculture – Direct Agriculture Soils, N_2O
5. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills, CH_4

The calculation of trend uncertainty was performed with and without the LULUCF sector. The trend uncertainty, excluding LULUCF, was found to be 1%. Therefore, the total increase in emissions since 1990 of 129 Mt CO_2 eq (+21%) falls within an uncertainty range of a minimum of +128 Mt CO_2 eq to a maximum of +129 Mt CO_2 eq. The trend uncertainty, including LULUCF, was found to be 1%.

A2.4. Planned Improvements

Continuous improvement is one of the principles upon which Canada develops its annual GHG inventory. Planned improvements associated with uncertainty assessment will likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2003–2004. New methodological changes and refinements consider the impact on uncertainty prior to implementation and therefore provide a basis for regular incremental improvement to the uncertainty analysis.

Uncertainty estimation of national emissions is the topic of a working paper to be released in 2020 (Laferrière et al. 2020). This study compares actual Tier 1 uncertainty estimates with a more general approach, namely Monte Carlo simulations (MCS). The comparison highlights:

- the impact on emissions uncertainty related with asymmetrical probability distribution function (PDF) and PDF other than normal;
- the effect of incorporating emission correlation across IPCC source category—often, it is difficult to justify the Tier 1 assumption that emission factors are uncorrelated across categories—the paper shows the importance of its recognition and compares trend uncertainty and category contribution to uncertainty; and
- the possibility to factor in dual uncertainty levels for the activity variables (for example, categories comprised of multiple activity datasets may individually have high uncertainty values but when aggregated the final result may have a lower uncertainty value).

Results of the recent uncertainty analysis were used for the category of Product Uses as Substitutes for Ozone Depleting Substance – HFCs. Improvements with respect to uncertainty estimates will continue for other categories in future inventories. Chapter 8 provides a summary of planned improvements.

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF**

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
	TOTALS		**601 524**	**730 245**	**1.90**	**2.00**	**3.1**	**3.1**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**0.59**
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CO_2	93 982	68 043	0.48	4.60	4.60	0.00	0.35	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CH_4	44	158	0.65	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	N_2O	492	432	0.47	160.00	160.00	0.00	0.04	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CO_2	17 300	14 662	1.00	9.60	9.70	0.00	0.10	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CH_4	11	8	0.87	190.00	190.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	N_2O	49	32	0.63	280.00	280.00	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	26 967	47 356	1.00	4.90	5.00	0.00	0.12	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 463	2 509	1.20	140.00	140.00	0.00	0.17	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O	184	291	1.20	550.00	550.00	0.00	0.06	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	64 281	103 940	2.70	4.00	4.30	0.00	0.17	0.02	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CH_4	65	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	N_2O	496	856	2.70	41.00	41.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CO_2	35 295	33 790	1.10	0.11	1.10	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CH_4	1 288	509	1.10	11.00	11.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	N_2O	118	467	1.80	69.00	69.00	0.00	0.04	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CO_2	7 203	8 223	0.77	0.40	0.87	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CH_4	11	5	0.73	240.00	240.00	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	N_2O	67	71	0.74	670.00	670.00	0.00	0.01	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CH_4	308	245	1.00	110.00	110.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	1.30	38.00	38.00	0.00	0.06	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CO_2	6 200	6 887	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	N_2O	709	806	3.20	200.00	200.00	0.00	0.02	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CO_2	2 149	4 027	2.70	0.40	2.70	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CH_4	5	10	2.80	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	N_2O	17	33	2.80	130.00	130.00	0.00	0.00	0.00	0.00

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
1.A.3.e	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.99	1.40	1.70	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	CH_4	167	199	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CO_2	69 546	78 070	2.00	1.60	2.20	0.00	0.02	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CH_4	2 202	1 456	5.70	15.00	15.00	0.00	0.03	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	N_2O	639	765	4.40	31.00	31.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CO_2	866	213	2.70	0.25	2.70	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CH_4	2	1	16.00	260.00	260.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	N_2O	7	2	2.60	120.00	120.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CO_2	231	239	0.64	0.32	0.72	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CH_4	0	0	0.50	350.00	350.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	N_2O	2	2	0.63	570.00	570.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CO_2	28	74	0.92	0.09	0.92	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CH_4	0	0	5.80	89.00	90.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	N_2O	0	1	0.95	41.00	41.00	0.00	0.00	0.00	0.00
1.B.1.a	Fugitive Sources – Coal Mining and Handling	CH_4	2 824	1 391	0.00	0.00	57.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CO_2	121	665	0.00	0.00	25.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CH_4	17 984	16 892	0.00	0.00	22.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	N_2O	30	104	0.00	0.00	310.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting	CO_2	6 995	9 513	0.00	0.00	26.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Flaring	CO_2	4 594	5 769	0.00	0.00	7.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	CH_4	16 406	19 505	0.00	0.00	6.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	N_2O	2	8	0.00	0.00	120.00	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	-	0	2.00	100.00	100.00	0.00	0.00	0.00	0.00
2.A.1	IPPU – Cement Production	CO_2	5 823	7 177	0.00	0.00	8.50	0.00	0.00	0.00	0.00
2.A.2	IPPU – Lime Production	CO_2	1 813	1 339	8.00	2.00	6.60	0.00	0.00	0.00	0.00
2.A.3	IPPU – Glass Production	CO_2	71	0	0.00	0.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU – Other Uses of Soda Ash	CO_2	194	98	0.00	0.00	6.20	0.00	0.00	0.00	0.00
2.A.4.c	IPPU – Other (Magnesite Use)	CO_2	147	116	7.80	2.10	8.10	0.00	0.00	0.00	0.00
2.A.4.d	IPPU – Other (Limestone and Dolomite Use)	CO_2	449	101	0.00	0.00	36.00	0.00	0.00	0.00	0.00
2.B.1	IPPU – Ammonia Production	CO_2	2 796	2 551	2.00	5.00	9.20	0.00	0.01	0.00	0.00
2.B.2	IPPU – Nitric Acid Production	N_2O	973	258	2.00	10.00	0.96	0.00	0.02	0.00	0.00
2.B.3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.10	10.00	11.00	0.00	0.21	0.00	0.00
2.B.7	IPPU – Soda Ash Production	CO_2	-	0	0.00	0.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.00	0.00	3.10	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	143	135	0.00	0.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	N_2O	15	13	0.00	0.00	9.60	0.00	0.00	0.00	0.00

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Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
2.B.9.a	IPPU – Fluorochemical Production	HFCs	971	0	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.00	0.00	5.60	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.00	0.00	7.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	PFCs	7 558	556	0.00	0.00	9.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	SF_6	56	1	0.00	0.00	5.00	0.00	0.00	0.00	0.00
2.C.4	IPPU – Magnesium Production	SF_6	2 738	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.7	IPPU – Other (Magnesium Casting)	SF_6	225	290	0.00	0.00	9.20	0.00	0.00	0.00	0.00
2.D.3.a	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.00	20.00	20.00	0.00	0.15	0.00	0.00
2.D.3.b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	-	32	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	PFCs	0	8	2.00	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	SF_6	4	20	15.00	30.00	45.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	Ok	0	1	0.00	0.00	300.00	0.00	0.00	0.00	0.00
2.E.5	IPPU – Other Emissive Applications	PFCs	-	0	2.00	50.00	50.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 414	0.00	0.00	11.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	0.00	0.00	23.00	0.00	0.00	0.00	0.00
2.G.1	IPPU – Electrical Equipment	SF_6	202	170	11.00	30.00	32.00	0.00	0.00	0.00	0.00
2.G.3.a	IPPU – Other (Medical Applications of N_2O)	N_2O	146	438	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU – Other (Uses of N_2O for Propellant)	N_2O	26	80	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.4	IPPU – Other Contained Product Uses	PFCs	-	30	2.00	50.00	51.00	0.00	0.00	0.00	0.00
	Agriculture – Total CH_4	CH_4	24 970	27 922	1.20	19.00	18.00	0.00	0.07	0.00	0.00
3.A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	1.20	18.00	22.00	0.01	0.09	0.00	0.00
3.B.1	Agriculture – Manure Management	CH_4	2 453	3 876	0.19	4.50	32.00	0.00	0.01	0.00	0.00
	Agriculture – Total N_2O	N_2O	20 779	28 505	0.00	0.02	24.00	0.01	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Direct Emissions	N_2O	3 062	3 348	0.00	0.00	51.00	0.00	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Indirect Emissions	N_2O	613	700	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.D.1	Agriculture – Direct Agriculture Soils	N_2O	14 261	20 249	0.00	0.00	34.00	0.01	0.00	0.00	0.00
3.D.2	Agriculture – Indirect Agrictulure Soils	N_2O	2 790	4 197	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.00	0.00	0.00
	Agriculture – Total CO_2	CO_2	1 191	2 631	13.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture – Limestone $CaCO_3$	CO_2	385	171	30.00	50.00	58.00	0.00	0.02	0.00	0.00

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
3.H	Agriculture – Urea Application	CO_2	754	2 191	15.00	50.00	52.00	0.00	0.11	0.00	0.00
3.I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	52	268	15.00	50.00	52.00	0.00	0.02	0.00	0.00
5.A.1	Solid Waste Disposal – Managed Waste Disposal Sites	CH_4	20 984	22 989	59.00	46.00	76.00	0.06	0.19	0.01	0.00
5.A.2	Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills	CH_4	3 847	3 003	0.00	0.00	190.00	0.01	0.00	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	CH_4	34	168	0.00	87.00	87.00	0.00	0.02	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	N_2O	39	194	0.00	61.00	61.00	0.00	0.01	0.00	0.00
5.B.2	Biological Treatment of Solid Waste – Anerobic Digestion – Industrial & Municipal Facilities	CH_4	-	19	0.00	79.00	79.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CO_2	178	105	4.50	36.00	37.00	0.00	0.01	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CH_4	2	1	4.90	98.00	59.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	N_2O	92	80	4.40	88.00	88.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	CH_4	486	532	43.00	36.00	55.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	342	490	10.00	50.00	51.00	0.00	0.01	0.00	0.00

Notes:

a. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods—as related to categories in the Energy, IPPU, and Waste sectors—the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N_2O and CH_4, combined with error propagation calculations for CO_2. For IPPU categories where the uncertainty values for activity data and emission factor are not provided, the combined uncertainty value is calculated using many subcategory inputs which have varying activity data and emission factor uncertainty values.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

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Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF**

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
	TOTALS		**544 707**	**740 123**	**1.90**	**1.90**	**8.9**	**8.8**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**0.84**
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CO_2	93 982	68 043	0.48	4.60	4.60	0.00	0.50	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CH_4	44	158	0.65	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	N_2O	492	432	0.47	160.00	160.00	0.00	0.07	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CO_2	17 300	14 662	1.00	9.60	9.70	0.00	0.16	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CH_4	11	8	0.87	190.00	190.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	N_2O	49	32	0.63	280.00	280.00	0.00	0.02	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	26 967	47 356	1.00	4.90	5.00	0.00	0.10	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 463	2 509	1.20	140.00	140.00	0.00	0.13	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O	184	291	1.20	550.00	550.00	0.00	0.04	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	64 281	103 940	2.70	4.00	4.30	0.00	0.12	0.01	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CH_4	65	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	N_2O	496	856	2.70	41.00	41.00	0.00	0.01	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CO_2	35 295	33 790	1.10	0.11	1.10	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CH_4	1 288	509	1.10	11.00	11.00	0.00	0.03	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	N_2O	118	467	1.80	69.00	69.00	0.00	0.04	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CO_2	7 203	8 223	0.77	0.40	0.87	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CH_4	11	5	0.73	240.00	240.00	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	N_2O	67	71	0.74	670.00	670.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CH_4	308	245	1.00	110.00	110.00	0.00	0.03	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	1.30	38.00	38.00	0.00	0.10	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CO_2	6 200	6 887	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	N_2O	709	806	3.20	200.00	200.00	0.00	0.06	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CO_2	2 149	4 027	2.70	0.40	2.70	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CH_4	5	10	2.80	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	N_2O	17	33	2.80	130.00	130.00	0.00	0.00	0.00	0.00

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Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
1.A.3.e	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.99	1.40	1.70	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	CH_4	167	199	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.01	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CO_2	69 546	78 070	2.00	1.60	2.20	0.00	0.05	0.01	0.00
1.A.4	Fuel Combustion – Other Sectors	CH_4	2 202	1 456	5.70	15.00	15.00	0.00	0.04	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	N_2O	639	765	4.40	31.00	31.00	0.00	0.01	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CO_2	866	213	2.70	0.25	2.70	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CH_4	2	1	16.00	260.00	260.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	N_2O	7	2	2.60	120.00	120.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CO_2	231	239	0.64	0.32	0.72	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CH_4	0	0	0.50	350.00	350.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	N_2O	2	2	0.63	570.00	570.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CO_2	28	74	0.92	0.09	0.92	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CH_4	0	0	5.80	89.00	90.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	N_2O	0	1	0.95	41.00	41.00	0.00	0.00	0.00	0.00
1.B.1.a	Fugitive Sources – Coal Mining and Handling	CH_4	2 824	1 391	0.00	0.00	57.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CO_2	121	665	0.00	0.00	25.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CH_4	17 984	16 892	0.00	0.00	22.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	N_2O	30	104	0.00	0.00	310.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting	CO_2	6 995	9 513	0.00	0.00	26.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Flaring	CO_2	4 594	5 769	0.00	0.00	7.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	CH_4	16 406	19 505	0.00	0.00	6.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	N_2O	2	8	0.00	0.00	120.00	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	-	0	2.00	100.00	100.00	0.00	0.00	0.00	0.00
2.A.1	IPPU – Cement Production	CO_2	5 823	7 177	0.00	0.00	8.50	0.00	0.00	0.00	0.00
2.A.2	IPPU – Lime Production	CO_2	1 813	1 339	8.00	2.00	6.60	0.00	0.00	0.00	0.00
2.A.3	IPPU – Glass Production	CO_2	71	0	0.00	0.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU – Other Uses of Soda Ash	CO_2	194	98	0.00	0.00	6.20	0.00	0.00	0.00	0.00
2.A.4.c	IPPU – Other (Magnesite Use)	CO_2	147	116	7.80	2.10	8.10	0.00	0.00	0.00	0.00
2.A.4.d	IPPU – Other (Limestone and Dolomite Use)	CO_2	449	101	0.00	0.00	36.00	0.00	0.00	0.00	0.00
2.B.1	IPPU – Ammonia Production	CO_2	2 796	2 551	2.00	5.00	9.20	0.00	0.01	0.00	0.00
2.B.2	IPPU – Nitric Acid Production	N_2O	973	258	2.00	10.00	0.96	0.00	0.02	0.00	0.00
2.B.3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.10	10.00	11.00	0.00	0.26	0.00	0.00
2.B.7	IPPU – Soda Ash Production	CO_2	-	0	0.00	0.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.00	0.00	3.10	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	143	135	0.00	0.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	N_2O	15	13	0.00	0.00	9.60	0.00	0.00	0.00	0.00

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Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
2.B.9.a	IPPU – Fluorochemical Production	HFCs	971	0	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.00	0.00	5.60	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.00	0.00	7.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	PFCs	7 558	556	0.00	0.00	9.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	SF_6	56	1	0.00	0.00	5.00	0.00	0.00	0.00	0.00
2.C.4	IPPU – Magnesium Production	SF_6	2 738	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.7	IPPU – Other (Magnesium Casting)	SF_6	225	290	0.00	0.00	9.20	0.00	0.00	0.00	0.00
2.D.3.a	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.00	20.00	20.00	0.00	0.14	0.00	0.00
2.D.3.b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	-	32	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	PFCs	0	8	2.00	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	SF_6	4	20	15.00	30.00	45.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	NF_3	0	1	0.00	0.00	300.00	0.00	0.00	0.00	0.00
2.E.5	IPPU – Other Emissive Applications	PFCs	-	0	2.00	50.00	50.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 414	0.00	0.00	11.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	0.00	0.00	23.00	0.00	0.00	0.00	0.00
2.G.1	IPPU – Electrical Equipment	SF_6	202	170	11.00	30.00	32.00	0.00	0.01	0.00	0.00
2.G.3.a	IPPU – Other (Medical Applications of N_2O)	N_2O	146	438	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU – Other (Uses of N_2O for Propellant)	N_2O	26	80	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.4	IPPU – Other Contained Product Uses	PFCs	-	30	2.00	50.00	51.00	0.00	0.00	0.00	0.00
	Agriculture – Total CH_4	CH_4	24 970	27 922	1.20	19.00	18.00	0.00	0.21	0.00	0.00
3.A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	1.20	18.00	22.00	0.01	0.21	0.00	0.00
3.B.1	Agriculture – Manure Management	CH_4	2 453	3 876	0.19	4.50	32.00	0.00	0.00	0.00	0.00
	Agriculture – Total N_2O	N_2O	20 779	28 505	0.00	0.02	24.00	0.01	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Direct Emissions	N_2O	3 062	3 348	0.00	0.00	51.00	0.00	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Indirect Emissions	N_2O	613	700	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.D.1	Agriculture – Direct Agriculture Soils	N_2O	14 261	20 249	0.00	0.00	34.00	0.01	0.00	0.00	0.00
3.D.2	Agriculture – Indirect Agrictulure Soils	N_2O	2 790	4 197	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.01	0.00	0.00
	Agriculture – Total CO_2	CO_2	1 191	2 631	13.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture – Limestone $CaCO_3$	CO_2	385	171	30.00	50.00	58.00	0.00	0.03	0.00	0.00
3.H	Agriculture – Urea Application	CO_2	754	2 191	15.00	50.00	52.00	0.00	0.11	0.00	0.00
3.I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	52	268	15.00	50.00	52.00	0.00	0.02	0.00	0.00

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	Uncertainty in trend in national emissions introduced by **emission** factor uncertainty	Uncertainty in trend in national emissions introduced by **activity** data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
4.A.1	LULUCF – Forest Land Remaining Forest Land	CO_2	(201 589)	(133 575)	0.00	0.00	38.00	0.48	0.00	0.00	0.00
4.A.1	LULUCF – Forest Land Remaining Forest Land	CH_4	439	375	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.A.1	LULUCF – Forest Land Remaining Forest Land	N_2O	222	228	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.A.2	LULUCF – Land Converted to Forest Land	CO_2	(1 069)	(302)	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.B	LULUCF – Cropland	CO_2	(1 798)	(9 224)	0.00	0.00	23.00	0.00	0.00	0.00	0.00
4.B	LULUCF – Cropland	N_2O	14	13	0.00	0.00	40.00	0.00	0.00	0.00	0.00
4.C	LULUCF – Grassland	CH_4	0	1	0.00	0.00	64.00	0.00	0.00	0.00	0.00
4.C	LULUCF – Grassland	N_2O	0	0	0.00	0.00	69.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	CO_2	2 498	1 605	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	CH_4	6	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	N_2O	2	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.E	LULUCF – Settlements	CO_2	(4 175)	(4 403)	0.00	0.00	39.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	CO_2	17 532	12 205	0.00	0.00	17.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	CH_4	446	232	0.00	0.00	31.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	N_2O	222	121	0.00	0.00	29.00	0.00	0.00	0.00	0.00
4.G.	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	0.00	0.00	24.00	0.21	0.00	0.00	0.00
5.A.1	Solid Waste Disposal – Managed Waste Disposal Sites	CH_4	20 984	22 989	59.00	46.00	76.00	0.05	0.47	0.02	0.00
5.A.2	Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills	CH_4	3 847	3 003	0.00	0.00	190.00	0.01	0.00	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	CH_4	34	168	0.00	87.00	87.00	0.00	0.02	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	N_2O	39	194	0.00	61.00	61.00	0.00	0.02	0.00	0.00
5.B.2	Biological Treatment of Solid Waste – Anerobic Digestion – Industrial & Municipal Facilities	CH_4	-	19	0.00	79.00	79.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CO_2	178	105	4.50	36.00	37.00	0.00	0.01	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CH_4	2	1	4.90	98.00	59.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	N_2O	92	80	4.40	88.00	88.00	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	CH_4	486	532	43.00	36.00	55.00	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	342	490	10.00	50.00	51.00	0.00	0.00	0.00	0.00

Notes:

a. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods—as related to categories in the Energy, IPPU, and Waste sectors—the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N_2O and CH_4, combined with error propagation calculations for CO_2. For IPPU categories where the uncertainty values for activity data and emission factor are not provided, the combined uncertainty value is calculated using many subcategory inputs which have varying activity data and emission factor uncertainty values.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

ANNEX 3

METHODOLOGIES

A3.1. Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following presents an overview of the methodology, activity data and emission factors used to estimate CO_2, CH_4 and N_2O emissions from fuel combustion sources for the Energy sector.

A3.1.1. Methodology

In general, estimating greenhouse gas (GHG) emissions from fuel combustion activities uses a top-down method, following the Tier 3 and Tier 2 sectoral approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). As illustrated by Equation A3.1–1, to calculate the emission for each source category, the quantity of fuel at the national and/or provincial level is multiplied by the corresponding fuel-specific emission factor. Sections A3.1.4.1 and A3.1.4.2 discuss refinements and deviations from the general approach to estimating combustion emissions for the stationary combustion and transport sections, respectively. The purpose of these refinements is to increase the accuracy and allocation of the emissions associated with each source category when additional details or parameters are available. The Energy chapter (Chapter 3) of this report discusses specific methodological issues.

Equation A3.1–1 **for general fuel combustion**

$$E_{Category,G} = FC_{F,R} * EF_{G,F,R,T}$$

$E_{Category,G}$ = GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)

$FC_{F,R}$ = quantity of fuel consumed (in physical units, such as kg, L, or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region

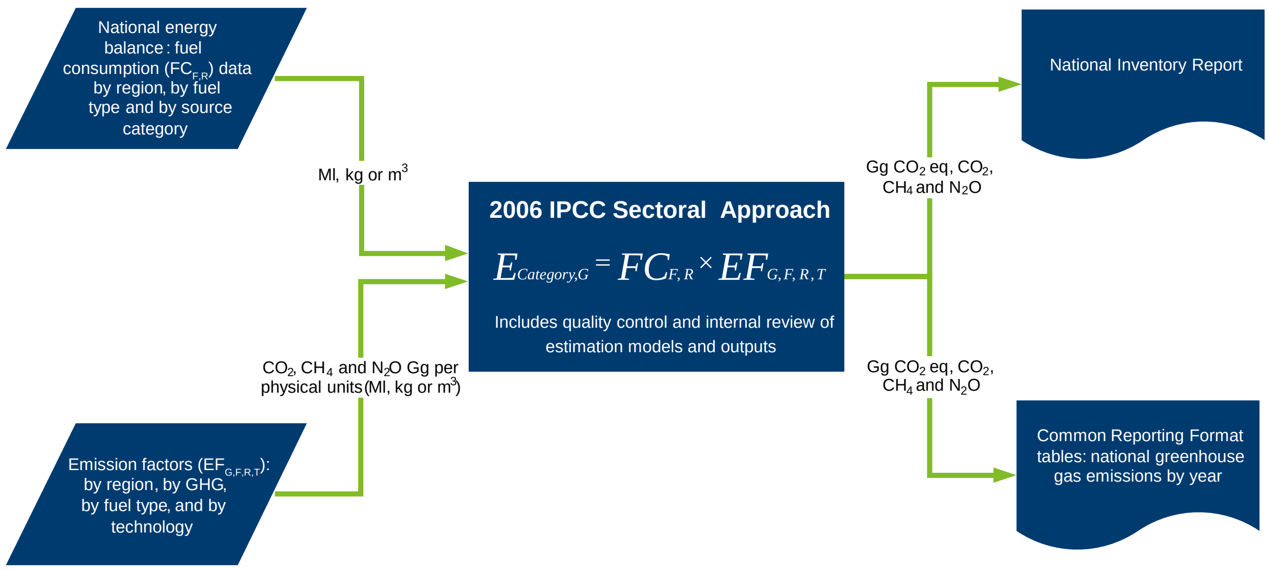
$EF_{G,F,R,T}$ = country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

The stationary combustion and transport models primarily use relational databases to process the national and provincial activity data and emission factors used to estimate GHG emissions (Figure A3.1–1). Statistics Canada prepares the national energy balance using data reported in physical units by the producing and consuming sectors. For this reason, the physical units were judged the most accurate for generating emission estimates. Country-specific emission factors, as applied, are in physical units to minimize the number of additional conversion factors and thus limit the uncertainty associated with estimates. The uncertainty of estimates are further reduced by applying available higher-resolution emission factors at the provincial/regional level rather than the national level (e.g. regional coal and natural gas emission factors are used to account for the variation in carbon content). Non-CO_2 emission factors address any existing combustion technology differences.

A3.1.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 1990–), also referred to as the national energy balance. The RESD uses both top-down and bottom-up approaches to estimate the supply of, and demand for, energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, residential, and industry. Industrial energy-use data is allocated using the North American Industrial Classification System (NAICS). Currently, the RESD reports energy used to generate electricity or steam by industry (auto producers) in two separate lines (one for electricity and one for steam), without any further disaggregation by industrial subcategories. Prior to 1998, the Industrial Consumption of Energy Survey (ICE) (Statistics Canada 2013) provided these summary line quantities. From 1998 on, the electricity line (from auto producers) is based on the quantities reported in the Electric Power Thermal Generating Station Fuel Consumption Survey (EPTGS) (Statistics Canada 2013). Statistics Canada implemented this improvement to

Figure A3.1–1 **GHG Estimation Process Flow**



increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. The steam line continues to be populated using the ICE data.

While the RESD provides fuel use data at a provincial level, the accuracy of these data is generally not as high as that of the national data. Statistics Canada typically allocates final fuel demand by subcategories for the RESD through a number of surveys directed at producers and suppliers of energy, provincial energy ministries and some users of energy. The accuracy following these allocations is less than that of the total available energy supply at the national level. As a result, the total emission estimates for Canada are more certain than the emissions from specific subcategories. Since 1995, Statistics Canada has been collecting energy statistics directly from end users through the annual ICE survey. Estimating fuel use by industry using a bottom-up approach provides more accurate subcategory information. Refer to Annex 4, National Energy Balance, for additional discussion on the development of the RESD and the ICE data set, including a discussion of Statistics Canada's quality assurance / quality control activities. Sector-specific surveys provide verification of sector trends and emissions allocation.

The combustion and transport models apply the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how Statistics Canada collects data from reporting facilities under the *Statistics Act.* The quantities of fossil fuel consumed are also available in gross calorific units; however, as discussed, this is assumed to be less accurate. When converting to energy values, with the exception of natural gas, Statistics Canada applies constant energy conversion factors (a factor for 1990 to 1997 and another factor for 1998 onward) to each fuel type without taking into account year-to-year variability in fuels such as coal, petroleum coke and refinery fuel gas (still gas). These energy conversion factors are applied for the reporting of fuel quantities in the CRF tables, and nationally weighted values were determined for reference approach calculations (refer to Table A4–2 for details). One exception involves waste fuels, for which the data are only available in energy units from the Cement Association of Canada. Statistics Canada and Environment and Climate Change Canada (ECCC) have initiated a multi-year work program to better track and update energy conversion factors. Refer to the Planned Improvement section of Chapter 3 for further details.

Additional non-Statistics Canada data sources used by the combustion and transport models, such as landfill gas quantities, waste fuel consumption and vehicle fleet information, are included in the specific methodological discussions (sections A3.1.4.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission and Oxidation Factors

The following is a brief summary of the emission factors for fuels that are the largest contributors to Canadian GHG emissions. A detailed description of emission factors used in the current fossil fuel combustion models can be found in Annex 6.

Natural Gas: The emission factors for CO_2 vary depending on the source of natural gas and whether the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). Therefore, provinces have varying emission factors based on the origin and quality of the natural gas. The emission factors for CH_4 and N_2O vary with the combustion technology.

Refined Petroleum Products (RPP): Refined petroleum products include, but are not limited to, fuels such as diesel, gasoline, light fuel oil and heavy fuel oil. The emission factors vary with fuel type and/or combustion technology (for CH_4 and N_2O).

Coal: The CO_2 emission factors vary by the coal properties, province of use and coal origin, whether domestic or foreign. The emission factors for CH_4 and N_2O vary by the combustion technology.

The IPCC default oxidation value applies to all fuels except coal, where country-specific oxidation factors applied at the provincial level reflect regional variations in combustion efficiencies. Refer to the Recalculation section of Chapter 3 and Annex 6 for more detail on coal oxidation factors.

A3.1.3.1. CO_2 Emission Factors

CO_2 emissions from fuel combustion activities depend on the amount of fuel consumed, the carbon content of the fuel and the applied oxidation factor. The applied emission factors vary by fuel type and by region, where applicable. There is discussion of CO_2 emission factor derivation in Annex 6, in *Fossil Fuel and Derivative Factors* (McCann 2000), in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b) and in *Updated Carbon Dioxide Emission Factors for Coal Combustion* (ECCC 2019). Fuel properties, such as carbon content, density and heating value, were determined using accepted industrial testing standards from the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB).

The waste fuel emission factor is based on energy content since activity data reported by the Cement Association of Canada (CAC) are in energy units.

A3.1.3.2. Non-CO_2 Emission Factors

Emission factors for all non-CO_2 GHGs from combustion activities vary to a greater or lesser degree with:

- fuel type
- technology
- operating conditions
- maintenance and vintage of technology

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH_4. Additional research is needed to better establish CH_4 emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors.

During combustion, some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent on the combustion temperature and the emission control technology employed. Additional research is needed to better establish N_2O emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors. Annex 6 lists non-CO_2 emission factors used in this inventory.

A3.1.4. Methodology for Stationary Combustion and Transport

This section discusses methods used to calculate and report emissions associated with the Energy sector, and specifically stationary combustion and transport.

For reporting under the United Nations Framework Convention on Climate Change (UNFCCC), CO_2 emissions from biomass fuels (including landfill gas) are not to be included in the Energy sector total. The Land Use, Land-Use Change and Forestry (LULUCF) sector accounts for CO_2 emissions from biomass fuel combustion as a loss of biomass (forest) stocks. CO_2 emissions from biomass combustion for energy use is a memo item in the UNFCCC's Common Reporting Format (CRF) tables and is provided for information purposes. The Energy sector reports CH_4 and N_2O emissions from biomass fuel combustion in the appropriate subcategories and includes it in the inventory totals.

A3.1.4.1. Stationary Combustion

The methodology used to estimate GHG emissions from stationary fuel combustion is consistent with the IPCC Tier 2 sectoral approach, along with country-specific emission factors as outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The Industrial Processes and Product Use sector (Annex 3.3) presents the methodology for calculating SF_6 emissions from electrical transmission systems.

Emission calculations use nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the national total is the aggregated sum of the provincial/territorial emissions.

Emission estimates are calculated using Equation A3.1–1 exclusively.

Table A3.1–1 presents activity data sources used in the stationary combustion model methodology. The data provided to ECCC is in electronic format and may differ slightly when compared with Statistics Canada's published values, which are rounded.

Much of the stationary combustion model's complexity lies in the reallocation of data presented in the RESD in order to comply with the requirements of IPCC categories and UNFCCC CRF reporting tables. In addition, in keeping with the 2006 IPCC Guidelines, the allocation of all fuel types uses the CRF fuel grouping (solid, liquid, gaseous, biomass and other) (see Table A4–2 in Annex 4).

Combined Heat and Power Allocation

Activity data, in the form of fuel used by utilities, are currently aggregated to two summary lines in the RESD (Electricity by Utilities and Steam Generation), representing, electricity generation, and combined heat and power facilities. In addition, solid wood waste and spent pulping liquor used by utilities are allocated to Table 10 – Solid Wood Waste and Spent Pulping Liquor.

Since the Electricity by Utilities line (RESD Line 10) is populated with EPTGS survey data, the reallocation was completed using fractions developed using the quantities reported by the Electricity Generation subcategory in the EPTGS survey. For each fuel and each province, the fuel use data reported in the EPTGS, along with a listing of facilities that are combined heat and power facilities (generated by ECCC), are used to develop the combined heat and power fraction of the total fuel use. The fractions are then used with RESD Line 10 to determine what portion of that line should be reallocated to combined heat and power. The remainder is allocated to electricity generation.

The solid wood waste and spent pulping liquor allocation are discussed below.

Electricity by Industry Allocation

Activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Electricity by Industry and Steam Generation). In addition, solid wood waste and spent pulping liquor used by industry are allocated to Table 10 – Solid Wood Waste and Spent Pulping Liquor.

The Electricity by Industry line (RESD Line 11) is populated with EPTGS survey data. The reallocation of RESD Line 11 values from 1998 to present was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the EPTGS survey, as follows:

- For each fuel and each province, the fuel use data reported by industry in the EPTGS for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated to a particular industry.
- This portion is added to the activity data already reported for that industry.

The reallocation of RESD Line 11 values between 1990 and 1997 was completed using fractions developed using the quantities reported by the Electricity Generation subcategory in the ICE survey, since EPTGS data are not available prior to 1998.

- For each fuel and each province, the fuel use data reported by industry in the ICE survey for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated to a particular industry.
- This portion is added to the activity data already reported for that industry.
- Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

Since the Steam Generation line (RESD Line 14) is populated with ICE data, the procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the RESD Line 14 values (for all years) using corresponding ICE data representing steam generation by facilities falling under the Electricity Generation subcategory.

The solid wood waste and spent pulping liquor allocation is discussed below.

Solid Wood Waste and Spent Pulping Liquor Allocation

Activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor).

The Solid Wood Waste and Spent Pulping Liquor table (RESD Table 10) is populated with ICE data. The procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the Table 10 values (for all years) using corresponding ICE data representing solid wood waste and spent pulping liquor consumption by facilities falling under the Electricity Generation subcategory.

Table A3.1–1 **Activity Data Model References**
Statistics Canada. 1990. *Report on Energy Supply and Demand in Canada*. Annual Report, Statistics Canada Catalogue no. 57-003-X.
Waste fuel data – Based on CEEDC. CEEDC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Energy and Emissions Data Centre.
Residential fuelwood consumption – Environment Canada. 2020. *Residential Fuelwood Consumption in Canada*. Unpublished report. Prepared by J. Kay, Pollutant Inventories and Reporting Division, Environment Canada.
Landfill Gas Utilization and Waste Incineration – Environment and Climate Change Canada. 2020. National Inventory Report (NIR). Section A3.6: Methodology for Waste Sector.

A3.1.4.1.1. Public Electricity and Heat Production (CRF Category 1.A.1.a)

The Public Electricity and Heat Production subcategory includes 1.A.1.a.i – Electricity Generation, 1.A.1.a.ii – Combined Heat and Power Generation, and 1.A.1.a.iii – Heat Plants. This subcategory should include all emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation, and heat plants. Emissions from auto producers are allocated to their respective industrial subcategories.

Two lines in the RESD (one for electricity and one for steam) report activity data from this subcategory; however, they are summary lines and are not divided into electricity generation, combined heat and power, and heat plants. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data need to be reallocated to the appropriate subcategory where the fuel is used. Section A3.1.4.1 provides a detailed discussion of the method used.

CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3.1–1 to activity data and emission factors for each specific fuel. As previously discussed, in order to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data where available. For this sector, there are regional emission factors for coal and natural gas. For the remaining fuels, the emission factors are applied to the nationally reported data.

Table A3.1–2 provides a summary of the methodology for the Public Electricity and Heat Production category.

A3.1.4.1.2. Petroleum Refining (CRF Category 1.A.1.b) and Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)

To meet the UNFCCC reporting requirements, activity data from the Manufacture of Solid Fuels and Other Energy Industries category were reallocated to two separate IPCC subcategories, both of which comprise the emissions associated with the combustion of fuels produced at the facilities (e.g. combustion of coal at a coal mine or natural gas at an oil and gas facility) as well as the combustion of purchased fuels. Combustion emissions that support coal production are allocated to 1.A.1.c.i – Manufacture of Solid Fuels, while combustion emissions that support crude oil and natural gas production and upgrading of oil sands bitumen are allocated to 1.A.1.c.ii – Oil and Gas Extraction.

The methodology for estimating emissions from these subcategories involves applying Equation A3.1–1 on a national basis and subtracting emissions associated with flaring from the total GHG emissions for Petroleum Refining and Oil and Gas Extraction. The fuel use data reported in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive category. To avoid double counting, the model subtracts fuel use, energy content and emission data associated with flaring. See Annex 3.2.2.7 for more details.

Determining the activity data associated with the Petroleum Refining subcategory requires the reallocation of some of the data reported as Producer Consumption in the RESD. The Petroleum Refining subcategory includes all refined petroleum products reported as Producer

Table A3.1–2 **Emission Estimation Methodology for Public Electricity and Heat Production**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.1.a.i Electricity Generation	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[d] Steam Generation[d]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[d] Steam Generation[d]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.1.a.iii Heat Plants	NO			

Notes:

NO = Not occurring

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC 2006, Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

Consumption, except in provinces where no refinery exists; these producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of liquefied petroleum gases (LPGs) reported in the RESD as producer consumption are divided between propane and butane using energy data reported in the RESD.

Calculating the emissions associated with the fuels listed below involves summing the activity data reported under the RESD's Petroleum Refining and Producer Consumption lines and applying Equation A3.1–1 to:

- petroleum coke
- still gas
- kerosene
- light fuel oil
- heavy fuel oil
- butane
- propane

In addition, activity data in the form of fuel used by industry to generate electricity or steam are currently aggregated to two summary lines in the RESD (Line 11 – Electricity by Industry and Line 14 – Steam Generation). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Reallocation involves one of the two methods discussed in detail in section A3.1.4.1. Because of a lack of resolution in the RESD Producer Consumption line by specific industry, the Manufacture of Solid Fuels and Other Energy Industries subcategory does not include emissions associated with the transportation fuels listed below; these emissions are reported in the Petroleum Refining subcategory. In general, the combustion emissions calculations from the following transportation fuels, for the Petroleum Refining subcategory, use activity data reported in the RESD under Producer Consumption, together with Equation A3.1–1:

- aviation gasoline
- aviation turbo fuel
- diesel
- motor gasoline

The estimated N_2O emissions for petroleum coke and motor gasoline use IPCC default emission factors, which are based on the calorific value of the fuel. The RESD reports the gross calorific value for petroleum coke, and this can change annually. As a result, the petroleum coke emission factors for both crude bitumen upgrading and crude oil refining change on an annual basis. The conversion between the gross calorific value and the net calorific value, a necessary step in generating annual emission factors, uses data reported to, and published by, the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC 2012).

To calculate GHG emissions from the Manufacture of Solid Fuels and Oil and Gas Extraction subcategories, activity data associated with the fuels listed below and reported under the producer consumption line and applicable portion of the total mining and oil and gas extraction line of the RESD are used in Equation A3.1–1:

- natural gas
- coal
- diesel
- propane
- butane
- petroleum coke
- still gas
- heavy fuel oil

The producer consumption line of the RESD includes petroleum coke, still gas and diesel used by refineries and by the crude bitumen upgrading industry. Information on the proportion of fuel consumed by the crude bitumen upgrading industry is provided in Table 11, Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil, of the RESD. This information is used to reallocate the relevant quantities of petroleum coke and still gas to the Oil and Gas Extraction subcategory (CRF category 1.A.1.c.ii). Diesel reported as producer consumption is used in oil sands mining trucks and is reallocated to Other Transportation (Off-Road) (see section A3.1.4.2.1).

The total mining and oil and gas extraction line of the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations to allocate into the following CRF categories; Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii). Other data sources therefore are used to allocate the fuel consumption to the proper categories. Fuel consumption at coal mining operations is estimated based on data from the study of the Canadian coal mining industry (Cheminfo/Clearstone 2014), while fuel consumption for the non-energy mining industry is based on data from the Canadian Energy and Emissions Data Centre (CEEDC no date; NAICS 2122 and 2123). As the oil and gas industry in Canada is the largest of these three industries, the remainder of fuel consumed in the total mining and oil and gas extraction line after subtracting coal mining and non-energy mining fuel consumption is allocated to Oil and Gas Extraction. For a more detailed explanation of the allocation procedure, please see Annex 10 – Reallocation of Emissions from IPCC Sector to Canadian Economic Sector.

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Table A3.1–3 Estimation Methodology for Petroleum Refining, Manufacture of Solid Fuels and Oil and Gas Extraction

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.1.b Petroleum Refining	Solid Fuels	NA		
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Electricity by Industry[d] Steam Generation[d]
			11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Steam Generation[d] Refined Petroleum Products Manufacturing
	Biomass	NA		
1.A.1.c.i Manufacture of Solid Fuels	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Producer Consumption Total Mining and Oil and Gas Extraction[e]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	NA		
1.A.1.c.ii Oil and Gas Extraction	Solid Fuels	NA		
	Liquid Fuels	RESD	3 – Refined Petroleum Products 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Producer Consumption Total Mining and Oil and Gas Extraction[f]
			11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Producer Consumption Total Mining and Oil and Gas Extraction[f]
	Biomass	NA		

Notes:

NA = Not applicable (national aggregation only)

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
e. The portion of fuel consumed at coal mining operations is allocated to this CRF category.
f. The portion of fuel consumed at oil and gas extraction facilities is allocated to this CRF category.

As previously mentioned in section A3.1.4.1.1, national level coal emissions from combusted coal use aggregated provincial/territorial level estimates.

Table A3.1–3 provides a summary of the methodology for this CRF category.

A3.1.4.1.3. Manufacturing Industries and Construction (CRF Category 1.A.2)

The Manufacturing Industries and Construction category includes a number of industrial categories. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories; however, this does not include fuel used to generate electricity or steam by industry. This energy is captured in the RESD in two separate summary lines (one for electricity and one for steam), which are not broken down by industrial categories. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Section A3.1.4.1 describes this reallocation method in detail.

Emissions are calculated for the following categories:

- Mining
- Iron and Steel
- Non-Ferrous Metals
- Chemicals
- Pulp, Paper and Print
- Non-Metallic Minerals
- Construction
- Other Manufacturing (includes Food Processing, Beverages and Tobacco)

GHG emissions associated with the Manufacturing Industries and Construction category are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for each fuel type (as presented in A6.1). Section A3.1.4.1.1 describes the handling of coal emissions. The Industrial Processes and Product Use sector reports emissions from fuels used as feedstocks, while the Transport category reports emissions generated from the use of transportation fuels (e.g. diesel and gasoline).

The Industrial Processes and Product Use sector reports all emissions associated with the manufacture and use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces.

Industrial consumption of biomass and spent pulping liquor is reported in the RESD; however, some of the data are limited. The RESD data for Newfoundland and Nova Scotia are combined. Facility-level data are used to reallocate this consumption to Nova Scotia.

As previously described in section A3.1.4.1.2 the total mining and oil and gas extraction line in the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations for allocation to the Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii) categories, respectively. Other data sources are therefore used to allocate the fuel consumption to the proper categories. Fuel consumption for the non-energy mining industry is based on data from CEEDC (no date; NAICS 2122 and 2123). For a more detailed explanation of the allocation procedure, please see Annex 10 – Reallocation of Emissions from IPCC Sector to Canadian Economic Sector.

The Other Manufacturing category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is considered biogenic, so CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included in the national total.

CO_2 emissions from the combustion of waste fuels in the cement industry are calculated using data provided by the Cement Association of Canada and reported by CIEEDAC (2013) on an energy basis. Table A3.1–4 provides a summary of the methodology for the Non-Metallic Minerals category.

A3.1.4.1.4. Other Sectors (CRF Category 1.A.4)

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential, and Agriculture/Forestry/Fishing. GHG emissions associated with the Other Sectors category (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for specific fuels (refer to Annex 6.1).

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use, as determined from the *Residential Fuelwood Consumption in Canada* study (ECCC 2020). Firewood consumption data were collected through a survey of residential wood use for the years 1997, 2003, 2007, 2015 and 2017 (Statistics Canada 1997, 2003, 2007, 2015, 2017). Pellet and manufactured log consumption data were collected for the years 1996, 2006, 2012, and 2017 (Canadian Facts 1997; TNS 2006; TNS 2012; Statistics Canada 2017). These data were collected by province and grouped into eight major appliance-type categories:

- Fireplaces
- Fireplace Inserts
- Wood Stoves
- Wood Furnaces
- Pellet Stoves
- Hydronic Heater
- Water Heater
- Other Equipment

Some of these appliance types were further broken down into either advanced technology (catalytic or non-catalytic) or conventional technology (air-tight or not-air tight).

The 2017 survey also collected data on the type of wood used, by reconciliation unit, and the moisture content of the wood. Section A3.5.1 describes the boundaries of reconciliation units in detail. Since the firewood consumption data were collected on a volume basis, an average density value was determined by reconciliation unit, based on the proportion of the different types of wood used, the corresponding wood densities and the moisture content of the wood. The wood densities were taken from various Canadian wood density studies (Alemdag 1984; Gonzalez 1990; Jessome 2000). The ratio of wood used, by reconciliation unit, and the moisture content of the wood compared to the total firewood consumption in the province was applied to all surveys. The pellet and manufactured log consumption data were collected on a mass basis.

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Table A3.1–4 **Estimation Methodology for Manufacturing Industries and Construction**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.2.a. Iron and Steel	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Iron and Steel Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.b. Non-Ferrous Metals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Aluminum and Non-ferrous Metal Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.c. Chemicals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Chemicals and Fertilizer Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.d. Pulp, Paper and Print	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Pulp and Paper Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.e. Food Processing, Beverages and Tobacco	Emissions for this subcategory are included in 1.A.2.g.viii.1 Other Manufacturing			
1.A.2.f. Non-Metallic Minerals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Cement
		Waste fuel data from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC)		
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Electricity by Industry[d] Steam Generation[d] Cement
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.g.iii Mining	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Total Mining and Oil and Gas Extraction[f]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.v Construction	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Construction
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.viii.1 Other Manufacturing	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Other Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–13[e]	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
		NIR	Table A3.6–13[e]	

Notes:

NA = Not applicable (national aggregation only)

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
e. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels, the biogenic portion is under biomass.
f. The portion of fuel consumed at non-energy mining operations is allocated to this CRF category.

The mass of biomass consumed for the other years was interpolated and extrapolated using the number of heating degree days in each province in relation to the survey years. GHG emissions were calculated by multiplying the amount of biomass burned in each appliance by the emission factors.

CO_2 emissions associated with biomass combustion in the Residential category are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

The Commercial/Institutional category includes GHG emissions associated with the combustion of landfill gas. As landfill gas is considered a biofuel, CO_2 emissions associated with combustion are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

The Commercial/Institutional category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is biogenic, and CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included.

In addition, activity data in the form of fuel used by industry (including the Commercial/Institutional category) to generate electricity are currently aggregated to a summary line in the RESD (Line 11 – electricity by industry). Activity data in the form of solid wood waste and spent pulping liquor are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated fuel use data need to be reallocated to the appropriate subcategory. Section A3.1.4.1 discusses the disaggregation method used.

The Agriculture/Forestry/Fishing category (CRF category 1.A.4.c) includes emissions from stationary fuel combustion only from the agricultural and forestry industries. Emissions are from on-site machinery operation and space heating and are estimated using fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transport or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and are all included as off-road or marine emissions reported under the Transport category.

Table A3.1–5 provides a summary of the methodology for this CRF category.

Table A3.1–5 **Estimation Methodology for the Other Sectors Category**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.4.a.i Commercial/Institutional – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Commercial and Other Institutional Public Administration
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–13[e]	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
		NIR	Table A3.6–13[e]	
		NIR	Table A3.6–6	
1.A.4.b.i Residential – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Residential
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Residential
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Residential
	Biomass	Estimated using Environment Canada residential fuelwood consumption model.		
1.A.4.c.i Agriculture/Forestry/Fishing – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Forestry and Logging and Support Activities for Forestry Agriculture
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	

Notes:

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.

b. As outlined in IPCC (2006) Volume 2, Table 1.1.

c. Publication references are provided in Table A3.1–1.

d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

e. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels and the biogenic portion under Biomass.

A3.1.4.2. Transport (CRF Category 1.A.3)

GHG emissions from the Transport category are divided into six subcategories:

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Other Transportation (Pipeline Transport)
- Other Transportation (Off-Road)

Emission estimates are developed at the provincial/territorial level and aggregated to the national level. Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3.1–1.

CO_2 emissions are predominantly dependent on the type and characteristics of fuel being combusted, whereas N_2O and CH_4 emissions are dependent on both the fuel combusted and emission control technologies present. Annex 6 provides a complete listing of transportation-related emission factors and their specific references.

For the Road Transportation and Other Transportation (Off-Road) categories, Canada uses the Motor Vehicle Emissions Simulator (MOVES) model, MOVES2014 version, developed by the U.S. EPA, and a modified version of the U.S. EPA's NONROAD model (NONROAD2012c). The primary reasons for these updates are to remain current with regulatory changes in the Canadian vehicle fleet, which are harmonized with those of the United States, to align GHG estimates with those published in *Canada's Air Pollutant Emissions Inventory Report 1990–2019* and *Canada's Black Carbon Inventory Report 2013–2019* and to create a bottom-up inventory for off-road emissions by making use of equipment and operational data. Use of the NONROAD model also has the added benefit of allocation to additional economic subsectors on an equipment basis. Therefore, under the CRF classification system, some emissions that were previously reported in the 1.A.3 categories are allocated to the 1.A.2 and 1.A.4 categories. The Aviation Greenhouse Gas Emission Model (AGEM) is used to calculate aviation emissions. The Marine Emissions Inventory Tool (MEIT) is used to calculate navigation emissions. Railway emissions are derived from fuel reported in the RESD. Combustion emissions associated with pipeline transport are estimated separately.

A3.1.4.2.1. Road Transportation (CRF Category 1.A.3.b.i-v) and Other Transportation (Off-Road) (CRF Categories 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii)

The methodology used to estimate Road Transportation and Other Transportation (Off-Road) GHG emissions follows a detailed IPCC Tier 3 approach. Since these two categories are collectively normalized to fuel available as reported in the RESD, a combined methodology for the two categories is outlined below.

Step 1: On-Road Activity Data—Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Kilometre Accumulation Rates, Fuel Consumption Rates and Biofuels

Vehicle populations

Vehicles are separated into different classes depending on their fuel type, body configuration (car versus truck) and gross vehicle weight rating (GVWR). GVWR is the maximum allowable weight of a fully loaded road vehicle, including the weight of the vehicle, fuel, passengers, cargo and other miscellaneous items, including optional accessories.

Two distinct data sets are used to develop a complete vehicle population profile. Light-duty vehicle and truck populations for 1990–2002 and 2005–2015 were obtained from the Canadian Vehicles in Operation Census, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2004 were derived from Statistics Canada's Canadian Vehicle Survey. Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002 and 2005–2015. Heavy-duty vehicle populations for 2003–2004 were derived from Statistics Canada's Canadian Vehicle Survey, while populations for 1990–1993 were estimated based on historical population trends. The 2016–2019 populations were estimated based on scrappage and growth rates.[1] Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR of less than or equal to 3900 kg, whereas heavy-duty classes have a GVWR above 3900 kg.[2]

1 Scrappage rates for all vehicle classes (including motorcycles) were developed based on historical population trends. The growth rates for light-duty vehicles and motorcycles are from the U.S. EPA Motor Vehicle Emission Simulator (MOVES2014, 2014). For all other classes, Power Systems Research Inc. provided growth rates.

2 The 2005–2015 light- and heavy-duty populations received from DesRosiers and Polk were in a new format when compared with previously received data sets and were derived using updated vehicle identification algorithms. As a result, when the 1990–2004 data set was merged with the 2005–2015 data set, there were step changes in some classes between 2004 and 2005. The classes affected were light-duty trucks (GVWR less than or equal to 3900 kg) and heavy-duty vehicle 2b and 3 classes (GVWR between 3901 kg and 6351 kg). Since the newer data set with updated algorithms is believed to be more representative, the class ratios between light-duty trucks and heavy-duty vehicle 2b and 3 classes from the newer data were applied to the older data set while maintaining the overall population of the older data set.

Motorcycle populations for 1990–2013 were based on road motor vehicle annual registrations from Statistics Canada (CANSIM Table 405-0001 and Table 405-0004). The annual motorcycle counts were then stratified into model year bins with the aid of published age distributions found in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2015). The 2014–2019 population was estimated based on a scrappage and growth rate.

Technology penetration

To account for the effects of emission control technologies on emission rates of CH_4 and N_2O, estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. The vast majority of on-road vehicles in use in 2019 are subject to Tier 1 and Tier 2 regulatory tiers, approximately representing model years 1996 and onwards. However, since the National Inventory estimates a time series starting at 1990, as well as considering a small number of pre-1996 model year vehicle still in active fleet, additional technology emission rates for CH_4 and N_2O emission factors are also used. These include emission controls ranging from completely uncontrolled vehicles to those using Tier 1 regulatory standards. Similarly, heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs) and motorcycles (MCs) have advanced emissions controls starting with the 1996 model year. Emission factors for uncontrolled and/or moderate controls are used for 1995 and older model years. CH_4 and N_2O emission factors for the full range of emissions controls are listed in Annex 6.

Catalyst survival rate

With use, catalytic converters deteriorate, affecting tailpipe emission rates. Based on information from industry experts, a technology-specific deterioration rate is applied to LDGVs and LDGTs with catalytic-controlled technologies. To model the deterioration effect, the vehicles with deteriorated catalysts are assigned to the non-catalytic controlled technology. For provinces with inspection and maintenance programs (Ontario and British Columbia), the catalyst survival rate is not applied to Tier 0, Tier 1 or Tier 2 technologies, as these emission control technologies are inspected and replaced or repaired as necessary.

Fuel consumption rates (FCR)

With the adoption of MOVES2014, fuel consumption rates are now embedded within the model in the form of energy rates in kilojoules per second (kJ/s). The rates vary, taking into account a range of default parameters or user inputs, such as vehicle type, model year, speed, road type and operating mode. As the Canadian and U.S. vehicle markets are made virtually identical through regulation, it is believed that the MOVES energy rates are representative of fuel consumption for Canadian vehicles. MOVES also factors in more current fuel efficiency regulations, such as the *On-Road Vehicle and Engine Emission Regulations* for light-duty vehicles and the *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* for heavy-duty vehicles. Further documentation on MOVES energy rates for both light- and heavy-duty vehicles can be found on the U.S. EPA website at https://www.epa.gov/moves/moves-technical-reports.

For this submission, Canada only uses MOVES' energy allocation capability. MOVES output is on an energy basis and Canada's current emission factors are developed on a fuel-volume basis. The energy output from MOVES is therefore converted to fuel volumes using energy conversion factors, as reported in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b), taking into consideration the use of biofuels (see below). MOVES reports energy output on a lower heating value basis. Canada plans to review the GHG emission factors within MOVES for their potential use in a future submission.

Kilometre accumulation rates

Kilometre accumulation rates (KARs) are a measure of the average annual kilometres travelled by a single vehicle of a given age in a specific vehicle class. Light-duty car and truck KARs are estimated from the results reported in a study that examined observed differences in a vehicle odometer reading recorded between successive inspection and maintenance tests from Ontario and British Columbia (Stewart Brown Associates 2013). Given the absence of inspection and maintenance programs in other jurisdictions, the Ontario KAR estimates are adopted in all other provinces and territories excluding British Columbia, where the B.C. KAR estimates are directly applied.

Biofuels

MOVES requires biofuel content on a relative content basis (i.e., percent) as an input, as well as a range of other fuel characteristics, such as vapour pressure, sulphur content, and benzene content. These parameters are derived by ECCC using information collected under the *Renewable Fuels Regulations, Sulphur in Liquid Fuels* reports and related sources. However, volumes of biofuels are recalculated as outputs such that emissions can be estimated by selecting appropriate emission factors in Annex 6 and applying Equation A3.1–1.

Step 2: On-Road Fuel Calculation

Using the inputs from Step 1, on-road fuel consumption is estimated by converting MOVES2014 energy outputs into litres of fuel volume. This calculation represents the initial "bottom-up" fuel calculation for consideration in the fuel normalization process described below. On-road vehicles are grouped into eight major vehicle classes:

- Light-duty gasoline vehicles (LDGV)
- Light-duty gasoline trucks (LDGT)
- Heavy-duty gasoline vehicles (HDGV)
- Motorcycles (MC)
- Light-duty diesel vehicles (LDDV)
- Light-duty diesel trucks (LDDT)
- Heavy-duty diesel trucks (HDDV)
- Propane and natural gas vehicles

Step 3: Other Transportation (Off-Road) (CRF Category 1.A.3.e.ii)

GHG emissions for off-road transportation are calculated using NONROAD2012c, a Canadianized update to NONROAD2008 developed by the U.S. EPA. Key inputs to the model are equipment population, average rated power, load factor and activity (in hours/year). Further, the Canadian modifications to NONROAD include a user-defined age distribution of equipment that is not part of the U.S. model, as well as a unique coding for oil sands equipment and additional renewable fuels capabilities. NONROAD outputs are expressed on a fuel volume basis, to which Equation A3.1–1 is applied using the emission factors in Annex 6.

Activity data used in the model are largely derived from Power Systems Research (PSR) data. PSR is an independent supplier of data which maintains PartsLink, a comprehensive database that includes off-road equipment used in Canada. A significant study conducted by PSR in 2011 forms the basis of activity input, which includes parameters such as engine populations, age distribution, engine size, load factor and hours of use for the years 1990 to 2019. Construction equipment populations used in oil sands mining operations were identified with a mining equipment database provided by The Parker Bay Company (ECCC 2018b). Where possible, the hours-of-use parameter provided by PSR was replaced using Canada-specific information collected from resale markets. As an example, activity data from nearly 2000 used snowmobile advertisements were used to derive hours-of-use data, by engine stroke (ECCC 2018a). NONROAD default parameters used include deterioration and other factors. Updates to the 2011 data set were performed in 2012 and 2013. Unlike MOVES, which outputs on an energy basis, NONROAD calculates fuel use on a volume basis, which is later scaled upwards or downwards in the fuel normalization step (Step 4) once biofuels are taken into account.

A great advantage of NONROAD is its capability to allocate emissions to distinct sectors on an equipment basis. Primary sectors from NONROAD include agriculture, airport (equipment), commercial, construction and mining, industrial, residential, forestry, railway (equipment) and recreational equipment. Where applicable, emissions from these sectors are reported under the appropriate CRF sector.

Step 4: Normalization

In an effort to mitigate some of the uncertainties associated with separate bottom-up calculations for on- and off-road estimates, the fuel consumption estimates from these two subsectors are combined and balanced against top-down fuel availability information. The source of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate is the RESD (Statistics Canada 1990–).

Statistics Canada has stated that the volumes of gasoline reported in the RESD include ethanol. Therefore, the estimated volume of ethanol fuel is removed from the volume of gasoline reported. As a result, when comparing total volumes of gasoline in the RESD with that of the CRF, one should be cognizant that the CRF gasoline volume must be added to the CRF ethanol volume in order to equate to the RESD gasoline volume. For diesel fuel, the opposite is true: given that the RESD does not report biodiesel, diesel fuel volumes in the CRF will equate to the diesel fuel volumes in the RESD.

In Step 4, bottom-up estimates of fuel consumption from on- and off-road sources are pooled together on a fuel basis at the provincial/territorial level, and the total volume of fuel is scaled to match the fuel available as reported in the RESD. At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, the degree of correlation between the two estimates is higher. Please refer to Table A3.1–6 and Table A3.1–7 for the normalization factors calculated on a national basis for gasoline and diesel fuel, respectively.

Step 5: Emission Calculation

Once a final allocation of fuel is complete for all vehicle and equipment types, emissions are calculated using Equation A3.1–1 with the emission factors in Annex 6.

Table A3.1–6 **Gasoline Normalization Values, Selected Years**

Category	Statistic	1990	2005	2013	2014	2015	2016	2017	2018	2019
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	37 113	40 653	48 301	49 418	50 529	50 340	50 203	51 356	52 251
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	7 463	3 189	3 158	3 463	3 531	3 335	3 458	3 581	3 518
	Total Bottom-Up Fuel Consumption Estimate (ML)	44 576	43 842	51 459	52 881	54 060	53 675	53 661	54 937	55 770
	Bottom-Up On-Road Portion (%)	83	93	94	93	93	94	94	93	94
	Bottom-Up Off-Road Portion (%)	17	7	6	7	7	6	6	7	6
Target	Total Top-Down Fuel Available (ML)	33 943	40 850	44 263	43 437	44 423	46 046	46 390	47 037	47 633
	National Scaling Factor (%)	76	93	86	82	82	86	86	86	85
Scaled	Final On-Road Fuel Estimate (ML)	28 298	37 868	41 528	40 567	41 493	43 160	43 385	43 961	44 621
	Final Off-Road Fuel Estimate (ML)	5 645	2 981	2 735	2 870	2 930	2 886	3 005	3 076	3 012
	Sum of Final On- and Off-Road Fuel (ML)	33 943	40 850	44 263	43 437	44 423	46 046	46 390	47 037	47 633

Table A3.1–7 **Diesel Fuel Normalization Values, Selected Years**

Category	Statistic	1990	2005	2013	2014	2015	2016	2017	2018	2019
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	5 324	14 638	18 974	19 489	19 344	20 196	21 105	21 899	22 202
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	9 404	10 322	9 278	9 254	9 851	9 892	10 594	11 281	11 367
	Total Bottom-Up Fuel Consumption Estimate (ML)	14 728	24 960	28 252	28 743	29 195	30 089	31 699	33 180	33 569
	Bottom-Up On-Road Portion (%)	36	59	67	68	66	67	67	66	66
	Bottom-Up Off-Road Portion (%)	64	41	33	32	34	33	33	34	34
Target	Total Top-Down Fuel Available (ML)	13 188	22 766	27 613	27 475	27 462	26 186	27 927	29 629	29 506
	National Scaling Factor (%)	90	91	98	96	94	87	88	89	88
Scaled	Final On-Road Fuel Estimate (ML)	5 266	13 872	18 797	18 771	18 393	17 805	18 760	19 737	19 696
	Final Off-Road Fuel Estimate (ML)	7 922	8 894	8 816	8 704	9 070	8 381	9 167	9 891	9 810
	Sum of Final On- and Off-Road Fuel (ML)	13 188	22 766	27 613	27 475	27 462	26 186	27 927	29 629	29 506

A3.1.4.2.2. Domestic Aviation (CRF Category 1.A.3.a)

The methodology used to estimate GHG emissions from the Domestic Aviation category employs a modified IPCC Tier 3 approach. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

This category includes all emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines, and because of the Tier 3 approach, military air transportation emissions are reported in the Other – Mobile category (CRFcategory 1.A.5.b). Excluded are emissions from fuel used at airports for ground transport, which are reported under Other Transportation (Off-Road), and emissions from fuel used in stationary combustion applications at airports. Emissions from international flights are designated as “bunker” emissions and are not included in national totals, but are estimated and reported separately under International Bunkers.

Careful consideration should be paid when comparing emission estimates in this category against those reported to other institutions, such as the International Energy Agency (IEA). The IEA estimates are, in particular, quite different from those reported in the CRF when comparing domestic and international (bunker) emissions from aviation turbo fuel. The Tier 3 method employed by AGEM in the NIR allows detailed flight-by-flight distinction between domestic and international movements based on a flight’s origin and destination. The fuel consumption values (disaggregated into domestic and international sectors) reported to the IEA by Canada assume that all fuel sold to Canadian carriers is domestic and that all fuel sold to foreign carriers is international, which greatly underestimates the amount of emissions identified as aviation bunkers, given that many movements by Canadian carriers are international in nature. Because the reporting requirements for these two separate reports (UNFCCC, IEA) do not align, the reported values will not align either.

Step 1: Activity Data: Aircraft Movements, Flight Path Length, Airport Coordinates, Aircraft Fuel Use Characteristics, Representative Aircraft Mapping, Aircraft Emission Performance

Aircraft movements

The aircraft movement data (AMS 2020) used in AGEM are flight-by-flight tower data collected by NAV Canada (Canada’s civil air navigation services provider) starting in November 1996 and by Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. ECCC receives the information directly from Statistics Canada, including small airport movements that Statistics Canada collects directly and appends to the tower data from NAV Canada.

The data identify, among other things, the origin, destination and aircraft type for any given movement occurring in Canada. Statistics Canada’s processing of the data includes adding information based on other raw data fields provided to it as well as validation of airports, aircraft types and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated on the basis of movement data, as they are labelled as military by Statistics Canada.

Flight path length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model called the Aviation Environmental Design Tool (AEDT) (formerly System for Assessing Aviation’s Global Emissions [SAGE]) that is based on true radar data. The FAA provided Environment Canada with an extract from its model for calendar year 2005 involving Canadian

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airports and included the statistical measures (maximum, minimum, average, standard deviation) for the radar distance travelled between any Canadian origin and final destination for a given aircraft type (Fleming 2008a). The average distance from these combinations was then used as the distance flown when the same combination appeared in AGEM's movement data (regardless of the calendar year of the movement). There are cases, however, when a combination in AGEM exists without a corresponding average distance. In these cases, another method needed to be developed.

An adjusted great circle distance (GCD[3]) is used when the average radar distance is unknown. A factor applied to the GCD was developed by comparing GCD to radar distance for a given origin/destination/aircraft type. Graphing the known radar lengths against their corresponding GCDs leads to an equation that can be used for adjusting all raw GCD distances. Therefore, all GCDs are adjusted by a factor to approximate the flight path length, with the factors decreasing in magnitude as the GCD increases.

Airport coordinates

All possible airport entries within the AGEM movement data were extracted and defined. Information on the airports, such as latitude, longitude, name, and elevation, were compiled from various sources, including the 2009 and 2019 Canada Flight Supplement (NAV Canada 2009, 2019a), 2018 and 2019 Canada Water Aerodrome Supplement (NAV Canada 2018b, 2019b), Airport International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) codes (NAV Canada 2018a), the FAA (FAA 2020), Airline and Location Code Search database (IATA 2020), SAGE (Fleming 2008b), the Modeling and Database Task Force (MODTF) (Fleming 2008c) and World Airport Codes (2020). The main data required to calculate a GCD for use in determining the flight path length are the geographical coordinates.

Aircraft fuel use characteristics

Once the flight path length is determined, the fuel consumed by the aircraft for that movement can be calculated using the fuel characteristics of that aircraft. The fuel characteristics of various representative aircraft are drawn from the Base of Aircraft Data (BADA) (BADA 2019), the ICAO via their engine emissions databank (ICAO 2019), the Swedish Defence Research Agency (FOI) via their turbo prop engine emissions databank (Hagstrom 2010), and the Federal Office of Civil Aviation (FOCA) in Switzerland (FOCA 2007).

Information from ICAO, FOI and FOCA is used to estimate fuel use for the taxi-out, taxi-in and takeoff phases of each flight. Information from BADA is used to estimate fuel use for the climb-out, climb, cruise, descent and landing phases of each flight.

3 Great circle distance is the shortest distance between two points on a sphere; with respect to aviation, it is the shortest possible flight path length between the origin and destination of a flight movement.

Representative aircraft mapping

All possible aircraft type entries within the AGEM movement data were extracted and defined. Once defined, each aircraft was mapped to a representative aircraft with known fuel use characteristics so that fuel consumption could be calculated for all aircraft in AGEM. The mapping was done using published mapping guides whenever possible (BADA 2019, FAA 2018, IPCC 2006, ICAO 2016, ICAO 2020) and by matching aircraft characteristics (MTOW,[4] number of engines, engine type, etc.) when there was no published mapping for a given aircraft.

Aircraft emission performance

In an attempt to better estimate CH_4 emissions from aviation turbo fuel, aircraft-specific emission factors are used within AGEM, when applicable, for the LTO cycle. When there is no aircraft-specific CH_4 emission factor, the 2006 IPCC default factor is used. The factors are taken from Table 3.6.9 in the 2006 IPCC Guidelines and converted into grams per litre of fuel consumed. For the cruise portion, CH_4 emissions are assumed to be zero (Wiesen et al. 1994). For ease of use by the general public, the published CH_4 emission factor will be a fleet average across the entire time series and will be based on total fuel consumed (LTO and cruise).

Table 3.6.9 in the 2006 IPCC Guidelines also has N_2O aircraft-specific aviation turbo fuel emission factors on a total LTO cycle basis; however, they are calculated using a Tier 1 fuel-based emission factor. Therefore, the Tier 1 factor is used directly since the amount of fuel consumed during the LTO cycle is calculated by AGEM.

Country-specific emission factors on a g/L basis are used for CO_2 emissions from aviation turbo fuel aircraft and for CO_2, CH_4 and N_2O emissions from aviation gasoline aircraft.

Step 2: Aircraft Fuel Calculation

Fuel consumed by each individual movement is estimated using the following equation.

Equation A3.1–2

$$FC_{FlightTotal} = FC_{Taxi\text{-}out} + FC_{Takeoff} + FC_{Climb\text{-}out} + FC_{Climb} + FC_{Cruise} + FC_{Descent} + FC_{Landing} + FC_{Taxi\text{-}in}$$

$FC_{FlightTotal}$ = total fuel consumed on a per-flight basis

$FC_{Taxi\text{-}out}$ = fuel consumption during the taxi-out phase

$FC_{Takeoff}$ = fuel consumption during the takeoff phase

$FC_{Climb\ out}$ = fuel consumption during the climb-out phase

FC_{Climb} = fuel consumption during the climb phase

FC_{Cruise} = fuel consumption during the cruise phase

$FC_{Descent}$ = fuel consumption during the descent phase

$FC_{Landing}$ = fuel consumption during the landing phase

$FC_{Taxi\text{-}in}$ = fuel consumption during the taxi-in phase

4 Maximum takeoff weight.

The landing and takeoff (LTO) phase of flight (3000 ft and below) consists of takeoff (accelerating down the runway until liftoff), climb out (from liftoff to 3000 ft), landing (3000 ft to touchdown) and taxi in/out (manoeuvring from the airport runway to/from the gate). The various LTO phases of flight are quantified by using either standard time-in-modes for that phase multiplied by the fuel consumption rate for that phase (drawn from ICAO, FOI or FOCA) or BADA fuel use characteristics for the aircraft as applicable (only available for the climb-out and approach phases).

The cruise phase of flight (above 3000 ft) is calculated using the BADA fuel use characteristics of the aircraft and the flight path length of the movement. The cruise phase is broken up into three parts, consisting of climb (3000 ft to cruise altitude), steady-state cruise (constant cruise altitude reached after completion of climb) and descent (from cruise altitude to 3000 ft). The distance it takes to reach and descend from the steady-state cruise altitude (including the LTO portions of climb out and approach) is subtracted from the flight path length when determining the distance travelled at the steady-state cruise altitude.

The LTO and cruise phases of flight for any given movement are estimated by first using the representative aircraft mapping information, which relates the aircraft identified in the movement data to a representative aircraft with known performance characteristics. For the fuel rates of the representative aircraft that are distance-based, the flight path length for the movement is drawn from either the list of radar movement data provided by the FAA or calculated by quantifying the GCD and multiplying by an adjustment factor, as explained above. The fuel rates that are time-based in the LTO cycle already have the time-in-mode defined. With the known fuel characteristics of the aircraft, the time-in-mode and flight path length, the LTO and cruise fuel estimates can be computed.

Step 3: Normalization

All aviation turbo fuel and aviation gasoline consumed in Canada is reported in the RESD (Statistics Canada 1990–). The fuel consumed, as estimated by the bottom-up approach of AGEM, is adjusted to match that of the RESD at a national level. The adjustment to LTO and cruise fuel estimates takes place at the individual movement level, across all movements.

Step 4: Emission Calculation

Emission estimates are generated at the individual movement level based on the normalized total fuel consumed and the appropriate emission factor, as outlined in Equation A3.1–1. The individual emission estimates are then summed to generate the national emission estimate.

A3.1.4.2.3. Domestic Navigation (CRF Category 1.A.3.d)

The methodology used to estimate GHG emissions from the domestic navigation category is considered an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions.

This category includes emissions from vessels navigating between Canadian ports. In accordance with the 2006 IPCC Guidelines, military marine transportation emissions are reported in the Other Mobile category (CRF category 1.A.5.b). Likewise, emissions from fishing vessels are reported in the Fishing category (CRF category 1.A.4.c.iii). Excluded are emissions from smaller recreational vessels (reported under Other Transportation [Off-Road]). Emissions from international voyages are designated as “bunker” emissions and are not included in national totals but are estimated and reported separately under International Bunkers as a Memo Item.

Marine emissions are developed using the Marine Emissions Inventory Tool (MEIT), a model developed using vessel tracking information. Unlike the RESD, where fuel values are based on fuel sales data and organized by flag of vessel, MEIT is based on vessel movements and domestic or international emissions are assigned according to port origin destination information. Therefore, and similar to the Aviation subcategory, careful consideration should be paid when comparing fuel consumption (in terms of energy) in this subcategory against the national energy balance reported in the RESD and IEA data. Due to design and operating procedures of marine vessels, it is not uncommon for vessel to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD is based on fuel transactions in Canada, it is possible to have more fuel consumed in the marine sector than what is reported in the national energy balance. When using the reference approach, excess fuel is accounted for as a “temporary import”.

Step 1: Activity Data: Marine Emission Inventory Tool

The Marine Emission Inventory Tool uses vessel traffic data and vessel characteristics to estimate the quantity of fuel required for each vessel manoeuvre within Canadian waters. Vessel traffic data are used for the 2010, 2015, 2016, 2017 and 2018 calendar years. However, MEIT developed backcasts/forecasts for 1990 to 2050 in 5-year increments. Fuel quantities between those years were linearly interpolated. Since the 2015, 2016, 2017 and 2018 calendar years are the only years for which estimates are available at a detailed level, the proportions of fuel use for those years are applied to the other calendar years to further break down the fuel quantity.

For the 2010, 2015, 2016, 2017 and 2018 calendar years, the MEIT data are based on vessel traffic data from the Canadian Coast Guard Information System on Marine Navigation (INNAV) and Automatic Identification System (AIS) and the Department of Fisheries and Oceans' fishing license data. The vessel movements are grouped into 1-km segments, which provide the distance and time between each point. To estimate the fuel use, the vessel characteristics/classifications are taken into consideration. Three sources of fuel consumption are considered: main engines, auxiliary engines and boilers. MEIT uses general assumptions for the auxiliary engines and boilers, however, more parameters are used to determine the fuel consumed by the main engine. The load factor has a significant influence on the fuel estimate from the main engine and is therefore calculated for each data point based on the propeller law.

From 1990 to 2010 the data was backcasted using multiple factors including Transport Canada commodity data for 1990 to 2005, port dry bulk and containerized (TEU) data, Northwest and Canada Cruise Association (NWCCA) passenger data, and Statistics Canada population data.

From 2018 to 2050 the data was forecasted by scaling the ship movements per vessel class on the basis of estimated sector growth/contraction, and adjusting the emission factors on the basis of regulations and policies in place for that future year.

Step 2: Fuel allocation and time series consistency

The amount of fuel from the RESD is compared against the values estimated by the MEIT in order to determine how much of the fuel burned is likely to have been obtained from Canadian fuel suppliers. The comparison is performed systematically at a regional and category level.

In the event that the RESD values are greater than the fuel consumption values estimated by MEIT (Scenario 1), it is assumed that fuel values from MEIT for military, fishing, domestic and international navigation are all purchased from Canadian suppliers. Any fuel difference between the RESD and MEIT is attributed to the International Navigation (Bunkers) category. It is assumed in this scenario that the MEIT model underestimated the amount of fuel used for international navigation, which is likely due to the MEIT only covering movement within Canadian waters.

In the event that the RESD values are less than the fuel consumption values estimated by MEIT (Scenario 2), the following procedure is followed:

Case 1 – Military. If the amount of fuel available in the RESD is greater than the amount of fuel estimated by MEIT to be used by military vessels, then it is assumed that all fuel used for military operations was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the remainder of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 2 – Fishing. If the amount of fuel available in the RESD (minus that used for military operations) is greater than the amount of fuel estimated by MEIT to be used by fishing vessels, then it is assumed that all fuel used for commercial fishing was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 3 – Domestic Navigation. If the amount of fuel available in the RESD (minus that used for military and fishing operations) is greater than the amount of fuel estimated by MEIT used by vessels involved in domestic voyages, then it is assumed that all fuel used for domestic navigation was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 4 – International Navigation (Bunkers). The portion of fuel equal to the amount of fuel available in the RESD (minus that used for military, fishing and domestic navigation) is assumed to be purchased from a Canadian supplier to be used for international navigation (bunkers). Then the difference between the MEIT fuel and the RESD fuel is assumed to be purchased from foreign fuel suppliers.

Step 3: Emission Calculation

Emissions are calculated by multiplying the fuel quantity by the fuel-specific emission factors (see Annex 6).

A3.1.4.2.4. Railways (CRF Category 1.A.3.c)

The methodology is considered to be an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions. Railway fuel consumption reported in the RESD (Statistics Canada 1990–) is multiplied by fuel-specific emission factors (see Annex 6).

In Canada, locomotives are powered primarily by diesel fuel. A review of emissions attributable to steam train operations in Canada has determined that emissions associated with steam trains are insignificant. Electrically driven locomotives are accounted for under electricity production.

A3.1.4.2.5. Biomass (CRF Category 1.D.3)

The methodology used to estimate emissions from the consumption of biogenic transport fuels (ethanol and biodiesel) follows a modified IPCC Tier 1 method for gasoline and diesel fuel on-road transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels consumed for transportation is proportionally reallocated back into the respective diesel fuel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biofuels used for on- and off-road transportation are described in section A3.1.4.2.1. The volumes of biofuels used for the rail and marine categories are based on information collected from *Canada's Renewable Fuels Regulations*. Currently, it is assumed that no biofuels are used in the aviation sector.

In lieu of specific CH_4 and N_2O emission factors for biofuels, the gasoline and diesel fuel emission factors from the equivalent emission technology classes are applied. CO_2 emission factors are developed according to the chemical properties of the fuel.

A3.1.4.2.6. Pipeline Transport (CRF Category 1.A.3.e.i)

Pipelines represent fossil fuel combustion engines used to power motive compressors to transport oil and natural gas products. The fuel used is primarily natural gas, but some refined petroleum, such as diesel fuel, is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A3.1–1 to activity data and emission factors, at the provincial level for natural gas, and national level for other fuels.

A3.2. Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution

A3

Detailed methodologies for estimating fugitive emissions from solid fuel production and the oil and gas industry are covered in this annex.

As the primary source of fugitive emissions, Canada's large oil and gas industry consists of a mix of production types, including natural gas production and processing; light, medium and heavy crude oil production; oil sands mining and extraction; and synthetic crude oil production. For a description of all sources of fugitive emissions, refer to Chapter 3.

All greenhouse gas (GHG) emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission and distribution are reported under the Energy Industries (section 3.2.4) and Transport (section 3.2.6) sections of Chapter 3, and their respective methodologies can be found in Annex 3.1 (sections A3.1.4.1 and A3.1.4.2).

A3.2.1. Solid Fuels

A3.2.1.1. Coal Mining

Canada Specific Coal Mining Studies

Canada's fugitive emission estimates are largely based on three studies: *Methane Emissions from Canadian Coal Operations: A Quantitative Estimate*, prepared by B. Hollingshead (1990) for the Transalta Utilities Corp.; *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King (1994) for Neill and Gunter Ltd; and *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry*, prepared by Cheminfo Services Inc. and Clearstone Engineering Ltd (Cheminfo and Clearstone, 2014) for Environment and Climate Change Canada (ECCC). These three studies contain mine-specific information upon which Canada has based its country-specific data, parameters and information regarding surface and underground mines, and they are confidential.

The Hollingshead study was commissioned by Transalta Utilities Corp., with the goal of estimating methane (CH_4) emissions from coal mines and coal combustion in Canada. The study developed, for the year 1989, estimates of fugitive emissions from underground and surface mines and combustion emissions from all coal use in Canada. As such, the emphasis of this study was not on developing emission factors (EFs) that would be usable on a yearly basis, but rather on providing a snapshot of all emissions from coal for a particular year. However, in the process of estimating these total emissions, a large amount of useful data was collected pertaining to the CH_4 composition of coal mined in Canada.

Canada has had, in most years, both underground and surface coal mines, and the method developed by King (1994) produced CH_4 emission factors for all coal types and all individual coal mines. Where possible, King employed the Canada-specific data included in the Hollingshead study, while clearly identifying and explaining this data source. King's method for surface and underground mines is a modified version of a process developed for the International Energy Agency by the Coal Industry Advisory Board (CIAB). Further discussion of some of these modifications can be found in the section below on surface mines. Prior to the 2016 submission, the EFs for CH_4 determined in the King (1994) study were used to estimate the CH_4 fugitive emissions from all 23 operational mines and from all mines abandoned after 1990 in Canada.

In 2014, ECCC awarded a contract to Cheminfo Canada and Clearstone Engineering to update the EFs for coal mines in western Canada. The study produced new EFs for seven of the then 21 active surface mines using field tests from two sub-bituminous coal mines in central Alberta, one bituminous coal mine in northeast British Columbia and one bituminous coal mine in northwest Alberta. Results from the four tested mines were applied to three nearby mines that exploited the same coal seams and had similar geography. The mobile plume transect system (MPTS) that was employed develops a two-dimensional y-z plot of the pollutant concentration and wind profile downwind of the target source(s). The measurement system comprised: (1) a cavity ring-down spectrometer; (2) an 8-channel multiplexer sampling system; (3) an ultrasonic 3-D wind anemometer; (4) a GPS and inertial system; (5) a vehicle equipped with a vertical sampling mast; and (6) a computer and software.

The emissions model is a hybrid of IPCC Tier 2 and Tier 3 methodologies that depends on the availability of mine-specific data. Gross production values provided by Statistics Canada, before any cleaning and prep work, is used to calculate fugitive emissions for all mine types. The associated post-mining activity emissions are accounted for in the underground and surface mining EFs. Additional details of the methodologies used to estimate the emissions from underground and surface mines are provided in their respective sections.

The EFs vary for each coal field, region and mine type, whether above or below ground.

Underground Mines

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems and post-mining activities. In the absence of measured data, emissions from the mine shaft ventilation system were estimated using Equation A3.2–1.

Equation A3.2–1

$$Y=4.1+(0.023\times X)$$

Y = emissions of CH_4 per gross tonne of coal mined, m^3 CH_4/t coal

X = depth of mine, m

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH_4 (after removal from the mine) is emitted to the atmosphere before combustion. If the CH_4 content of the mined coal was unknown, then 1.5 m^3/t, the global average for coals (King, 1994) was assumed. All underground mines in Canada are drift mines and have an effective depth of zero metres. Emissions from post-mining activities are included in the coal production EFs, after all quantities are converted to mass units, using a standard conversion of 0.67 kg/m^3 CH_4.

Between 1992 and 1999, all underground mining ceased in eastern Canada. The remaining underground mines were located in Alberta and British Columbia and were less gassy than mines in eastern Canada. Between 2015 and 2017 there were no active underground coal mines in Canada, however, the Donkin mine in Nova Scotia resumed operation in 2018.

Surface Mines

The CIAB methodology was modified to incorporate confidential Canadian and U.S. site-specific data (from King, Hollingshead and Cheminfo and Clearstone) for the three coal types mined in Canada, rather than using a generalized international data set to represent country-specific circumstances. King developed EFs by region, by mine and by coal types; the average CH_4 content of bituminous or sub-bituminous coal was 0.4 m^3/t (based on tests at 50 mines in the United States, obtained by King) and the Canada-specific CH_4 content for lignite was 0.05 m^3/t (Hollingshead, 1990), with the assumption that 60% of the gas is released before combustion. A field testing campaign to measure fugitive emissions of CH_4, Carbon dioxide (CO_2) and Volatile Organic Compounds (VOCs) was performed on four coal mines in late February 2014:

- Sites 1 and 2: two sub-bituminous coal mines in central Alberta
- Site 3: one bituminous coal mine in northeast British Columbia
- Site 4: one bituminous coal mine in northwest Alberta

CH_4 emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo and Clearstone, 2014). Data from this field testing was used to modify the CH_4 emission factors of 7 of the 23 producing mines in Canada. The EFs in Table A3.2–1 incorporate these data and assumptions.

In addition, the overall CH_4 emission factor uncertainty is reported in Table A3.2–1 category 1.B.1.a Fugitive Sources – Coal mining and Handling.

Surrounding unmined strata are a significant source of emissions from surface mines. Using Canadian mine-specific data from the Hollingshead study, King applied a high-wall adjustment to the surrounding unmined strata, to a depth of 50 m below the mining surface. Base EFs for surface mining were increased by 50% (King 1994) to account for this out-gassing adjustment and are reflected in the EFs in Table A3.2–1.

To obtain the emissions from coal mining, Equation A3.2–2 is used.

Equation A3.2–2

$$\textit{Provincial Emissions} = \sum(EF_{i,j,k,l} \times Coal_{i,j,k,l})$$

$EF_{i,j,k,l}$ = the emission factor from the King (1994) or Cheminfo and Clearstone (2014) studies for province i, coal type j, mine k and coal field l

$Coal_{i,j,k,l}$ = the gross production of coal for province i, coal type j, mine k and coal field l

Emissions are calculated for each province and then summed to determine the emission estimate for Canada.

Despite the closing of east coast underground mines, production increases at less gassy surface mines in Alberta and British Columbia have sustained Canada's total annual coal production. The net effect is that, while production has stayed steady, total fugitive emissions associated with coal mining have declined significantly since 1990.

Activity Data

The model requires the gross mine output data for each type of coal mined in each province. Until 2002, the data was obtained from Statistics Canada's *Coal and Coke Statistics* publication (Cat. No. 45-002-X, Table 2). In 2002, the publication was discontinued, and Statistics Canada now provides this data directly to Environment and Climate Change Canada via a memorandum of understanding.

Emission Factors

EFs were developed by coal type, coal mine type and coal field. Because of confidentiality requirements, factors can only be reported at the provincial level. Therefore, weighted EFs were developed at the provincial level.

These weighted EFs, by mine and coal type, were developed using the King (1994), and Cheminfo and Clearstone (2014) studies and are listed in Table A3.2–1.

A3.2.1.2. Abandoned Underground Coal Mines

Coal mine methane (CMM) and other gases naturally exist within coal seams and are released to the atmosphere under suitable conditions. Of these gases, CH_4 is of greatest concern, while others releases, such as CO_2, are considered small and are not reported since the IPCC provides no method for estimating these emissions (IPCC, 2006).

As noted in A3.2.1.1, structural disturbance exposes the coal to lower atmospheric pressures, allowing the release of fugitive emissions during mining and post-mining operations, including handling, crushing and transportation. Once an underground mine closes and active venting stops, emissions may continue for decades. After production ceases, all subsequent emissions are estimated using the model described in this section.

Methodology

CMM is influenced by many factors, including geological seam structure, coal rank and characteristics, mining activities, pressure gradients, mine flooding and post-mining venting and capping. Though no Canadian data is available on post-mining venting and capping, provincial regulations require all recently abandoned mines to be capped for safety.

The IPCC Tier 2 equation for abandoned mines takes the general form in Equation A3.2–3.

Table A3.2–1 **Fugitive Emission Factors for Coal Mining**

Area	Coal Type	Mine Type	Emission Factor	Units
Nova Scotia	Bituminous	Surface	0.07	t CH_4 / kt coal mined
Nova Scotia	Bituminous	Underground	14.49	t CH_4 / kt coal mined
New Brunswick	Bituminous	Surface	0.07	t CH_4 / kt coal mined
Saskatchewan	Lignite	Surface	0.07	t CH_4 / kt coal mined
Alberta	Bituminous	Surface	0.53	t CH_4 / kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4 / kt coal mined
Alberta	Sub-bituminous	Surface	0.24	t CH_4 / kt coal mined
British Columbia	Bituminous	Surface	0.93	t CH_4 / kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4 / kt coal mined

Note: Adapted from King (1994) and Cheminfo et al. (2014).

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Equation A3.2–3 **IPCC Tier 2**

$$CH_4\ Emissions = Unflooded\ Mines \times Fraction\ Gassy \times Average\ Emission\ Rate \times EF \times Conversion\ Factor$$

CH_4 Emissions	=	yearly emissions (Gg/year)
Unflooded Mines	=	number of unflooded mines
Fraction Gassy	=	% of mines defined as gassy
Average Emission Rate	=	(m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)b
Conversion Factor	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

The IPCC Tier 3 equation for abandoned mines takes the general form in Equation A3.2–4.

Equation A3.2–4 **IPCC Tier 3**

$$CH_4\ Emissions = (Emission\ rate\ at\ closure \times EF \times Conversion\ Factor)$$

CH_4 Emissions	=	yearly emissions (Gg/year)
Emission rate at closure	=	known emission rate for specific mine (m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)b
Conversion Factor	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

Detailed data on mine CH_4 emission rates during production years was only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3.2–4, following the IPCC Tier 3 approach, to estimate abandoned mine emissions in this region. For all other regions of Canada, known production data for abandoned mines was averaged over the life of the mines, and the EFs in Table A3.2–1 were used to estimate emissions in the final year of production. On the basis of this estimate, Equation A3.2–3 was used to calculate emissions. Calculations were done using five time intervals, which can be seen in Table A3.2–4 following the Tier 2 approach for the determination of percent gassy mines per time interval. Mines abandoned before 1900 are assumed to be non-emitting (IPCC, 2006).

Following the end of mining activities, CH_4 emissions have been shown empirically to drop off following a hyperbolic decline curve. This is modelled using the IPCC Tier 2/3 emission factor equation (1+aT)b, where a and b are mine- or basin-specific constants and T is the time since abandonment (IPCC, 2006). See Table A3.2–2 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

CH_4 emissions from flooding mines decrease dramatically once active pumping ceases. Water pressure inhibits CH_4 from being emitted due to reduced relative permeability. U.S. EPA empirical studies (U.S. EPA, 2004) based on U.S. mines indicate that mine flooding occurs within eight years. The 2006 IPCC Guidelines (IPCC, 2006) indicate that fully flooded mines be assigned zero emissions but be explicitly listed.

For the purposes of calculating emissions, mines are assumed unflooded unless specific data exists. Provincial experts in Alberta indicated that most mines are flooded, but had knowledge of flooding at only the Bellevue Mine Museum. Therefore, only the 12 abandoned mines in the near vicinity of the Bellevue Mine Museum—that closed over 20 years ago—were assumed flooded. For Nova Scotia, provincial experts at Nova Scotia Environment confirmed that underground mines started flooding immediately after pumps were turned off and that all mines were flooded by end of summer 2013.[5] Table A3.2–3 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of

Table A3.2–2 **IPCC Tier 2/3 – Emission Factor Coefficients**

Coal Rank	a	b
Anthracite	1.72	-0.58
Bituminous	3.72	-0.42
Sub-bituminous	0.27	-1.00

5 Nova Scotia Environment. 2015. Personal communication (email from Miller M, Policy Analyst, Nova Scotia Environment to Baker W, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 16, 2015).

Table A3.2–3 **IPCC Tier 2/3 – Abandoned Underground Coal Mines, 2019**

Region	Number of Abandoned Coal Mines[a]	Number of Abandoned Mines Flooded[b]
Nova Scotia[c]	281	281
Saskatchewan[d]	245	0
Alberta	855	13
British Columbia	51	0
CANADA	**1 432**	**294**

Notes:

a. Only mines that produced more than 0.5 kilotonnes are included.
b. When no data is available, mines are assumed to be non-flooded.
c. Tier 2 and 3 estimates used for Nova Scotia.
d. Saskatchewan lignite mine estimate uses IPCC Tier 2 sub-bituminous emissions factor calculated for each time band (see IPCC 2006 4.27, Equation 4.1.12).

Table A3.2–4 **IPCC Tier 2, % Gassy Mines per Time Interval**

Time Interval	Low	High
1900–1925	0%	10%
1926–1950	3%	50%
1951–1975	5%	75%
1976–2000	8%	100%
2001–present	9%	100%

Canada that have underground coal mines. In 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned mines.

The IPCC defaults in Table A3.2–4 were used to estimate the percentage of gassy mines in each region and time interval. For all regions of Canada, with the exception of Saskatchewan, the default high values for gassiness were assumed.

The lower IPCC default percentage of gassy mines was chosen for Saskatchewan mines based on time since abandonment, lignite rank, small mine size and shallow depth—often dug from a riverbed into a slight hill. Additionally, during a public safety review, all mine entrances were either capped or sealed. The non-gassy nature of these mines was previously reported in Hollingshead (1990).

Activity Data

This model uses data obtained from industry and from provincial and federal government sources. The general lack of detailed data sources affected the choice of estimation methods, preventing the incorporation of likely but unconfirmed flooding and mine-specific emissions measurements. Conservative assumptions were made when accurate data was unavailable for mine gassiness, flooded status and EFs. As previousely noted, in 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned mines.

Emissions

The results of emission calculations, for select years, are shown in Chapter 3.3.1 of the NIR. Abandoned mines in Nova Scotia have historically contributed the largest proportion of emissions; the two emission peaks in 1993 and 2000 correspond to closures of large mines in that province. There were two recent mine abandonments in western Canada and the effect of these closures on the model's decline curves are visible in the latest reporting years.

A3.2.2. Oil and Natural Gas

A3.2.2.1. Upstream Oil and Natural Gas Production

Fugitive emissions from the upstream oil and gas (UOG) industry are estimated using two different methods:

- 2010–2019 reported venting and flaring emissions in Alberta (see section A3.2.2.1.2)
- All other fugitive emission sources in all other provinces and territories (see section A3.2.2.1.1)

Table A3.2–5 lists the emission sector categories and fugitive sources estimated and the allocation of these emissions according to the Common Reporting Format (CRF) categories.

A3.2.2.1.1. UOG and CAPP Study

Except where otherwise noted, fugitive emissions from the UOG industry are based on two separate studies: a study titled *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP, 2005a), prepared by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) and referred to hereafter as the CAPP study, and an update to the inventory that was completed in 2014 for Environment Canada by Clearstone Engineering Ltd. and referred to hereafter as the UOG study (EC, 2014). Both inventories used an IPCC Tier 3 bottom-up assessment to estimate all GHG emissions from the UOG sector, with the exclusion of oil sands mining, extraction and upgrading. The CAPP study provided a detailed emission inventory for the year 2000, while the UOG study produced inventories for the years 2005 and 2011.

In general, the emission inventories for the years 2000, 2005 and 2011 were used directly, except for a few special cases. If a specific source did not exist in one of the inventory years (e.g. the 2000 inventory) due to insufficient data, but did exist in another inventory year (e.g. the 2005 inventory), then emissions for that particular source were extrapolated from the known year and included in the inventory that was missing data to ensure completeness. A brief description of the methodology used in the CAPP and UOG studies follows, along with the methodology used to estimate the emissions for 1990–1999, 2001–2004, 2006–2010 and from 2012 onwards.

Methodology for the 2000, 2005 and 2011 Estimates

The emission estimates contained in the CAPP and UOG studies were developed using a bottom-up approach, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector's assets and operations are vast: the 2011 inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and finally to markets.

Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated. The basic methods used to estimate GHG emissions were:

- emission monitoring results
- emission source simulation results
- emission factors
- destruction and removal efficiencies

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Table A3.2–5 **Allocation of Upstream Oil and Gas Inventory Emissions to CRF Fugitive Categories**

	Emission Sector Categories	Emission Source Categories
1.B.2.a.2 Oil – Production	Light/Medium Crude Oil Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Cold Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Servicing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Testing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Disposal and Waste Treatment	Fugitive Equipment Leaks
1.B.2.a.3 Oil – Transport	Petroleum Liquids Transportation	Fugitive Equipment Leaks; Storage Losses
1.B.2.b.2 Natural Gas – Production	Natural Gas Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.3 Natural Gas – Processing	Natural Gas Processing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.4 Natural Gas – Transmission and Storage	Gas Transmission; Gas Storage	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.5 Natural Gas – Distribution	Gas Distribution	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.6 Natural Gas – Other – Accidents and Equipment Failures	Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration; Spills/Pipeline Ruptures
1.B.2.c.1.i Venting – Oil	Light/Medium Crude Oil Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Cold Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Thermal Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Petroleum Liquids Transportation	Reported Venting; Unreported Venting
1.B.2.c.1.ii Venting – Natural Gas	Natural Gas Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Natural Gas Processing	Glycol Dehydrator Off-Gas; Formation CO_2; Reported Venting; Unreported Venting
	Gas Transmission	Reported Venting
	Gas Distribution	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Gas Storage	Reported Venting; Unreported Venting
1.B.2.c.1.iii Venting – Combined	Well Drilling; Well Servicing	Reported Venting
	Well Testing	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Disposal and Waste Treatment	Unreported Venting
1.B.2.c.2.i Flaring – Oil	Light/Medium Crude Oil Production; Heavy Crude Oil Production; Heavy Crude Oil Thermal Production; Petroleum Liquids Transportation	Flaring
1.B.2.c.2.ii Flaring – Natural Gas	Natural Gas Production; Natural Gas Processing; Gas Transmission; Gas Storage; Gas Distribution	Flaring
1.B.2.c.2.iii Flaring – Combined	Well Drilling; Well Servicing; Well Testing; Disposal and Waste Treatment	Flaring

In order to estimate emissions, large amounts of data were collected including:

- measured volumes of natural gas taken from the process
- vented and flared waste gas volumes
- fuel purchases (propane, diesel fuel, etc.)
- fuel analyses
- emission monitoring results
- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.)
- spill and inspection reports

Other required data included the following:

- types of processes being used
- equipment inventories
- emission source control features
- sulphur content of the fuels consumed and waste gas flared
- composition of the inlet and outlet streams

Refer to the CAPP study (CAPP, 2005a) and UOG study (EC, 2014) for further details.

Methodology for Extrapolating Emission Estimates

The method for extrapolating emissions from a known inventoried year to other non-inventoried years was developed by Clearstone Engineering Ltd. (CAPP, 2005b). This method was used to backcast the 2000 emission estimates for the 1990–1999 time period, to extrapolate the 2011 inventory for 2012 onwards and, in conjunction with other curve fitting methods, to interpolate the 2001–2004 and 2006–2010 time periods.

Equation A3.2–5 is used to estimate emissions for non-inventoried years by multiplying base year emissions data for a given source and sector by the ratio of activity data for the non-inventoried year to that of the base year. Various types of activity data for each province/territory and year were used, such as natural gas and crude oil production volumes, fuel, flare and vent volumes, number of wells drilled, number of spills, ruptures and blowouts, total capable oil and gas wells, and shrinkage. Not all activity data is available for all years or all regions. Emission sources for specific sectors and regions were extrapolated using the most appropriate activity data. Where activity data was not available for the entire time series, the methodology to interpolate intermediate years, which is described later in this section, was used to provide one consistent time series.

Table A3.2–6 lists the publicly available activity data used to extrapolate emissions along with the corresponding data source. Table A3.2–7 contains a list of the activity data used to estimate flaring emissions for each region, sector category and time period while Table A3.2–8 contains the same information for reported venting. Table A3.2–9 displays the activity data that is used to extrapolate emissions for all other UOG fugitive sources such as fugitive equipment leaks, unreported venting,[6] storage losses, etc.

Equation A3.2–5

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_j^k}{AF_j^{baseYr}}\right)$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k, t/year
$ER_{i,j}^{baseYr}$	=	base year (e.g. 2011) emission rate for compound i and source j, t/year
AF_j^k	=	activity factor for source j and year k
AF_j^{baseYr}	=	base year (e.g. 2011) activity factor for source j

6 Unreported venting includes venting from processes or equipment that is not typically included in reported venting volumes. This includes pneumatic devices (e.g. chemical injection pumps, natural gas operated instrumentation), compressor start gas, purge gas and blanket gas that is discharged directly to the atmosphere and gas vented from drill-stem tests.

The emissions for 1990–1999 were backcast by sector and source at the provincial level based on the year 2000 emission estimates from the CAPP study (CAPP, 2005a). The only exception to this was the province of Nova Scotia, which from 1992 to 1999 was an oil-only producing province. In 2000, it switched to a gas-only producing province. As such, the year 2000 data could not be used to estimate emissions for the 1990–1999 time period, and Nova Scotia's fugitive emissions were extrapolated based on CAPP's 1995 UOG study data (CAPP, 1999). Refer to the UOG study (CAPP, 2005a) for further details.

The emissions from 2012 onwards were extrapolated using emissions by sector and source at the provincial/territorial level based on the year 2011 emission estimates from the UOG study (EC, 2014).

Methodology for 2001–2004 and 2006–2010

In order to estimate emissions for the 2001–2004 and 2006–2010 time periods, all three base year inventories (2000, 2005 and 2011) were extrapolated for the 2000–2011 time period using the method described previously. This resulted in three curves which were used to interpolate the intermediate years by using either a "wedging" or "proportional adjustment" method, depending on the circumstance. The "wedging" method was used unless it resulted in negative emission estimates for any year in the time period. Less than 0.3% of cases required the use of the "proportional adjustment" method.

Wedging

The "wedging" method evenly distributes the difference in emissions for a given source and sector in a given province between an inventoried year and an extrapolated year to maintain the emissions trend using Equation A3.2–6.

Equation A3.2–6

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} + \frac{\left(ER_{i,j}^{k2\_inv} - ER_{i,j}^{k2,k1\_exp}\right)}{(k2 - k1)} \times (k - k1)$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011, and k is equal to k1, then the result of Equation A3.2–6 is the emission rate from the 2005 inventoried year. This occurs since the 2005 extrapolated data uses the 2005 inventoried year as is for the year 2005. If k is equal to k2, then the result is the emission rate from the 2011 inventoried year. This shows that this method will maintain the emission estimates for the inventoried years, while interpolating the intermediate years and maintaining the emissions trend.

Table A3.2–6 **Required Activity Data and Their Sources**

Publisher	Publication	Activity Data
Alberta Energy Regulator (AER)	ST60B: Upstream Petroleum Industry Flaring and Venting Report (AER, 2020a)	Reported venting and flaring volumes
	ST3: AER Industries Monthly Statistics, Gas Supply and Disposition (AER, 2020b)	Shrinkage
	Alberta's Energy Reserves and Supply/Demand Outlook (AER, 2020c)	In-situ bitumen production
	AER Compliance Dashboard (AER, 2020d)	Number of incidents
British Columbia Government	Production and distribution of natural gas (BC, 2019)	Reported venting volumes Shrinkage
	B.C. Gas Plant/Dehydrator Report (BC, 2020)	Shrinkage
British Columbia Oil and Gas Commission	Drilling Kicks and Blowouts by Area (BCOGC, 2020a)	Sum of kicks and blowouts
	Air Summary Report (BCOGC, 2019)	Reported flaring volumes
	2019 Fuel, Flare and Vent Volumes (BCOGC, 2020b)	Reported venting and flaring volumes
Canada Energy Regulator (CER)	Canada's Energy Future (CER, 2020)	Non-associated gas production
Canada – Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells – Hibernia (CNLOPB, 2020a)	Number of capable wells
	Development Wells – Terra Nova (CNLOPB, 2020b)	Number of capable wells
	Development Wells – White Rose (CNLOPB, 2020c)	Number of capable wells
	Development Wells – North Amethyst (CNLOPB, 2020d)	Number of capable wells
	Development Wells – Hebron (CNLOPB, 2020e)	Number of capable wells
	Environment Statistics – Spill Frequency and Volume Annual Summary (CNLOPB, 2020f)	Number of spills
	Monthly Gas Flaring (CNLOPB, 2020g)	Reported flaring volumes
Canadian Association of Petroleum Producers (CAPP)	Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP, 2020)	Total wells drilled (including dry and service) (Tables 1.2b–1.2f)
		Sum of Operated Oil Wells (Table 3.17a) and Operated Gas Wells (Table 3.18a)
Manitoba Government	Petroleum Industry Spill Statistics (MB, 2020)	Number of spills
New Brunswick Natural Resources and Energy Development	Monthly Production Statistics (NB NRED, 2020a)	Light/medium crude oil production Natural gas production
Saskatchewan Ministry of Energy and Resources	2018 Crude Oil Volume and Value Summary (SK MER, 2020a)	Light/medium crude oil production Heavy crude oil production
	2018 Natural Gas Volume and Value Summary (SK MER, 2020b)	Non-associated gas production
	Saskatchewan Fuel, Flare and Vent (SK MER, 2020c)	Reported flaring and venting volumes
	Saskatchewan Upstream Oil and Gas IRIS Incident Report (SK MER, 2020d)	Number of spills
	Saskatchewan Annual Petroleum Statistics (SK MER, 2009–2011)	Reported flaring and venting volumes Shrinkage
	Saskatchewan Mineral Statistics Yearbook, Petroleum and Natural Gas. (SK MER, 1990–2008)	Reported flaring and venting volumes Shrinkage
Statistics Canada	Table 25-10-0047-01 (formerly CANSIM 131-0001) Natural gas, monthly supply and disposition (Statistics Canada, n.d.[a])	Gross production Field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	Table 25-10-0055-01 (formerly CANSIM 131-0004) Supply and disposition of natural gas, monthly (Statistics Canada, n.d.[b])	Gross withdrawals
	Table 25-10-0014-01 (formerly CANSIM 126-0001) Crude oil and equivalent, monthly supply and disposition (Statistics Canada, n.d.[c])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Crude bitumen production
	Table 25-10-0063-01 (formerly CANSIM 126-0003) Supply and disposition of crude oil and equivalent (Statistics Canada, n.d.[d])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Non-upgraded production of crude bitumen
	Report on Energy Supply and Demand in Canada (Statistics Canada, 2003)	Total RPP Retail Pump Sales

Table A3.2–7 **Activity Data Used to Extrapolate Flaring Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2009	Flaring – Oil batteries
	Heavy Crude Oil Cold Production				Flaring – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production				Flaring – Bitumen batteries
	Natural Gas Production				Flaring – Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring – Gas plants
	Well Testing				Flaring – Well testing
	Petroleum Liquids Transportation				Flaring – Total
	Disposal and Waste Treatment				Flaring – Total
BC	Light/Medium Crude Oil Production	1990–1995	Field flared and waste	1996–2019	Flaring – Solution Gas
	Natural Gas Production				Flaring – Production Facilities
	Natural Gas Processing				Flaring – Gas Processing Plants
	Well Testing		Wells Drilled		Flaring – Well Cleanup and Testing
	Well Drilling				Flaring – Underbalanced Drilling
SK	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2019[a]	Flaring – Non-heavy oil
	Heavy Crude Oil Cold Production				Flaring – Heavy oil
	Heavy Crude Oil Thermal Production				Flaring – Heavy oil
	Natural Gas Production				Flaring – Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring – Gas plants
NL	Light/Medium Crude Oil Production	1997–2019	Total flaring		
MB, NB, NT	Light/Medium Crude Oil Production	1990–2019	Light/medium crude production		
NB, NS, ON, YT	Natural gas production	1990–2019	Natural gas production		
NT	Natural gas processing	1990–2019	Field flared and waste		
NS, ON	Natural gas processing	1990–2019	Natural gas production		
BC, ON, SK	Petroleum Liquids Transportation	1990–2019	Total crude production		
AB	Well Servicing	1990–2019	Wells Drilled		
SK	Well Testing	1990–2019	Wells Drilled		

Note:

a. Delineation of flaring volumes by oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, flaring volumes from crude oil facilities in Saskatchewan were available as Associated flaring. Associated flare volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude flaring.

Table A3.2–8 **Activity Data Used to Extrapolate Reported Venting Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Light/medium crude production	2000–2009	Venting – Oil batteries
	Heavy Crude Oil Cold Production		Heavy crude production		Venting – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production		In-situ thermal production		Venting – Bitumen batteries
	Natural Gas Production		Natural gas production		Venting – Gas batteries + Gas gathering systems
	Natural Gas Processing		Natural gas production		Venting – Gas plants
	Well Testing		Wells drilled		Venting – Well testing
	Petroleum Liquids Transportation		Total crude production		Venting – Total
BC	Light/Medium Crude Oil Production	1990–2011	Light/medium crude production	2011–2019	Field vented
	Natural Gas Production		Natural gas production		Field vented
	Natural Gas Processing		Natural gas production		Natural gas production
SK	Light/Medium Crude Oil Production	1990–2005	Light/medium crude production	2005–2019[a]	Venting – Non-heavy oil
	Heavy Crude Oil Cold Production		Heavy crude production		Venting – Heavy oil
	Heavy Crude Oil Thermal Production		Heavy crude production		Venting – Heavy oil
	Natural Gas Production	1990–2011	Natural gas production	2011–2019	Venting – Gas batteries + Gas gathering systems
MB	Light/Medium Crude Oil Production	1990–2019	Light/medium crude production		
NT	Natural gas processing	1990–2019	Natural gas production		
AB, SK, BC	Well Servicing, Well Drilling	1990–2019	Wells Drilled		

Note:

a. Delineation of venting volumes by crude oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, venting volumes in Saskatchewan were available as non-associated and associated venting. Non-associated vent volumes were used to extrapolate reported venting from Natural gas production, while associated vent volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude reported venting.

Table A3.2–9 **Activity Data Used to Extrapolate Other Fugitive Emissions by Region for All Years**

Emission Sector Category	Emission Source Category	Region	Activity Data
Accidents and Equipment Failures	Spills/Pipeline Ruptures	All	Total number of spills, ruptures and blowouts
Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration	All	Total number of capable oil and gas wells
Light/Medium Crude Oil Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Light/medium crude oil production
Heavy Crude Oil Cold Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, SK	Heavy crude oil production
Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB	In-situ bitumen production
		SK	Heavy crude oil production
Natural Gas Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, BC, SK	Non-associated gas production
		All other provinces	Natural gas production
Natural Gas Processing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Natural gas production
Natural Gas Processing	Formation CO_2	All	Shrinkage
Disposal and Waste Treatment	Fugitive Equipment Leaks Storage Losses Unreported Venting	AB	Total crude production
Petroleum Liquids Transportation	Fugitive Equipment Leaks Storage Losses Unreported Venting	PE and QC	Total RPP Retail Pump Sales
		All other provinces	Total crude production
Well Servicing Well Testing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Storage Losses Loading/Unloading Unreported Venting	All	Wells drilled
Gas Storage	Fugitive Equipment Leaks Unreported Venting	All	Natural gas delivered to and received from storage
Gas Transmission Gas Distribution	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Spills/Pipeline Ruptures Unreported Venting	All	Kilometres of pipeline

Figure A3.2–1 shows the results of the “wedging” method in graphical form. In general, the 2000 and 2005 inventory years are used to interpolate emissions by sector, source and province/territory for the 2001–2004 time period, while the 2005 and 2011 inventory years are used to interpolate emissions for the 2006–2010 time period. However, there are a few special cases where the 2000 and 2011 inventory years are used to interpolate emissions for the 2001–2010 time period. This occurs when data was missing or incomplete for the 2005 data year and, as a result, specific sector, source and province/territory combinations were not able to be estimated for the 2005 inventory. In addition, on the basis of conversations with the contractor and the province of Saskatchewan, the Saskatchewan venting emissions for the cold production heavy crude oil sector in the 2005 inventory were determined to be unreliable. As a result, emissions for this source and sector were interpolated using the 2000 and 2011 data as end points with the 2005 data point being omitted.

Finally, if any specific source and sector in a given province/territory only existed in one of the inventoried years, then the inventoried data was extrapolated for the entire time series. All of this was done to ensure time-series consistency.

Proportional Adjustment

As stated previously, if the “wedging” method resulted in negative emissions in any year of the interpolation time period, then the method was abandoned for that given sector, source and province/territory and the “proportional adjustment” method was used, as shown in Equation A3.2–7.

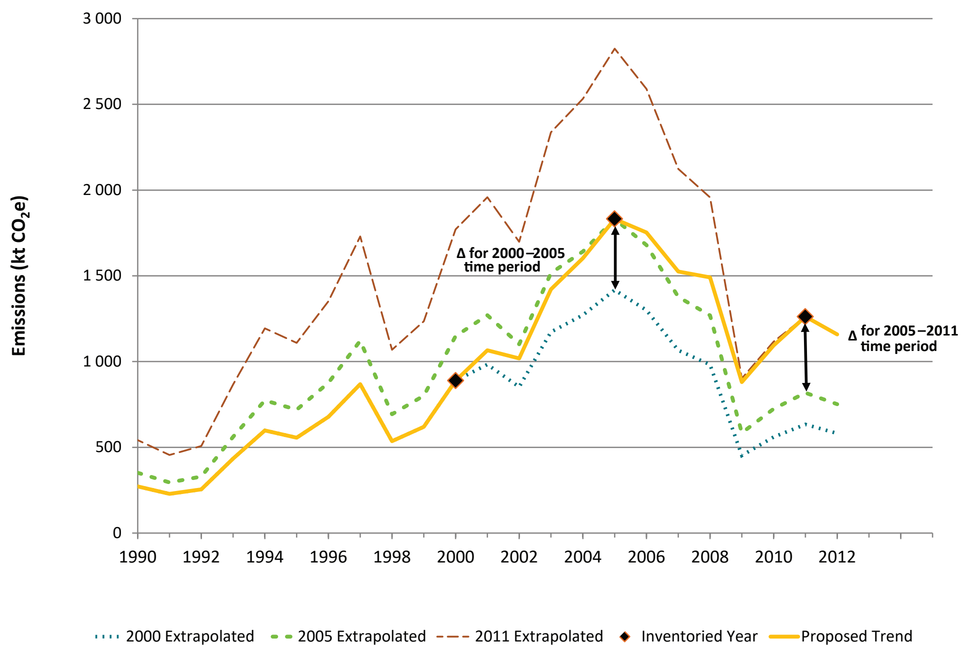
Equation A3.2–7

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} \times \frac{\left(ER_{i,j}^{k2\_inv}\right)}{\left(ER_{i,j}^{k2,k1\_exp}\right)}$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1+1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011 and k is equal to k2, then the result of Equation A3.2–7 is the emission rate of the inventoried year for 2011. Otherwise, the emission rate of the extrapolated data is modified by the same percentage for each year in the interpolated time period. This method was required in less than 0.3% of all cases and was generally only required for sources with very low emissions.

Figure A3.2–1 **Graphical Representation of the “Wedging” Method**



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A3.2.2.1.2. Alberta Reported Venting and Flaring

Methodology

Reported venting and flaring emissions from 2010–2019 for the province of Alberta are estimated directly instead of extrapolated from the CAPP and UOG studies (CAPP, 2005a; EC, 2014). Reported volumes of gas flared and vented by operator and facility from the Petrinex reporting system (Petrinex, 2020) are used in conjunction with gas composition data by Alberta township (Tyner and Johnson, 2020) to estimate emissions.

Activity Data

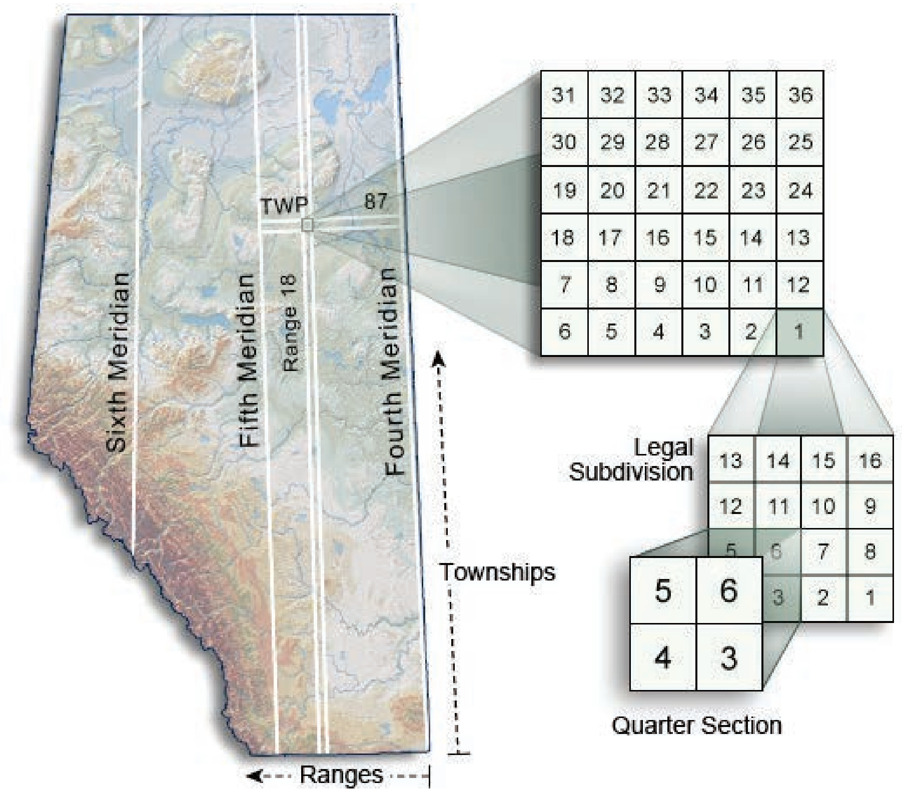
The Petrinex reporting system collects various volumetric production accounting data for the primary purpose of collecting royalties. Oil and gas facilities in Alberta must report various data to Petrinex on a monthly basis. This data includes tombstone data for each facility such as FacilityID, subtype classification, facility name, operator, geographic location, etc. as well as volumetric data corresponding to a specific ProductID (e.g. crude oil, crude bitumen, water, gas, etc.) and ActivityID (e.g. flare, vent, fuel, production, receipts, disposition). Petrinex reported gas flaring and gas venting volumes are summarized by Alberta township.

The Alberta Township Survey (ATS) system follows the Dominion Land Survey (DLS) method, whereby any parcel of land in Western Canada can be located by its legal land description. In the ATS, land is designated as being west of the 4th, 5th, or 6th Meridians (110°, 114°, 118° west longitude, respectively). Six-mile-wide columns between meridians are called ranges and are numbered consecutively from east to west. Townships are six-mile-wide rows that intersect ranges and are numbered consecutively from south to north. The term township also describes the six-by-six mile square formed by the intersection of ranges and townships. Townships are further sub-divided into 36 sections, and sections are then divided into quarters (NE, NW, SE, SW), or into 16 legal subdivisions (LSD), as indicated in Figure A3.2–2.

Emission Factors

In order to reflect the regional variability in gas composition, emissions for flaring and reported venting are estimated using recently developed natural gas composition data for the UOG industry in Alberta by the Energy and Emissions Research Laboratory (EERL) of Carleton University (Tyner and Johnson, 2020) (hereafter referred to as EERL study). The EERL study uses measured gas composition data from approximately 400 000 wells in Alberta taken over a

Figure A3.2–2 **Alberta Township System (ATS)**



Note: Source – Government of Alberta (2021) span of several decades across the province's many oil and gas producing regions to generate gas compositions by Alberta township (see Figure A3.2–3).

CO_2, CH_4 and N_2O emission factors for flaring are calculated using the EERL study data as shown in Equation A3.2–8, Equation A3.2–9, and Equation A3.2–10, respectively. The calculated EFs by township are then multiplied by the volumetric data from Petrinex (2020) to estimate emissions. Similarly, CO_2 and CH_4 emissions from reported venting are estimated using Equation A3.2–11. Township level emissions are summed to calculate flaring and reported venting emission estimates for the province of Alberta.

Equation A3.2–8

$$EF_{CO2,i} = \sum_j \frac{y_{i,j} \cdot n_{c,j} \cdot MW_{CO2}}{V_{STP}} \cdot g_c$$

$EF_{CO2,i}$ = CO_2 emission factor for flaring in township i (g/m³)

$y_{i,j}$ = mole fraction of component *j* in township *i*

$n_{c,j}$ = number of carbon atoms per molecule of component *j*

MW_{CO2} = molecular weight of CO_2 (g/mol) = 44.010 g/mol

V_{STP} = volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m³/kmol

g_c = constant of proportionality = 1000 mol/kmol

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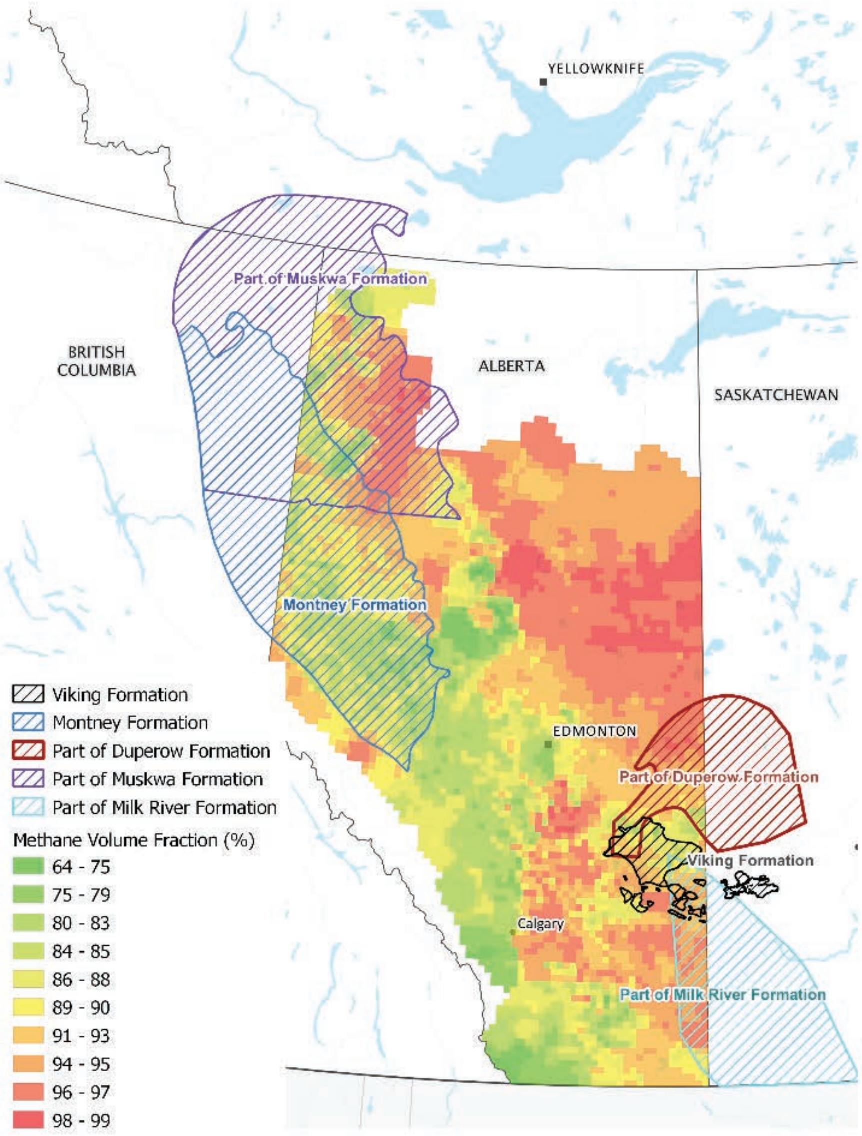
Figure A3.2–3 **Methane Content by Alberta Township with Select Oil and Gas Producing Formations**



Equation A3.2–9

$$EF_{CH4\,i} = \sum \frac{y_{CH4\,i} \cdot MW_{CH4} \cdot (1 - CE)}{V_{STP}} \cdot g_c$$

$EF_{CH4,i}$ = CH_4 emission factor for flaring in township *i* (g/m^3)

$y_{CH4,i}$ = mole fraction of CH_4 in township *i*

MW_{CH4} = molecular weight of CH_4 (g/mol) = 16.04206 g/mol

CE = combustion efficiency = 0.98 (EC 2014)

V_{STP} = volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m^3/kmol

g_c = constant of proportionality = 1000 mol/kmol

Equation A3.2–10

$$EF_{N2O,i} = ER_{N2O} \cdot HHV_i$$

$EF_{N2O,i}$ = N_2O emission factor for flaring in township *i* (g/m^3)

ER_{N2O} = flaring emission rate for N_2O (g/MJ) = 0.0000952 g/MJ (WCI.363(k) 2012)

HHV_i = higher heating value for township i (MJ/m^3)

Equation A3.2–11

$$Emis_{i,j} = y_{i,j} \cdot Vol_i \cdot \rho_j$$

$Emis_{i,j}$ = vented emissions of component *j* in township i (kilotonnes)

$y_{i,j}$ = mole fraction of component *j* in township *i*

Vol_i = volume of gas vented in township *i* (10^3 m^3)

ρ_j = density of component *j* at standard conditions (101.325 kPa and 15°C) (kg/m^3)

A3.2.2.2. Natural Gas Transmission and Storage

Methodology

Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by high-pressure pipelines. The majority of emissions are from equipment leaks and process vents along these pipelines.

Fugitive emissions for natural gas transmission are based on several documents. The first, *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP, 1999), was prepared by Clearstone Engineering Ltd. for CAPP in July 1999. The second source is ancillary tables provided by Clearstone Engineering Ltd. that describe the CO_2 emissions. There are no N_2O fugitive emissions from natural gas transmission. The CO_2 and CH_4 emissions for 1990–1996 are taken directly from the two sources. The CO_2 and CH_4 emissions for 1997–1999 were estimated based on province/territory natural gas transmission pipeline length and leakage rates, which were developed based on the 1996 emissions from CAPP (1999) and pipeline lengths from Statistics Canada.

For the years 2005 and 2011, emissions are taken from the UOG study (EC, 2014), which followed an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. Input data for the natural gas transmission and storage industry was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2019 were extrapolated from 2014 data using the same extrapolation method as described for the UOG sector (see Equation A3.2–5), with the length of natural gas transmission pipeline used as the activity factor.

The emissions are calculated per province/territory and then summed to obtain the total CO_2 and CH_4 emissions for Canada. Newfoundland and Labrador, Prince Edward Island, Yukon, and Nunavut do not have natural gas transmission pipelines. However, there are natural gas gathering lines in Yukon, and fugitive emissions from those lines are accounted for in the 1.B.2.b.2 – Natural Gas – Production category of the CRF table.

No natural gas transmission pipelines were operating in Nova Scotia, New Brunswick or the Northwest Territories until 1999.

Similar to natural gas transmission, fugitive emissions from natural gas storage are taken from the UOG study (EC, 2014) for the years 2005 and 2011. Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI. Emission estimates for 1990–1999 and 2015–2019 were extrapolated using the previously described extrapolation methods, with the volume of gas delivered to and withdrawn from storage as the activity factor.

Activity Data

The activity data required to estimate the fugitive emissions from natural gas transmission for 1997–1999 and 2015–2019 is the annual length of the natural gas transmission pipeline by region. Transmission pipeline lengths were published annually by Statistics Canada in *Natural Gas Transportation and Distribution.* Statistics Canada has discontinued this publication but still collects the data and releases it to Environment and Climate Change Canada (ECCC) (Statistics Canada, 2020). However, pipeline length data was only available up to and including 2018; pipeline lengths for 2019 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2019 pipeline lengths were estimated based on the average annual change in length between 2000 and 2018. The 2019 values were assumed to be the same as 2018 for New Brunswick and Nova

Scotia since the natural gas transmission pipeline lengths have not changed since 2003 and 2002, respectively. Improvements to the model are being investigated.

For natural gas storage, annual volumes of natural gas delivered to storage and withdrawn from storage are taken from *Canadian natural gas storage, Canada and provinces* (Statistics Canada, n.d.[f]) for the 2015–2019 time period and *Natural gas utilities, monthly receipts and disposition* (Statistics Canada, n.d.[g]) for data prior to 2015.

A3.2.2.3. Petroleum Refining

The refinery model is based on the study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI, 2004), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada and Industry Canada in 2004 by Levelton Consultants Ltd. The study surveyed the refining industry and used this data, along with data collected by the Canadian Industrial Energy End-Use Data and Analysis Centre, to develop GHG emission estimates for 1990 and 1994–2002.

There are three sections in the refinery methodology: fugitive (unintentional releases), process venting and flaring. The combustion methodology for petroleum refining is discussed in Annex 3.1 of the National Inventory Report.

Methodology

Fugitive Emissions

The CO_2 and CH_4 emission factors were developed by Levelton Consultants Ltd. and were presented in the refinery study (CPPI, 2004). These EFs are used to estimate the fugitive emissions for the years not included in the study, i.e. 1991–1993 and 2003 onwards.

The fugitive emissions are generated using Equation A3.2–12.

Equation A3.2–12

$$FugitiveGHGEmissions(t) = EmissionFactor(t/GJ) \times RefineryAnnualEnergyConsumption(GJ)$$

The refinery annual energy consumption (in GJ) is the sum of the energy of all fuels consumed by refineries in the Report on *Energy Supply and Demand in Canada* (Statistics Canada 2003 – #57-003-XIB), including fuels listed under producer consumption from the refined petroleum products table. The energy consumption value is the same as that in the stationary combustion model for 1.A.1.b Petroleum Refining of the CRF table.

The EFs are 2.78 t CO_2/GJ for CO_2 and 11.89 t CH_4/GJ for CH_4.

The refinery study has listed fugitive N_2O emissions for 1990 and 1994–2002 as a constant 100 t N_2O/year; however, there were not enough data to develop an emission factor for them. The N_2O emissions were kept constant at 100 t N_2O/year for the years 1991–1993 and 2003 onwards. It is assumed that the reported N_2O emissions from the refinery study are a residual from combustion sources and that the majority of N_2O emissions associated with petroleum refining are correctly reported in the stationary combustion section of the inventory.

Process Emissions (Venting)

Process emissions are mainly associated with the venting of CO_2 from the production of hydrogen using natural gas. This hydrogen is used as an input in the production of refined petroleum products (RPPs). Using data provided from the refinery study for the years 1990, 1994–1998 and 2000–2002, CO_2 emissions from the production of hydrogen were correlated to refinery annual RPP production. These results were used to estimate CO_2 emissions for the years 1991–1993, 1999 and 2003 onwards.

Flaring Emissions

Flaring emissions have been determined for CO_2, CH_4 and N_2O using the estimates from the refinery study and RPP production by Canadian refineries. The study provided emissions for the years 1990, 1994–1998 and 2000–2002, and these emissions were correlated to refinery annual RPP production. Flaring emissions for the years 1991–1993, 1999 and 2003 onwards were estimated based on this correlation and known RPP production data.

Activity Data

The activity data required to estimate the fugitive emissions from refineries is listed in Table A3.2–10.

Table A3.2–10 **Required Refinery Activity Data and Their Sources**

Publisher	Publication	Activity Data
Statistics Canada	*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, 2003–)	Refinery and producer consumption (by refineries) annual energy consumption. Refinery RPP production
Canadian Petroleum Products Institute (CPPI)	*Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* by Levelton Consultants Ltd. (CPPI, 2004)	Fugitive Emissions
		Table 3-2 CPPI Regional GHG Inventory – Detailed (kilotonnes)
		Process Emissions
		Table 3-2 CPPI Regional GHG Inventory – Detailed (kilotonnes)
		Flaring Emissions
		Appendix E – Flare Gas

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A3.2.2.4. Natural Gas Distribution

Methodology

Fugitive emissions for the 1990–1999 time period from natural gas distribution are based on the Canadian Gas Association (CGA) report titled *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA, 1997) and the Gas Research Institute (GRI) report titled *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI, 2000). The CGA study estimated emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions were calculated based on EFs from the U.S. EPA, other published sources and engineering estimates. The activity data was obtained from published sources and specialized surveys of gas distribution system companies. The surveys contained information on equipment schedules, operating parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. The GRI (2000) report is an update to the CGA (1997) study with more accurate and better substantiated data for station vents. An emission factor was developed for the distribution system based on the study data (CGA, 1997; GRI, 2000) and on gas distribution pipeline distances by province provided by Statistics Canada, which were then used to estimate emissions for the 1990–1999 time period.

For 2000 and onwards, emissions are based on data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies for 2005 and 2011. Input data for the natural gas distribution industry was compiled by ORTECH Consulting Inc. (2013) for CEPEI. Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2019 were estimated using the length of natural gas distribution pipeline, taking the approach governed by Equation A3.2–5.

The fugitive emissions for natural gas distribution are estimated for each province and then summed to obtain the overall emissions for Canada. At present, no natural gas distribution pipelines exist in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nunavut, Yukon, and Nunavut.

Activity Data

The required activity data is the length of natural gas distribution pipeline per province, which was historically published in Statistics Canada's *Natural Gas Transportation and Distribution* report. Statistics Canada discontinued this publication in 2003 but still collects the data and releases it to ECCC (Statistics Canada, 2019). However, pipeline length data was only available up to and including 2018; pipeline lengths for 2019 were therefore estimated for all provinces based on the change in length between 2017 and 2018.

For New Brunswick and Nova Scotia, pipeline lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[7] and Heritage Gas,[8] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999. Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

The 2007 pipeline length for British Columbia provided by Statistics Canada was twice the 2006 value. Statistics Canada confirmed that the data for 2006 and previous years was incorrect but was unable to provide corrected distribution lengths. It was assumed that the 1999 value was correct, and a linear trend was used to fill in the 2000–2006 data.

A3.2.2.5. Oil Sands and Heavy Oil Upgrading Industry

The oil sands and heavy oil upgrading (OS/HOU) industry produces synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants (e.g. sulphur compounds); in its natural state, it will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. "Oil sands" is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contains concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water and bitumen.

In this area, bitumen is extracted from open-pit mined oil sands or from in situ bitumen operations using thermal extraction techniques. The emissions from in-situ bitumen extraction are included in the UOG study (CAPP, 2005a). Fugitive emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from two separate reports: *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP, 2006), prepared by Clearstone Engineering Ltd. for CAPP (referred to hereafter as the bitumen study), and an update to the study that was completed in 2017 by Clearstone for Environment and Climate Change Canada titled *An Inventory of GHGs, CACs, and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017) (referred to hereafter as the oil sands study).

In general, the bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC, 2017) is the basis for

7 Enbridge Gas New Brunswick. 2010. Personal communication (email from Nicholson L, Communications Coordinator, Enbridge Gas New Brunswick, to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

8 Heritage Gas. 2010. Personal communication (email from Bracken J, President, Heritage Gas to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

the 2004–2019 fugitive emission estimates for the OS/HOU industry. The major emission sources in the OS/HOU industry are the following:

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders
- CH_4 present in the oil sands deposits that is released during mining, mine dewatering and ore handling activities
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands
- biogenic gas formation (primarily CH_4) in tailings ponds
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants
- spills and accidental releases
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds

Bitumen Study: 1990–2003 Emission Estimates

The bitumen study (CAPP, 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry from 1990–2003. Table A3.2–11 lists the OS/HOU facilities included in the study.

The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

The bitumen study (CAPP, 2006) used emissions from individual facility reports, where available. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated on the basis of available activity data and emission factor data. There were two methods for estimating emissions. The first method—the emission factor method—uses specific activity data and standard EFs. If no activity data were available, the emission factor ratio technique was applied. Refer directly to the bitumen study (CAPP, 2006) for a discussion of the specific methodologies.

Table A3.2–11 **List of Oil Sands and Heavy Oil Upgrading Facilities in the Bitumen Study (CAPP, 2006)**

Operator	Facility Name
Husky Energy Inc.	Lloydminster Upgrader
Consumer's Co-operative Refineries Ltd.	Regina Upgrader
Suncor Energy Inc.	Tar Island
Syncrude Canada Ltd.	Mildred Lake and Aurora

The following sources were used to estimate emissions:

- facility operator information
- energy statistics published by the Alberta Energy Regulator (AER)
- source emission monitoring results reported to Alberta Environment
- data from company submissions to the Voluntary Challenge Registry
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry
- open literature

Consult the bitumen study (CAPP, 2006) for more details.

Oil Sands Study: 2003–2019 Emission Estimates

The oil sands study (ECCC, 2017) is a facility-based Tier 3 emissions inventory for the OS/HOU industry completed for the 2015 reference year. It was used as the basis for extrapolating emissions both forwards and backwards in time. Where facility emission reports were available from operators, extrapolation was not required and actual emissions were used. These emission records were verified by Clearstone Engineering Ltd. Table A3.2–12 is a list of the OS/HOU facilities included in the study.

Table A3.2–12 **List of Oil Sands and Heavy Oil Upgrading Facilities in the ECCC Bitumen Study (ECCC, 2017)**

Operator	Facility Name	Oil Sands Operations
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	Integrated Mining and Upgrading
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	
Husky Energy Inc.	Lloydminster Upgrader	Upgrading
Shell Canada Energy	Scotford Upgrader	
Nexen Energy ULC	Long Lake Upgrader	
Imperial Oil Resources	Kearl Mine	Mining and Ore Processing
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	
Aux Sable Canada Ltd.	Heartland Offgas Plant	Hydrocarbon Liquids Extraction
Inter Pipeline Offgas Ltd.	Suncor Liquids Extraction Plant	

The Regina Upgrader operated by Consumers' Co-operative Refineries Limited was excluded from the oil sands study because it is defined strictly as a refinery even though it does upgrade heavy crude oil. The refinery began operation in 1935 and added upgrading capabilities in 1988. It was included in the bitumen study (CAPP, 2006) due to its capabilities to upgrade heavy crude oil. Fugitive emissions for this facility are estimated using the refinery model (see section A3.2.2.3).

In 2016, the Horizon liquid extraction plant operated by Inter Pipeline Offgas Ltd. came online. Emissions from this facility were estimated using emissions data from the Suncor liquid extraction plant (ECCC, 2017) and facility-level activity data (AER, 2020e) for the two facilities. This method is justified due to the similar operations at the two facilities. In late 2017, both the Fort Hills mine and Sturgeon refinery started operations. Emission estimates for these facilities were developed using emissions data reported to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2020).

Depending on when each facility commenced operation, emissions were estimated using data from either the bitumen study (CAPP, 2006), the oil sands study (ECCC, 2017), or both. Table A3.2–13 shows the study used to estimate emissions for each year of the time series for each facility.

Methodology for Extrapolating Emission Estimates

The oil sands model provides emission estimates for the OS/HOU industry for 2003–2019 by multiplying base year emissions data (i.e. 2015) by the ratio of the activity data for the non-inventoried year to that of the base year, as shown in Equation A3.2–13. The base year emissions data were taken from the oil sands study (ECCC, 2017).

Equation A3.2–13

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}}\right)$$

$ER_{i,j}^{k}$ = emission rate of compound i, source j, and year k, t/year

$ER_{i,j}^{baseYr}$ = base year (e.g. 2015) emission rate for compound i and source j, t/year

AF_{j}^{k} = activity values for source j and year k

AF_{j}^{baseYr} = base year (e.g. 2015) activity factor for source j

Activity Data

Table A3.2–14 lists the activity data used to estimate fugitive emissions for each oil sands operation and emission subcategory.

A3.2.2.6. Abandoned Oil and Gas Wells

When an oil or gas well reaches the end of its productive life, the well operator is required to properly abandon the well by removing all the equipment and plugging the well. This is done to prevent gas leakage from the well and to prevent the migration of oil and gas to the surrounding strata. However, CH_4 can be emitted into the atmosphere even when well abandonment best practices are followed. Additionally, abandoned wells that were not properly decommissioned exist. There are a number of reasons for this, including abandonment prior to the enactment of regulations and bankruptcy of the well owner.

There are two main categories of abandoned wells: plugged and unplugged wells. Unplugged wells are wells without recent production (i.e. inactive, temporarily abandoned/suspended or dormant) or without an operator (i.e. orphaned wells). Plugged wells are wells that have been plugged with cement or any mechanical plug to prevent migration of fluid. Emissions result

Table A3.2–13 **Basis of Emission Estimates for Each Facility in the Oil Sands and Heavy Oil Upgrading Industry**

Operator	Facility Name	Bitumen Study	Oil Sands Study
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	1990–2003	2004–2019
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	1990–2003	2004–2019
Husky Energy Inc.	Lloydminster Upgrader	1992–2003	2004–2019
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	-	2002–2019
Shell Canada Energy	Scotford Upgrader	-	2003–2019
Inter Pipeline Offgas Ltd.	Suncor Liquid Extraction Plant	-	2003–2019
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	-	2008–2019
Nexen Energy ULC	Long Lake Upgrader	-	2009–2019
Aux Sable Canada Ltd.	Heartland Offgas Plant	-	2011–2019
Imperial Oil Resources	Kearl Mine	-	2013–2019
Inter Pipeline Offgas Ltd.	Horizon Liquid Extraction Plant	Emission estimates for 2016–2019 were developed using emissions data for the Suncor Liquid Extraction Plant (ECCC, 2017) and facility level activity data (AER, 2020e).	
Fort Hills Energy Corporation	Fort Hills Mine	Emission estimates for 2017–2019 were developed from data reported to the Greenhouse Gas Reporting Program (ECCC, 2020).	

Table A3.2–14 **Activity Data Required for the Oil Sands Model**

Oil Sands Operation	Source Category	Subcategory	Activity Data for Extrapolation
Hydrocarbon Liquids Extraction	Flaring and Incineration	All	Process Gas Receipts (AER, 2020e)
	Fugitive	Equipment Leaks	
	Venting	All	
Mining and Ore Processing	Flaring and Incineration	All	Crude Bitumen Production (AER, 2020e)
	Fugitive	Equipment Leaks	
		Exposed Mine Face	
		Other	
		Storage Losses	
		Tailings Ponds	
	Process Emissions	Sulphur Recovery	
	Venting	All	
Upgrading	Flaring and Incineration	All	Synthetic Crude Oil Production (AER, 2020e; Husky Energy Inc., 2020)
	Fugitive	Equipment Leaks	
		Other	
		Spills and Pipeline Ruptures	
		Storage Losses	
	Venting	All	
	Process Emissions	Sulphur Recovery	
		H_2 Production	

from both plugged and unplugged wells, but emissions from unplugged wells are significantly higher than emissions from plugged wells. Emissions may also vary depending on the type of production. However, due to data limitations, the approach described here does not differentiate on the basis of the type of production.

Estimation Methodology

A Tier 1 approach was used to estimate emissions from abandoned oil and gas wells using Equation A3.2–14.

Equation A3.2–14

$$ER_{i,j}^{k} = \sum_{j=1}^{n} EF_{i,l} \times WellCount_{j,l}^{k}$$

$ER_{i,j}^{k}$ = emission rate of compound i, province j and year k, tonnes/year

$EF_{i,l}$ = emission rate per abandoned well for compound i and well type l, tonnes/year

$WellCount_{j,l}^{k}$ = well count for province j, well type l and year k

Emission Factors

The CH_4 emission factors were taken from a study titled *Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States* (Townsend-Small et al., 2016) on abandoned oil and gas wells in the United States. There are currently no emissions data from abandoned oil and gas wells in Canada.

Table A3.2–15 shows the EFs used for estimating emissions for both abandoned oil and gas wells. The EFs are presented in terms of plugging status (i.e. plugged or unplugged) and location (i.e. onshore or offshore). For provinces where limited data is available on the well plugging status, the emission factor for all well types is used.

Table A3.2–15 **Emission Factors for Abandoned Oil and Gas Wells**

Abandoned Well Type	Value (kg CH_4/well/yr)	Uncertainty
Plugged wellsa (onshore)	0.02	-87% to +130%
Unplugged wellsa (onshore)	87.78	-99% to +150%
Plugged wellsa (offshore)	0.0035	-87% to +130%
Unplugged wells[a] (offshore)	17.6	-99% to +150%
All well types (plugged and unplugged, onshore)[a,b]	12.09	-83% to +124%
All well types (plugged and unplugged, offshore)[a,b]	2.4	-83% to +124%

Notes:

a. Emission factors taken from Townsend-Small et al. 2016, based on abandoned well results in the United States.

b. Assumption for all well types EF: Based on 86% plugged wells and 14% unplugged wells.

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Activity Data

Annual counts of abandoned wells by province were developed using the data sources shown in Table A3.2–16.

The count of abandoned wells for each year of the time series was further subcategorized into well type (gas or oil), well status (plugged, unplugged or unknown) and location (onshore or offshore). Several assumptions were made to assign the plugging status of a well.

- An unplugged well is a well with a well status of suspended or inactive.
- A plugged well is a well with a well status of abandoned, downhole abandoned, or junked and abandoned.
- Any offshore well that is abandoned or not producing for an extended period is considered plugged.
- Where the plugging status could not be determined, it was considered unknown and a default emission factor was used to estimate emissions.

For the Northwest Territories and Nova Scotia, this level of disaggregation of activity data was not possible. For the Northwest Territories, there is no publicly available data on abandoned wells for oil and gas operations, and it was therefore difficult to evaluate the number of abandoned wells. For this reason, data from CAPP (CAPP, 2020) was used to estimate the abandoned well count. It was assumed that the abandoned well count is the difference between the total number of wells drilled in the province and the number of oil and gas wells completed in the province. Following that, it is assumed that the average lifespan of completed wells is 20 years. For Nova Scotia, monthly production data by well was used to determine the abandonment date of the well. It was assumed that wells were abandoned 6 months after last production.

For the remaining provinces (i.e. Alberta, British Columbia, Saskatchewan, Yukon, Manitoba, New Brunswick, Newfoundland and Ontario), sufficient information was available in the provincial datasets to determine the number of abandoned wells by well type, well status and location.

Occasionally, the well type was not known. In this case, the emissions from these wells are allocated to oil or gas based on the known ratio of abandoned oil to gas wells in the same year.

A3.2.2.7. Flaring Special Case – Avoiding Double Counting

As defined in the *Report on Energy Supply and Demand in Canada* (Statistics Canada, 2003–), producer consumption “is the consumption by the producing industry of its own produced fuel—for example refined petroleum products consumed by the refined petroleum product industry, or natural gas used in the field, flared and waste, field uses, gathering uses, plant uses and metering adjustments.”

Table A3.2–16 **Activity Data Required for Abandoned Oil and Gas Wells**

Region	Source	Publication
Alberta	Alberta Energy Regulator	ST37: List of Wells in Alberta (AER, 2020f)
British Columbia	British Columbia Oil and Gas Commission	Well Surface Hole Locations (BCOGC, 2020c)
Saskatchewan	Saskatchewan Ministry of Energy and Resources	Abandoned well counts were provided upon request[a]
Manitoba	Government of Manitoba: Oil & Gas	Petroleum Statistics, Unique Well Identifier Key List Report (MB, 2020b)
Ontario	Ontario Oil, Gas & Salt Resource Library	Petroleum Well Data (OGSRL, 2020)
Newfoundland & Labrador	Canada–Newfoundland & Labrador Offshore Petroleum Board	Schedule of Wells Summary (CNLOPB, 2020h)
Nova Scotia	Canada–Nova Scotia Offshore Petroleum Board	Cohasset Panuke production report (CNSOPB, 2019)
		Sable Offshore production report (CNSOPB, 2019)
		Deep Panuke production report (CNSOPB, 2019)
Yukon	Yukon Government: Energy Mines and Resources	Yukon Well Listing (YK, 2020)
Northwest Territories	CAPP Statistical Handbook	Land, Exploration, Drilling Categories (CAPP, 2020)
		• Oil wells completed
		• Gas wells completed
		• Wells drilled
New Brunswick	New Brunswick Borehole Database	New Brunswick Well Listing (NB NRED, 2020b)

Note:

a. Saskatchewan Ministry of Economy. 2020. Personal communication (email from Perras, A, to Barrigar, O, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 1, 2020).

Statistics Canada determines natural gas producer consumption volumes by summing the following fields from *Natural gas, monthly supply and disposition* (Statistics Canada, n.d.[a]) for each province:

- field flared and waste
- field disposition and use
- gathering system and processing plant
- plant use
- adjustment

Up until and including the 2015 data year, the data contained in *Natural gas, monthly supply and disposition* was collected by Statistics Canada through administrative agreements with most provinces. For example, the AER collects detailed production accounting data from all oil and gas production facilities in the province. This production accounting data includes the volumes of gas produced, flared, vented, etc. and is incorporated into the Statistics Canada data and subsequently the *Report on Energy Supply and Demand in Canada* (RESD). In 2015 Statistics Canada stopped publishing the detailed data contained in the *Natural gas, monthly supply and disposition report*. They now use publically available provincial data to determine the producer consumption volumes reported in the RESD. ECCC has access to this same provincial data and knows the method used by Statistics Canada to determine the producer consumption volumes. The correct amount of gas flared and vented is therefore able to be subtracted to avoid double counting for the years 2015 onwards.

Combustion emissions from the consumption of producer-consumed fuels are estimated using the fuel volumes reported in the RESD (See Annex 3.1). Since flaring and venting emissions are estimated separately using the various fugitive models and reported as fugitives, it is necessary to subtract the volume of flared and vented gas, and the associated emissions, from the combustion estimates in order to avoid double counting, as described in section A3.1.4.1.2.

Based on the previously discussed information, the volume of gas reported as field flared and waste is subtracted from producer consumption.

The provinces that have producer consumption of natural gas values in the RESD accounted for over 98% of total crude oil production in Canada in 2018 and 99.9% of gross natural gas production.

In situations where flaring or venting emissions are estimated for a particular province that has no producer consumption reported in the RESD, the flaring emissions and associated natural gas volumes are not subtracted to ensure there is no underestimation of emissions.

Estimates for flaring emissions from petroleum refining are calculated using the refinery model (see A3.2.2.3). The volume of fuel flared is back-calculated from the flaring emissions and then subtracted from the producer consumption of still gas (also known as refinery fuel gas) since the method used by Statistics Canada to determine producer consumption of still gas is currently not well understood.

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A3.3. Methodology for Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) sector covers greenhouse gas (GHG) emissions arising from non-energy-related industrial activities. Categories included in this sector are Mineral Industry, Chemical Industry, Metal Industry, Non-energy Products from Fuels and Solvent Use, Electronics Industry, Product Uses as Substitutes for Ozone Depleting Substances (ODS), and Other Product Manufacture and Use. Chapter 4 presents methodological issues for each of these categories. This section of Annex 3 provides additional details on the methodologies used to estimate emissions in the following IPPU categories:

- Chemical Industry – CO_2 emissions from Ammonia Production
- Metal Industry – CO_2 emissions from Iron and Steel Production
- CO_2 emissions from Non-energy Products from Fuels and Solvent Use
- HFC emissions from Product Uses as Substitutes for ODS
- Other Product Manufacture and Use – SF_6 emissions from Electrical Equipment

A3.3.1. CO_2 Emissions from Ammonia Production

Steam methane reforming (SMR), which generates hydrogen—an essential feedstock for the Haber-Bosch process in the production of ammonia—may use natural gas as the energy source to drive the process. Natural gas is also used as feedstock for the SMR process to provide a source of hydrogen. In both uses, the majority of carbon in natural gas ends up as CO_2 emissions. The source category 2.B.1, Ammonia Production, includes CO_2 emissions from the feedstock use of natural gas in the SMR process and emissions recovered for urea production. GHG emissions (CO_2, N_2O, and CH_4) from the energy use of natural gas in SMR process and GHG emissions from fuels used in non-SMR ammonia production processes are accounted for in the Energy sector.

Facility-level data on feedstock use of natural gas and annual ammonia production were obtained as part of Environment Canada's voluntary data collection for the years 2005 through 2009. These data were then used to develop the facility-level ammonia-to-feed fuel (conversion) factors. Of the nine plants in operation, seven (two of which have two SMR units each) provided ammonia-to-feed fuel factors. One of the two plants that did not provide information does not operate an SMR unit. These facility-level ammonia-to-feed fuel factors are considered confidential and are therefore not publicly available. However, based on the data collected, the average ammonia-to-feed fuel factor is 671 m^3 of natural gas/tonne of NH_3 produced, and this average was used to estimate emissions from facilities that did not participate in the voluntary data collection. Furthermore, at plant level, the variability of ammonia-to-feed fuel factor is very stable (it varied less than 0.001% from year to year over the 5 surveyed years). Similarly, the average ammonia-to-feed fuel factor varied less than 0.001% from year to year over the 5 surveyed years.

The facility-level annual ammonia production data are then multiplied by the facility-specific (or average) ammonia-to-feed fuel factors to determine the amount of natural gas used as feedstock for each facility. The feedstock uses of natural gas are then aggregated according to the province in which the facilities are located (Equation A3.3–1).

Equation A3.3–1

$$NG_p = \sum_{i=1}^{n} P_{ammonia,i} \times FF_{ammonia,i}$$

NG_p	=	natural gas consumed as feedstock in province *p*, m^3 natural gas
i	=	the SMR facility
n	=	the total number of SMR facilities in province *p*
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
$P_{ammonia,i}$	=	the annual production of ammonia, in facility i, kt
$FF_{ammonia,i}$	=	the ammonia-to-feed fuel factor of facility i, m^3 natural gas/kt NH_3

The aggregated feedstock use (i.e., natural gas) for each province is then multiplied by the respective provincial natural gas carbon content found in Table A6.1–1 of Annex 6 (CO_2 emission factors for marketable natural gas) to determine the total carbon used. It is expected that all carbon present in the feedstock is transformed to CO_2 (IPCC, 2006). Based on these factors, the (gross) generated process CO_2 emissions from ammonia production are calculated using Equation A3.3–2.

Equation A3.3–2

$$Generated\ CO_2 = \sum_{p=1}^{m} NG_p \times CC_p \times COF$$

$Generated\ CO_2$	=	CO_2 emissions generated, kt
NG_p	=	natural gas consumed as feedstock in province *p*, m^3 natural gas
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
m	=	the total number of provinces containing one or more SMR ammonia-producing facilities
CC_p	=	carbon content factor of the fuel in province *p*, t CO_2/m^3 natural gas
CO_F	=	carbon oxidation factor = 1 (unitless)

The portion of emissions recovered for use in urea production is estimated using Equation A3.3–3, based on the assumption that urea production consumes a stoichiometric quantity of CO_2 and that 0.005 tonnes of CO_2 are emitted per tonne of urea produced.

Equation A3.3–3

$$Recovered\ CO_2 = \sum_{p=1}^{m}\left\{\sum_{i=1}^{n} P_{urea,i} \times R\right\}$$

Recovered CO_2	=	CO_2 emissions from Urea Production for a SMR facility
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
m	=	the total number of provinces containing one or more SMR ammonia-producing facilities
n	=	the total number of SMR facilities in province *p*
i	=	the SMR facility
$P_{urea,i}$	=	annual urea production of facility *i*, t urea
R	=	CO_2 emissions recovery factor per unit mass of urea production (where R = [M – L] = 0.728 t CO_2/t urea)
M	=	stoichiometric mass ratio of CO_2 required for urea production, 44/60 or 0.733 t CO_2/t urea
L	=	urea production process losses of CO_2, 0.005 t CO_2/t urea

The net national CO_2 emissions from ammonia production are then calculated by subtracting the recovered CO_2 for urea production in Equation A3.3–2 from the gross generated CO_2 emissions in Equation A3.3–3.

It should be noted that the quantity of natural gas feedstock used in the SMR process is subtracted from the overall non-energy use of natural gas, as reported by Statistics Canada, in order to estimate the residual (non-ammonia-related) process CO_2 emissions (refer to section A3.3.3, Non-energy Products from Fuels and Solvent Use).

The annual facility-level ammonia production data for the years 1990 to 2019 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from EC's voluntary data collection; and 2008 to 2019 from Statistics Canada's annual survey titled *Industrial Chemicals and Synthetic Resins* (Statistics Canada, 46-002-X).

Facility-level urea production data for the years 2008 through 2019 were also obtained from Statistics Canada's *Industrial Chemicals and Synthetic Resins* survey. Facility-level urea production values for earlier years (1990 through 2007) were estimated using the six-year average ratio of urea-to-ammonia production for the data years 2008–2013.

A3.3.2. CO_2 Emissions from Iron and Steel Production

Canadian Iron and Steel Manufacturing Facilities

As of 2019, the Canadian steel sector consisted of 14 facilities, namely 4 integrated mills and 10 non-integrated mills (9 mini-mills and 1 ilmenite mill). Of the 14 facilities, 8 are located in Ontario (including 4 integrated mills), 3 in Quebec and 1 in each of Alberta, Saskatchewan, and Manitoba. Table A3.3–1 provides a list of these facilities along with the type of manufacturing processes used.

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steelmaking processes (see Figure A3.3–1): basic oxygen furnaces and electric arc furnaces. The basic oxygen furnace is used in integrated mills in conjunction with coke making, sintering, and blast furnace iron making operations. Integrated mills, which smelt iron ore and melt scrap, produce the greatest diversity of products, including bars, rods, structural shapes, plates, sheets, pipes and tubes, and wire rods. Although electric arc furnace technology is gaining importance, it is usually used in non-integrated mills (mini-mills or specialty steel mills) fed by scrap or direct reduced iron to produce a wide product range of carbon and alloy steels. ArcelorMittal Dofasco Inc. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. ArcelorMittal Contrecoeur operates the only Canadian steel mill that produces and uses direct reduced iron as part of its raw material feed. Ancillary or secondary steelmaking processes that are common to

Table A3.3–1 **Iron, Steel and Ilmenite Smelting Facilities (2019)**

Integrated Mills	
ArcelorMittal Dofasco	Hamilton, ON
Essar Steel Algoma	Sault Ste. Marie, ON
U.S. Steel Canada – Hamilton Works	Hamilton, ON
U.S. Steel Canada – Lake Erie Works	Nanticoke, ON
Mini-Mills [a, b]	
AltaSteel Ltd.	Edmonton, AB
ArcelorMittal Contrecoeur	Contrecoeur, QC
ArcelorMittal Contrecoeur – Ouest	Contrecoeur, QC
ASW Steel	Welland, ON
EVRAZ North America	Regina, SK
Gerdau Ameristeel – Cambridge	Cambridge, ON
Gerdau Ameristeel Manitoba	Selkirk, MB
Gerdau Ameristeel – Whitby	Whitby, ON
Ivaco Inc.	L'Orignal, ON
Ilmenite Smelting Facility	
Rio Tinto – Fer et Titane Inc.	Sorel-Tracy, QC

Notes:

Information adapted from ECCC 2017.

a. Removed Mini-mill: Hamilton Specialty Bar Corp., Hamilton, ON, which closed permanently in 2018.

b. Added ASW Steel, Welland, ON, which is a small mini-mill that was excluded from the Canada Gazette notice.

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both integrated and non-integrated steelmaking include ladle metallurgy, continuous casting, hot forming, cold forming and finishing.

The following is a list of all process materials that are considered in the CO_2 emission estimates for CRF category 2.C.1, Iron and Steel Production.

- metallurgical coke (source: Statistics Canada, 1990–2019)
- pig iron production (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP, 2018–2019)
- pig iron charge to steel furnace (including direct reduced) (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP 2018–2019)
- scrap steel (own and purchased) (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP, 2018–2019)
- limestone and dolomite use (source: NRCan, 1990–2019)

Emission factors and carbon contents applied are included in Annex 6.

Note that due to the integrated nature of the iron and steel facilities that manufacture coal-based metallurgical coke in Canada, it is currently not possible to disaggregate the data submitted by this industry for energy use. All emissions related to the use of metallurgical coke as a reagent for reduction of iron ore in the production of pig iron are allocated in CRF category 2.C.1. As illustrated in Chapter 4 (Equation 4–8), emissions from pig iron production are estimated on the basis of various parameters, including the mass of metallurgical coke used as a reductant and its respective emission factor.

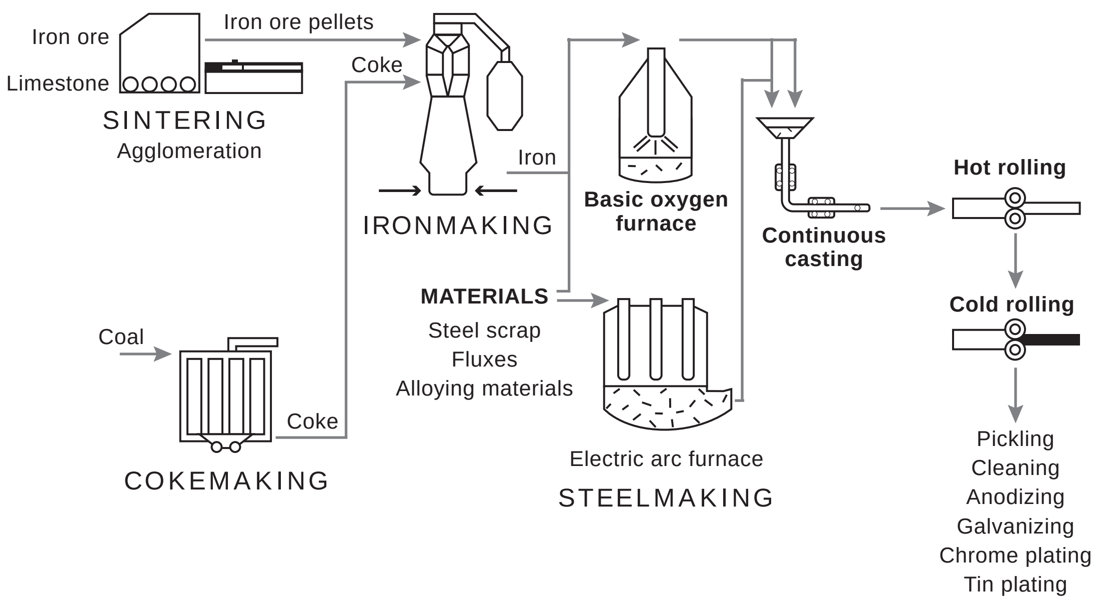
Also note that CO_2 emissions from CRF category 2.C.2, Ferroalloys Production, are included in CRF category 2.C.1.a, Steel Production, since production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace process using reductants. However, disaggregation of the reductant portion (i.e., metallurgical coke) is not available and therefore these emissions are included in CRF category 2.C.1.b, Pig Iron Production.

A3.3.3. CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use

Industrial activities in Canada that use fuel for non-energy purposes (e.g., feedstock material) include ammonia production, petrochemical production, non-ferrous mining and processing, iron and steel production, and other chemical industries.

CO_2 emissions from non-energy use of hydrocarbons—which are not reported elsewhere in the inventory—are reported under the category of Non-energy Products from Fuels and Solvent Use. The emission estimates are based on non-energy fossil fuel use data collected by Statistics Canada (*Report on Energy Supply and Demand in Canada* [RESD] [Statistics Canada 1990–2019]) and aggregated by fuel type (e.g., natural gas, coke, butane, ethane, etc.) at the provincial/territorial level. Statistics Canada does not disaggregate this fuel data by industry

Figure A3.3–1 **Canadian Steelmaking Processes**



or industrial activity, which means that without other supporting information, it is not possible to allocate this fuel data to a specific industry.

In some cases, Canada has obtained supporting information (e.g., through studies, surveys, other data sources, etc.) such that all or part of the non-energy fuel use data can be disaggregated and allocated to the appropriate source category. Allocation of non-energy fuel use data to specific source categories is possible for the following industrial activities:

- natural gas used to produce hydrogen for ammonia production
- various fuels used as feedstock in the production of petrochemicals (methanol, ethylene and ethylene dichloride)
- carbon anodes used to electrically reduce alumina to aluminium in the aluminium production process
- coke used in iron and steel production

For these industrial activities, known or estimated non-energy fuel types and quantities are used in estimating emissions. The known or estimated fuel quantities are then subtracted from the RESD non-energy fuel use data, and the remaining (residual) fuel quantities represent the non-energy fuel used by other industries. This avoids double counting of emissions and improves transparency in the inventory.

To estimate emissions, average national level CO_2 emission factors are available for each fuel type and are applied to the total non-energy fuel quantities (or residual quantities, if applicable) at the provincial/territorial level. Provincial/territorial estimates are then aggregated to provide a national total for CRF source category 2.D, Non-energy Products from Fuels and Solvent Use.

The following describes the methods used to estimate emissions for each category of non-energy use of fossil fuels (gaseous, solid and liquid fuels) and, where possible/applicable, explains how emissions are disaggregated and allocated to specific source categories (previously mentioned) in order to avoid double counting of emissions.

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas. Natural gas can be used for methanol and thermal carbon black production; however, a large portion is used in the SMR process to manufacture ammonia.

CO_2 emissions from ammonia production and methanol production are estimated and reported in CRF source categories 2.B.1 and 2.B.8.a, respectively. The quantities of natural gas used as feedstock in ammonia and methanol manufacturing are subtracted from the RESD's overall non-energy natural gas to determine the remaining (residual) quantity of non-energy natural gas.

Based on a study conducted in 2005 (Cheminfo Services, 2005a), a CO_2 emission factor for the residual non-energy use of natural gas was developed (38 g CO_2/m^3) and applied to the residual non-energy natural gas quantity to estimate emissions from this source.

Note that emissions arising from non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy sector of the inventory.

Solid Fuels

Solid fuels considered in the Non-energy Products from Fuels and Solvent Use category are:

- Canadian bituminous coal
- sub-bituminous coal
- foreign bituminous coal
- lignite
- anthracite
- metallurgical coke
- petroleum coke

CO_2 emissions from the non-energy use of these solid fuels are determined by applying the fuel-, province- and/or year-specific emission factors presented in tables A6.1–6, A6.1–9 and A6.1–10 of Annex 6 for petroleum coke, coal and metallurgical coke (coke from coal), respectively, to the RESD data.

The emission factors used for estimating releases of CO_2 from the non-energy use of coal are the same as those for combustion; it is assumed that 100% of the carbon in these products will eventually be oxidized and emitted as CO_2.

CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are reported in CRF source category 2.C.3, Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. Non-energy coke is also used to make electrodes used in electric arc furnaces in the iron and steel industry (CRF source category 2.C.1, Iron and Steel Production). The quantities of petroleum coke used in the aluminium industry and iron and steel industry are subtracted from the RESD's overall non-energy use of petroleum coke. The CO_2 emissions from the residual non-energy petroleum coke use are calculated by applying the emission factors provided in Table A6.1–6 of Annex 6.

Liquid Fuels

In addition to the emissions from gaseous and solid fuels, CO_2 emissions from the non-energy use of liquid fuels (natural gas liquids (NGLs), oil refinery petrochemical feedstocks and lubricants) are also reported in CRF category 2.D, Non-energy Products from Fuels and Solvent Use.

CO_2 emissions resulting from the use of liquid fuels (feedstock use) in the production of ethylene are estimated and reported in CRF source category 2.B.8.b. The quantities of liquid fuels (specifically propane, butane, ethane, petrochemical feedstocks) used as feedstock in the production of ethylene are subtracted from the RESD's overall non-energy liquid fuels. The remaining quantities of non-energy liquid fuels are multiplied by the corresponding emission factors, as shown in Table A6.2–9 in Annex 6 to estimate CO_2 emissions from this source.

It should also be noted that, owing to the way in which energy statistics are currently collected in Canada, a portion of non-energy use of liquid fuels has been reported under energy use, which is accounted for in the Energy sector.

In the case of the residual non-energy use of NGLs—i.e., residual of petrochemical production use—the emission factors provided in the McCann (2000) study assume that all the carbon is oxidized and are presented in Table A6.2–9 in Annex 6.

The residual and non-residual non-energy use of petroleum products coming out of the oil refineries (i.e., petrochemical feedstocks, naphthas, lubricants, greases and other petroleum products) also results in CO_2 emissions and is accounted for in the Non-energy Products from Fuels and Solvent Use category. Derivations of the non-energy use emission factors are shown in Table A6.2–9 in Annex 6. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

A3.3.4. HFC Emissions from Product Uses as Substitutes for Ozone Depleting Substances (ODS)

A3.3.4.1. Activity Data

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by EC in 1996.[9] The Department revised subsequent surveys to obtain more detailed activity data for later years. The 1998, 1999, 2001 and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 emails from Y. Bovet and Y. Guilbault).[10] In some cases, one survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services, 2005b). These data were provided by market segment, such that the total quantity used for each type of application could be determined. HFC import and sales data for 2005–2010[11] were collected by EC through a voluntary data submission process, whereby requests for data were sent to the main importers of bulk HFCs and to companies that import/export manufactured items containing HFCs. For 2009, the distribution list for data collection was expanded, as EC became aware of other importers/exporters in the market (either importers of bulk HFCs or importers/exporters of manufactured items containing HFCs) by looking at HFC import data collected by the Canada Border Services Agency (CBSA).[12] Information on HFC-245fa received in these surveys were incorporated for bulk HFCs from 2001 to 2007 and for manufactured items containing HFCs for 2010. Data sets from 1995 to 2000 were verified for use, import and export of HFC-245fa, and no instances were found. Where data were unavailable, the quantities were extrapolated to the current inventory year.

In 2014, EC performed a mandatory survey of bulk importers for the data years 2008 to 2012, and the results of the survey (ECCC 2015a) were incorporated into the inventory. Where duplicate reporting occurred between the mandatory and voluntary surveys, the mandatory survey was chosen for the inventory due to the legal reporting requirements.

In 2016, Environment and Climate Change Canada (ECCC) performed mandatory surveys of bulk importers (ECCC, 2016a, 2016b) for the data years 2013–2014 and 2015, which have been included in the inventory. No surveys were performed for the 2016 data year.

In 2018, 2019 and 2020, ECCC collected bulk import and export HFC data for the data years 2017, 2018 and 2019 respectively, under the mandatory reporting system set out under the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* (ODS Regulations), which came into force December 29, 2016 (ECCC, 2018). Updates to the mandatory surveys of bulk importers for the data years 2008–2015 were also received and implemented in this submission.

Table A3.3–2 shows the years where there are activity data for bulk HFC imports and exports, the years when the activity data were collected, and the source of the data. Table A3.3–3 shows the years where there are activity data for imported and exported manufactured items containing HFCs, the years when the activity data were collected, and the source of the data.

9 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). Use Patterns and Control Implementation Section.

10 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). Use Patterns and Control Implementation Section.

11 Except for 2010, data collected by EC on bulk HFCs only covered sales. However, with no Canadian production existing for HFCs and an insignificant amount of exports, the import values should theoretically be close to the sales values.

12 It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as they are collected and categorized only under three types: HFC-134a, HFC-152a and others. Also, the data are not presented by use type. However, company-specific data from the CBSA are a useful tool for data verification and for expanding the distribution list for the HFC data collection.

Table A3.3–2 **Years of Activity Data for Bulk HFC Imports and Exports, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1995	1996	Mandatory survey from UPCIS
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
1999	2001	Mandatory survey from UPCIS
2000	2001	Mandatory survey from UPCIS
2001	2005	Voluntary survey from Cheminfo Services
2002	2005	Voluntary survey from Cheminfo Services
2003	2005	Voluntary survey from Cheminfo Services
2004	2005	Mandatory survey from UPCIS
2008	2014	Mandatory survey from section 71 of CEPA 1999
2009	2014	Mandatory survey from section 71 of CEPA 1999
2010	2014	Mandatory survey from section 71 of CEPA 1999
2011	2014	Mandatory survey from section 71 of CEPA 1999
2012	2014	Mandatory survey from section 71 of CEPA 1999
2013	2016	Mandatory survey from section 71 of CEPA 1999
2014	2016	Mandatory survey from section 71 of CEPA 1999
2015	2016	Mandatory survey from section 71 of CEPA 1999
2017	2018	Mandatory survey from ODS Regulations of CEPA 1999
2018	2019	Mandatory survey from ODS Regulations of CEPA 1999
2019	2020	Mandatory survey from ODS Regulations of CEPA 1999

Table A3.3–3 **Years of Activity Data Imported and Exported Manufactured Items Containing HFCs, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
2004	2005	Mandatory survey from UPCIS
2005	2006	Voluntary survey from UPCIS
2006	2007	Voluntary survey from UPCIS
2007	2008	Voluntary survey from UPCIS
2008	2009	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2009	2010	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2010	2011	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2011	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2012	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2013	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2014	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2015	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999

A3.3.4.2. Methodology

Canada uses a relatively detailed sector breakdown of HFC sub-applications (Table A3.3–4), requiring that the HFC use data be broken down at this level annually. To meet this requirement, missing data had to be filled in, and data collected at an application level had to be broken down to sub-application levels.

A variety of techniques were used to fill in the data gaps from reporters between voluntary surveys. For instance, when a company did not report in subsequent years, the data were held constant. Another technique employed for years in which no surveys were performed (e.g., imports/exports of manufactured items from 1999 to 2003) was the use of linear interpolation to estimate the missing data.

To meet the requirements of a Tier 2 methodology, ECCC used two approaches to break down the 1995 to 2004 application- level data to the sub-application level. In a given year, the HFCs reported at an application level were broken down based on the proportions of the corresponding sub-application levels if a large amount of HFCs were reported in those corresponding sub-application levels in the same year. If sufficient breakdown was not available for the year and application level, the breakdown from the closest historical year for the same HFC and application level was used.

For the 2008 to 2012 mandatory survey data, the HFCs reported at an application level were broken down based on the 2004 breakdown. The 2004 data were used because the breakdown for this year was the most complete and is currently the best information available. For the 2013 to 2015 data from the mandatory surveys, the HFCs reported at an application level were broken down to sub-application levels based on the 2012 breakdown and, when sufficient information was not available, on the 2004 breakdown. For some of the 2008–2015 data, when bulk importers had initially only reported HFCs (by HFC type) without specifying the associated applications or sub-applications, the surveyed bulk importers were asked to provide, to the best of their knowledge, a list of sub-application levels for the reported HFCs. This list of sub-applications was then used by ECCC to evenly distribute the reported HFC quantities.

For the 2017 to 2019 bulk import and export data collected under the ODS Regulations, all the reported data needed to be broken down to sub-application levels. The 2015 breakdown was determined to be the most appropriate because it was the most recent mandatory survey where breakdowns by sub-application were available.

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Table A3.3–4 **Canadian HFC Applications and Sub-Applications**

Application/Sub-Application Description
Aerosols
Personal care products
Pharmaceutical products
Medical products
Household products
Mining application products
Commercial/industrial products
Blowing Agent in Foams
Cushioning – automobiles (seats, roof, etc.)
Cushioning – other (furniture, mattresses, etc.)
Thermal insulation – homes and buildings
Thermal insulation – pipes
Thermal insulation – refrigerators and freezers
Thermal insulation – other (specify)
Packaging – food (specify)
Packaging – non-food (specify)
Other foam uses (specify)
Air Conditioning (Original Equipment Manufacture)
Air conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Air Conditioning (Service/Maintenance)
Air conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Refrigeration (Original Equipment Manufacture)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, process equipment, etc.)
Residential (freezers, refrigerators)
Other equipment (specify)
Refrigeration (Service/Maintenance)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, processes, etc.)
Residential (refrigerators, freezers, etc.)
Other equipment (specify)
Solvent
Electronic industry
Metal cleaning/drying
Dry cleaning
Laboratory solvent
General cleaning (specify)
Fire Suppression/Extinguishing Systems (Original Equipment Manufacture)
Portable (mobile) systems
Total flooding (fixed) systems
Fire Suppression/Extinguishing Systems (Service/Maintenance)
Portable (mobile) systems
Total flooding (fixed) systems
Miscellaneous
Hospital/institutional sterilizing
Leak testing
Other (Specify)

For the information on new HFCs received under the ODS Regulations, existing breakdowns of an application to the sub-application level of other HFCs (generally HFC-134a) were used.

The bulk import and export data collected through voluntary submission for the 2005 to 2007 data years were considered incomplete and were therefore estimated using linear interpolation between the 2004 and 2008 data years.

The 1995 data on the quantities of HFCs contained in imported and exported manufactured items, except imported and exported vehicles, were not available. Therefore, the 1996 to 1998 results were used to linearly extrapolate back to 1995. For 1999–2003, these quantities were linearly interpolated from the data available in 1998 and 2004.

The data were reviewed with respect to time series consistency according to Volume 1, Chapter 5, Section 5.3.3.4 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and some gaps were noted for data on bulk imports and exports and on imported and exported manufactured items containing HFCs. The 2016 data year is a year for which bulk import and export data do not exist, and the 2011 to 2019 data years are years for which a complete set of data on imported and exported manufactured items containing HFCs does not exist. Extrapolation using proxy variables were applied to fill in the data gaps as required. Table A3.3–5 lists the various proxy variables applied for the extrapolation process.

Table A3.3–5 **Proxy Variables Used for HFC Trend Extrapolation**

Proxy Variable Description
Commercial floor space
Residential floor space
Population
Gross domestic product
Gross output for the following categories:
Computer and Electronic Products Manufacturing
Fabricated Metal Products
Food
Furniture and Related Products
Health Care and Social Assistance
Mining (excluding Oil, Gas and Coal)
Other Manufacturing
Other Services (excluding Public Administration)
Professional, Scientific and Technical Services
Transportation Equipment

A3.3.4.3. Emission Factors and Lifetimes

In 2013, EC conducted a survey of the air-conditioning and refrigeration applications to obtain information for developing emission factors.

The information was reviewed ([EHS 2013; ECCC 2015b), in accordance with the quality control measures set out in Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006. The emission factors developed using the collected information were also compared to default emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006 and most were found to be within the same range. Some emission factors (e.g. end-of-life decommissioning) did not meet the quality control checks from Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006 for expert elicitation; values were therefore chosen within the range of emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006, guided by other information such as the regulatory environment in Canada. These emission factors have been applied to the whole time series from 1995 onwards.

The emission factors for the sub-application of "Other equipment" under Refrigeration—a mix of specialty applications—were derived through a weighted average of the emission factors from the other specific refrigeration sub-applications.

For the air conditioning and refrigeration applications, the expected lifetimes applied in the emission estimations were chosen based on the survey results and the information published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006.

For the remaining HFC applications, emission factors and lifetimes were chosen from Volume 3, Chapter 7 of IPCC 2006.

Table A6.2–11 in Annex 6 presents the emission factors used to estimate the HFC emissions.

A3.3.4.4. Emission Estimations

The net consumption of a HFC in a specific sub-application are calculated using Equation A3.3–4. This equation is a modified version of Equation 7.1 from Volume 3, Chapter 7 of IPCC 2006 that has been adapted to the Canadian context. The total quantity of each HFC that remains in products after assembly, in-service and end-of-life losses, also known as a HFC bank, is also calculated.

Equation A3.3–4

$$C_{net,i} = IM_{bulk,i} + IM_{manufacture,i} - EX_{manufacture,i}$$

$C_{net,i}$ = net consumption of HFC i, kg

$IM_{bulk,i}$ = imports of bulk of HFC i, kg

$IM_{manufacture,i}$ = imports of manufactured items of HFC i, kg

$EX_{manufacture,i}$ = exports of manufactured items of HFC i, kg

Annual emissions for each applicable lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. It is assumed that once an item is manufactured, the technology and its inherent in-service emissions rate will remain constant throughout its lifetime. The in-service emission estimate takes into consideration the quantity of HFC that has already been emitted during the assembly stage. Likewise, the emission estimate from the end-of-life of the product is based on the quantity of HFC available after the assembly and in-service emissions have taken place and on the corresponding emission factor for the sub-application. The end-of-life emission factor used also considers regulations in place at the time of decommissioning.

The following sections explain the HFC emission estimation equations applied for each unique application/sub-application in more detail.

A3.3.4.4.1. HFC Emissions from Aerosols

HFC emissions from aerosols application are estimated using Equation A3.3–5, which is Equation 7.6 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–5

$$EA_t = (A_t \times EF_A) + (A_{t-1} \times (1 - EF_A))$$

EA_t = emissions from aerosols in year t, tonnes

A_t = quantity of HFC contained in aerosol products sold in year t, tonnes

A_{t-1} = quantity of HFC contained in aerosol products sold in year t-1, tonnes

EF_A = in-service emission factor for aerosols, fraction

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A3.3.4.4.2. HFC Emissions from Blowing Agent in Open-cell Foams

HFC emissions from open-cell foam blowing are estimated using Equation A3.3–6, which is Equation 7.8 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–6

$$EOCF_t = M_t$$

$EOCF_t$ = emissions from blowing agent in open-cell foams in year t, tonnes

M_t = quantity of HFC used in manufacturing new open-cell foams in year t, tonnes

A3.3.4.4.3. HFC Emissions from Blowing Agent in Closed-cell Foams

HFC emissions from closed-cell foam blowing are estimated using Equation A3.3–7, which is a modified version of Equation 7.7 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on recovery and destruction of HFCs in closed-cell foams and their blowing agents is available.

Equation A3.3–7

$$ECCF_t = (CCF_t \times (EF_A + EF_{IS})) + (CCFBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$ECCF_t$ = emissions from blowing agent in closed-cell foams in year t, tonnes

CCF_t = quantity of HFC used in manufacturing new closed-cell foams in year t, tonnes

EF_A = assembly emission factor for closed-cell foams, fraction

$CCFBank_{t-n}$ = quantity of HFC charged into closed-cell foam manufacturing between year t and year t-n, tonnes

EF_{IS} = in-service emission factor for closed-cell foams, fraction

DL_t = decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the product/equipment is scrapped, tonnes

EF_{EOL} = end-of-life emission factor for closed-cell foams, fraction

n = product lifetime of closed-cell foam

t = current year

A3.3.4.4.4. HFC Emissions from Air Conditioners and Refrigerators Manufactured in Canada

HFC emissions from air conditioning and refrigeration equipment manufactured in Canada are estimated using Equation A3.3–8, which is a modified version of Equation 7.10 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–8

$$EACROEM_t = (ACROEM_t \times (EF_A + EF_{IS})) + (ACROEMBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EACROEM_t$ = emissions from air conditioners or refrigerators manufactured in Canada in year t, tonnes

$ACROEM_t$ = quantity of HFC used in manufacturing new air conditioners or new refrigerators in year t, tonnes

EF_A = assembly emission factor for new air conditioners or new refrigerators, fraction

$ACROEMBank_{t-n}$ = quantity of HFC charged into air conditioners or refrigerators between year t and year t-n, tonnes

EF_{IS} = in-service emission factor for air conditioners or refrigerators, fraction

DL_t = decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the air conditioner or refrigerator is scrapped, tonnes

EF_{EOL} = end-of-life emission factor for air conditioners or refrigerators, fraction

n = product lifetime of air conditioner or refrigerator

t = current year

A3.3.4.4.5. HFC Emissions from Air Conditioners and Refrigerators Manufactured Elsewhere

Equation A3.3–8 is applied for estimating HFC emissions from air conditioners and refrigerators manufactured elsewhere, except that the assembly emission factor in this case is zero.

A3.3.4.4.6. HFC Emissions from Solvents

HFC emissions from solvents are estimated using Equation A3.3–9, which is a modified version of Equation 7.5 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on destruction of HFCs used as solvents is available.

Equation A3.3–9

$$ES_t = (S_t \times EF_S) + (S_{t-1} \times (1 - EF_S))$$

ES_t = emissions from solvents in year t, tonnes

S_t = quantity of HFC contained in solvents sold in year t, tonnes

S_{t-1} = quantity of HFC contained in solvents sold in year t-1, tonnes

EF_S = in-service emission factor for aerosols, fraction

A3.3.4.4.7. HFC Emissions from Fire Suppression and Extinguishing Systems

HFC emissions from fire suppression/extinguishing systems are estimated using Equation A3.3–10, which is a modified version of Equation 7.17 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on the destruction of HFCs used in fire suppression and extinguishing systems is available.

Equation A3.3–10

$$EFSES_t = ((FSES_t + FSESBank_{t-n})) \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EFSESM_t$	=	emissions from fire suppression and extinguishing systems in year t, tonnes
$FSES_t$	=	quantity of HFC used in fire suppression and extinguishing systems in year t, tonnes
$FSESBank_{t-n}$	=	quantity of HFC charged into fire suppression and extinguishing systems between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for fire suppression and extinguishing systems, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the fire suppression and extinguishing system is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for fire suppression and extinguishing systems, fraction
n	=	product lifetime of fire suppression and extinguishing system
t	=	current year

A3.3.4.4.8. HFC Emissions from Miscellaneous and Other Applications

HFC emissions from miscellaneous and other application are estimated using Equation A3.3–11, which is Equation 7.18 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–11

$$EMOA_t = (MOA_t \times EF_{MOA}) + (MOA_{t-1} \times (1 - EF_{MOA}))$$

$EMOA_t$	=	emissions from miscellaneous and other applications in year t, tonnes
MOA_t	=	quantity of HFC contained in miscellaneous and other products sold in year t, tonnes
MOA_{t-1}	=	quantity of HFC contained in miscellaneous and other products sold in year t-1, tonnes
EF_{MOA}	=	in-service emission factor for miscellaneous and other products, fraction

A3.3.4.4.9. Total Annual HFC Emission Estimations

The total annual emission estimates for each HFC are derived by summing the emissions from all applicable applications. Once the total annual emission estimates at the national level are obtained, they are distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration and number of households for residential refrigeration.

A3.3.5. SF_6 Emissions from Electrical Equipment

A3.3.5.1. Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF_6 emissions (for 2006–2019), the Canadian electricity industry uses a method derived from the basic Tier 3 IPCC 2006 life-cycle Equation 8.10 (Volume 3), as explained in the following sections.

A3.3.5.1.1. Equipment Manufacturing Emissions

According to some utilities, electrical equipment purchased by the Canadian electricity sector is manufactured in the United States, Europe or Asia and hence emissions associated with manufacturing would have occurred mainly outside of Canada.

A3.3.5.1.2. Equipment Installation Emissions

SF_6 equipment is delivered to utilities pre-charged with some SF_6 and charged to full capacity at the time of installation. In the Canadian electricity industry, the potential for SF_6 emissions during equipment installation is considered to be extremely low. A vacuum hold check is typically performed prior to the installation of new equipment to ensure that the equipment is gas tight.

A3.3.5.1.3. Equipment Use Emissions

The primary source of SF_6 releases is associated with the cumulative minute releases that occur during normal equipment operation. Gas releases could potentially occur during gas handling and transfer operations, although such releases would be significantly smaller in magnitude than emissions that occur during normal operations.

Due to the SF_6 leakage that occurs during the above circumstances, utilities are required to “top-up” their equipment to keep it properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

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A3.3.5.1.4. Equipment Decommissioning and Failure Emissions

During the decommissioning of retired equipment, SF_6 gas must be recovered from the retired equipment prior to disposal. As SF_6 gas releases may occur as a result of the way in which the gas is transferred out of the equipment during gas recovery, decommissioning of retired equipment becomes a potential source of SF_6 releases.

When catastrophic failures of equipment occur, a significant amount of SF_6 leaks out of the equipment. Equipment damage is therefore a potential source of emissions.

Retired equipment and damaged equipment that cannot be repaired are sent off-site for disposal.

A3.3.5.1.5. Emissions from SF_6 Recycling

When SF_6 gas is recovered from equipment, it is filtered through a gas cart or other filtering equipment to remove moisture and impurities before it is reused. When SF_6 gas has been contaminated with air and impurities and has a purity of less than a certain level (the acceptable level can vary between 95% and 99%, depending on utility practices), it cannot be reused and is sent for off-site purification in the United States. There are no facilities in Canada that perform SF_6 gas purification. One of the methods utilized to purify SF_6 gas is the use of a cryogenic process to separate and remove the air/nitrogen from the SF_6 gas. The purification of SF_6 gas does not produce SF_6 emissions. Hence, emissions from SF_6 recycling are eliminated from the calculation of total emissions.

Given the reasoning above, the Canadian electricity industry uses a modified, country-specific Tier 3 IPCC approach to estimate SF_6 releases. Only emissions from equipment use and equipment decommissioning and failure are calculated, as shown in Equation A3.3–12.

Equation A3.3–12

$$\textit{Total utility } SF_6 \textit{ emissions} = \sum \textit{Equipment use emissions} + \sum \textit{Equipment decommissioning and failure emissions}$$

A3.3.5.2. Methodology – Quantifying Equipment Use Emissions

Emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and during normal operation of the equipment. In order to keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped. This amount is referred to as a “top-up.”

Leakages of SF_6 are also seen during maintenance/repair activities. When equipment needs to be repaired or sent for maintenance, the SF_6 gas is recovered from it and, once the equipment is repaired, it is refilled with the SF_6 gas that was recovered. There will be an additional amount needed to refill the equipment, since some gas may have escaped due to normal operations and during the transfer of the recovered gas from the equipment to gas carts (or storage cylinders) and back to the equipment. It is this additional/incremental amount of SF_6 gas that is referred to as the “top-up.” Hence, an accurate estimate of the amount of SF_6 released is the amount used by utilities to top up their equipment during the equipment use stage.

A3.3.5.2.1. Options for Tracking SF_6 Consumed for Top-ups

The following is a list of options for Canadian electric utilities to track the amount of SF_6 that is used for top-up purposes in order to quantify emissions of SF_6 from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top-ups, and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. Each utility will have discretion over which method to use. Canadian electric utilities may track the amount of SF_6 that is used annually for top-up purposes (i.e., the amount that has been emitted) by using mass flow meters or a mass balance, or by counting the number of cylinders consumed.

For all of these tracking options, it is assumed that the quantities of SF_6 tracked do not include the gas used to pressurize the new switchgear to its full capacity at time of installation. Quantities of gas used for pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (see also A3.3.5.1.2, Equipment Installation Emissions).

Option 1: Mass Flow Meters

Mass flow meters provide the most accurate method for measuring the quantity of SF_6 consumed during each equipment top-up operation. The sum of all measured quantities during top-up operations will be used to determine the equipment use emissions.

Option 2: Mass Balance

Utilities may choose to weigh their SF_6 cylinders to determine the quantity of SF_6 consumed for top-up operations. The difference in mass of the cylinders can be determined either every time there is an equipment top-up operation or on an inventory basis. Utilities must also account for any purchases or additions to the inventory, the weight of SF_6 cylinders returned to suppliers, and the quantity of SF_6 sent off-site for recycling or destruction during the year. When using a mass balance, utilities should ensure that the accuracy of the weigh scale is compatible with the weight of the cylinders to be weighed. For example, utilities should use a scale accurate to ±1 kg, rather than ± 5 kg, to weigh a 50-kg cylinder.

Option 3: Cylinder Count

In the absence of mass flow meters or weigh scales, utilities may choose to rely on information from supplier or inventory records and from purchase receipts to obtain the number and weight of SF_6 cylinders purchased for top-up purposes. The mass of SF_6 consumed can be assumed to be equal to the amount of SF_6 purchased in a year or equal to the change in maintenance inventory.

The weight of SF_6 found in different types of cylinders should be known. Therefore, utilities can simply obtain the weight of SF_6 consumed for top-up purposes by performing a cylinder count. If more than one type of cylinder is used, utilities must ensure that the number of cylinders of each type is multiplied by the cylinder weight for that type. The products obtained for all cylinder types are then summed together to give the total SF_6 use.

A3.3.5.3. Methodology – Quantifying Equipment Disposal and Failure Emissions

Equipment disposal and failure emissions include emissions from decommissioning of retired equipment and emissions that result from the rare event of catastrophic equipment failures.

In the decommissioning of retired equipment, SF_6 losses occur as gas is being recovered from the retired equipment. Emissions can be estimated by taking the difference between the nameplate capacity of the equipment and the recovered amount of SF_6.

Equation A3.3–13

$$\text{Equipment decommissioning emissions} = \text{Nameplate capacity of retired equipment} - SF_6 \text{ amount recovered from retired equipment}$$

The value of nameplate capacity (in mass units) can be obtained from equipment specifications provided by the equipment manufacturer or from sound engineering estimates. The amount of recovered SF_6 gas is weighed.

When equipment failure or damage occurs to the point where it cannot be repaired, it is assumed that the nameplate capacity of the equipment is representative of the emissions that have taken place as a result of equipment failures.

The information provided in this section (5) is extracted from the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* (ECCC and Canadian Electricity Association 2008), available at http://www.publications.gc.ca/site/eng/454401/publication.html. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to ECCC, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

A3.3.5.4. Data Sources

The SF_6 emissions by province for 2006–2019 were provided by the Canadian Electricity Association and BC Hydro.

A3.4. **Methodology for the Agriculture Sector**

Overview of Agricultural Emission Methodologies

This section of Annex 3 describes the estimation methodologies, equations, activity data, emission factors and parameters that are used to derive the greenhouse gas (GHG) estimates in the Agriculture sector, namely:

- methane (CH_4) emissions from enteric fermentation
- CH_4 and nitrous oxide (N_2O) emissions from manure management and field burning of agricultural residues
- N_2O emissions from agricultural soils (direct emissions, indirect emissions and animal manure emissions on pasture, range and paddock)
- carbon dioxide (CO_2) emissions from agricultural use of lime and urea

The sources of animal population data required to calculate agricultural emissions of CH_4 and N_2O are presented in section A3.4.1. The methods used to calculate agricultural GHG emissions are described in sections A3.4.2 to A3.4.8. Note that agricultural soils also emit and sequester CO_2, but these sources/sinks are reported in the Land Use, Land-Use Change and Forestry (LULUCF) sector (see Annex 3.5).

Livestock and crop production are integrated systems that interact in the production of GHG emissions. The GHG estimation methodology described in Annex 3.4 begins with an estimation of emissions related to livestock production, followed by emissions related to crop production (Figure A3.4–1). All approaches prescribed by IPCC (2006) for calculating emissions follow the basic formula of "activity data" x "emission factor." In the case of agricultural emissions, "activity data" refers mainly to the number of animals or amount of nitrogen applied to soils. "Emission factor" is an average emission rate for a specific GHG from a given source, relative to a unit of activity data. The calculation of emissions is sequential because activity data in the form of nitrogen are passed from the livestock system to the cropping system and nitrogen is tracked as it moves from one source to another.

Livestock emissions are primarily driven by animal populations, but emission factors are dependent on other drivers. The quality and quantity of animal feed influences how quickly animals grow and how much they produce (milk production for example) but animal feed also affects the amount of methane that is produced by an individual animal and how much manure (and therefore both carbon and nitrogen) they excrete back into the environment. As a result, feed quality and animal productivity can be drivers that change livestock emission factors over time. Furthermore, changes in manure management infrastructure (for manure storage and spreading), or farming practices such as changes to the amount of time animals spend on pasture, may further alter the quantity or profile of emissions. Therefore, activity data changes from year to year, but so do emission factors in some cases.

Livestock estimation methodologies used in the NIR can generally be grouped into four categories: (1) dairy, (2) beef (non-dairy), (3) swine, and (4) all other animals (Figure A3.4–1). For the beef category, emission estimates from the process of enteric fermentation and management of animal manure are based on IPCC Tier 2 methodologies populated with country-specific parameters collected through an expert consultation (Boadi et al., 2004a; Marinier et al., 2004), and animal production data in the form of carcass weight increase (Agriculture and Agri-Food Canada, n.d.). For the dairy category, the expert consultation was improved by the introduction of better feed data and production data, and the introduction of information derived from Statistics Canada's farm environmental survey data. For the "swine" and "all other animals" categories, the default IPCC tier 1 methodology is used to estimate emissions from the process of enteric fermentation. Emissions from the management of swine manure are estimated using a Tier 2 methodology based on expert consultation data (Marinier et al., 2004), animal production data in the form of carcass weight increases, and information derived from farm environmental surveys. For most other livestock, emissions from the management of manure emissions are calculated based on expert consultations or IPCC Tier 1 methods.

N_2O emissions from crop production on agricultural soils are primarily driven by nitrogen fertilizer sales and annual crop yields, but where and how much nitrogen is applied to the land are also influenced by nitrogen from manure and human biosolids. A combination of activity data (animal populations) and drivers feed quality and quantity; animal productivity and manure management infrastructure influence the total quantity of nitrogen that is passed from the livestock system to agricultural soils and the amount of nitrogen lost to the environment during these transfers.

Spatially, nitrogen is distributed to agricultural ecodistricts, which represent one level within Canada's National Ecological Framework. The country is divided into 1027 ecodistricts, characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna. Application rates are calculated as a function of the total manure N in the ecodistrict and crop requirements, which are then adjusted to provincial fertilizer sales as outlined in section A3.4.5. A country-specific emission factor for agricultural soils is calculated for each ecodistrict (section A3.4.5.1) that is adjusted based on the topography, soils and climate of the ecodistrict, as well as management practices such as tillage, summerfallow and irrigation. Emissions are then calculated from the amount of nitrogen applied to the soil, multiplied by the unique emission factor for the ecodistrict in which it was applied. The quantity of emissions that results from a given unit of nitrogen added to soils therefore varies by ecodistrict. Sources of nitrogen include inorganic fertilizers, organic fertilizers and crop residue (nitrogen contained in plant matter remaining in fields after harvest).

Nitrogen is tracked throughout the process of crop production and ammonia losses after application of fertilizer and manure to croplands are calculated at a Tier 2 level for fertilizer and manure nitrogen from dairy and swine (Tier 1 IPCC default loss factors are used for all other animals). Indirect emissions of N_2O from nitrogen that is lost from the agriculture system are estimated using Tier 1 IPCC 2006 emission factors (section A3.4.5.2).

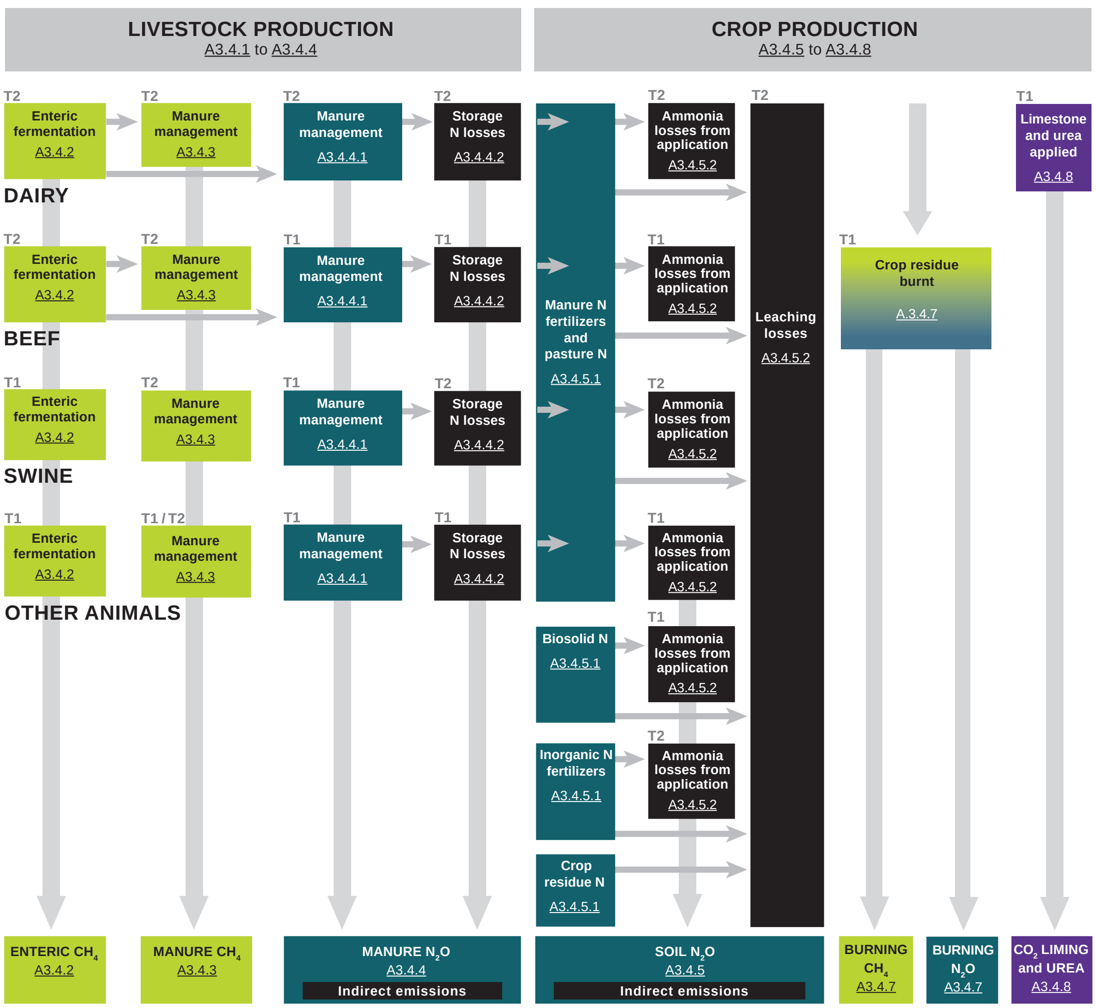
Minor emission sources, such as CO_2 emissions from agricultural use of lime and urea and CH_4 and N_2O emissions from field burning of agricultural residues, are described in sections A3.4.8 and A3.4.7, respectively.

A3.4.1. Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. Livestock and poultry populations, by animal subcategory and by province, were obtained from Statistics Canada and other sources, as described in Table A3.4–1.

Annual cattle, sheep and swine populations are presented as the simple mean of semi-annual or quarterly surveys. These smaller surveys are corrected by Statistics Canada to the *Census of Agriculture* (COA) population estimates, which are collected every five years, to assure the accuracy of the estimates.

Figure A3.4–1 **Overview of the Key Methodologies and IPCC Tier Levels Used in Livestock and Crop Production**



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The population estimates for horses, goats, bison,[13] llamas and alpacas, deer and elk, wild boars, rabbits and poultry are taken from the COA exclusively, and annual populations are developed by linear interpolation in order to avoid large changes in census years. Populations of deer and elk, considered new to Canadian livestock production and only reported in the COA for census years beginning in the reporting period, were extrapolated back to zero for the census year previous to their first appearance in the COA. Mule and ass populations were received via personal communication[14] and originate from recently compiled responses to the COA for the years 2001, 2006 and 2011. Mule and ass populations were not compiled prior to the 2001 census year and were assumed to be constant at the 2001 level from 1990 to 2000. Wild boar populations for census years 1991, 1996 and 2016 were received via personal communication[15,16] and were compiled from responses to the COA. Wild boar and buffalo populations were not collected in 1986; thus, the populations were set constant for 1990 at the 1991 level.

13 In the CRF tables, the IPCC animal category Buffalo is used to report values for North American bison (*Bison bison*) raised for meat.

14 Laborde L. 2015. Personal communication (e-mail from Laborde L to Section Head, Agriculture, Forestry and Other Land Uses, dated September 2, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

15 Laborde L. 2016. Personal communication (e-mail from Laborde L to Flemming C, Agriculture, Forestry and Other Land Uses, dated October 26, 2016). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

16 Taylor, P. 2016. Personal communication (e-mail from Taylor P to Flemming C, Agriculture, Forestry and Other Land Use, dated September 21, 2018).

Table A3.4–1 **Animal Categories and Sources of Population Data**

Category	Sources/Notes
Cattle	Statistics Canada. Table: 32-10-0130-01 (formerly: CANSIM 003-0032)—Number of cattle, by class and farm type, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001 (accessed September 29, 2020)
– Dairy Cattle	All cattle used in the production of milk and milk products
– Non-dairy Cattle	All other cattle
Bison, Goats, Horses, Llamas and Alpacas, Deer and Elk	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X), 2011 and 2016 Census of Agriculture: Statistics Canada. Table: 32-10-0427-01 (formerly CANSIM 004-0224). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census
Wild Boars	Census year 2016[a]: Taylor, Patrick (Statistics Canada). Personal communication received September 21, 2018. Census years 2001 to 2011: Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census Census years[a] 1991, 1996: Laborde, Leon (Statistics Canada). Personal communication received October 26, 2016. – linear interpolation between census years, 1990 kept constant from 1991
Mink and Foxes	Statistics Canada. Table 32-10-0116-01 (formerly CANSIM Table 003-0015)—Supply and disposition of mink and fox on fur farms, annual (Number). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210011601 (accessed November 6, 2019). Populations for year 2019 were not available as of November 20, 2020 and as a result the 2018 populations were held constant for 2019.
Mules and Asses[a]	Census year 2016: Laborde, Leon (Statistics Canada). Personal communication received May 16, 2018. Census years 2001 to 2011: Laborde, Leon (Statistics Canada). Personal communication received September 2, 2015. – population held constant prior to 2001 Ccensus, and after the last census
Rabbits	Agriculture and Agri-Food Canada, Red Meat Market Information, Alternative Livestock. https://www.agr.gc.ca/eng/animal-industry/red-meat-and-livestock-market-information/rabbit-industry-at-a-glance/?id=1415860000120 – linear interpolation between census years, remains constant after last census – correction factor applied to isolate the breeding population based on expert opinion from Brian Tapscott, Alternative Livestock Specialist, OMAFRA
Sheep and Lambs	Statistics Canada. Table 32-10-0129-01 (formerly CANSIM 003-0031)—Number of sheep and lambs on farms, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210012901 (accessed September 30, 2020)
Swine	Statistics Canada. Table 32-10-0290-01 (formerly CANSIM 003-0004)—Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). Years 1990–2006. Statistics Canada. Table 32-10-0145-01 (formerly CANSIM 003-0100)—Hogs statistics, number of hogs on farms at end of semi-annual period, (Head). Years 2007–2018. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210014501 (accessed September 30, 2020)
Poultry	Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a])
	Selected historical data from the Census of Agriculture, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada Catalogue No. 95-632). (Statistics Canada [2007b]) 2011 and 2016 Census: Statistics Canada. Table: 32-10-0428-01 (formerly CANSIM 004-0225). Poultry inventory on census day. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042801 (accessed October 22, 2018) – linear interpolation between census years and remains constant after latest census

Note:

a. These data may be affected by errors due to coverage.

The estimates for breeding mink and fox populations are taken from an annual Statistics Canada survey titled *Supply and Disposition of Mink and Fox on Fur Farms*, which provides the number of foxes and mink on farms for January 1 of the survey year. Rabbit populations were taken from responses to the COA as provided on the AAFC Red Meat Market website (see Table A3.4–1), but were modified based on expert opinion[17] using a correction factor in order to estimate the number of does, as opposed to total rabbits.

To populate an IPCC Tier 2 enteric fermentation model for the Beef and Dairy sectors, the subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into subannual production stages (i.e., “production subcategory”) to isolate and quantify the effect of specific production practices on gross energy intake and, as a consequence, CH_4 emissions. Data to describe the production environment and associated performance of classes of animals were collected from a combination of sources, including: (1) production and management practices published in scientific journals; (2) a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy livestock specialists across the country; (3) consultation with scientists at universities and federal research institutions; and (4) provincial/national associations and provincial/regional performance-recording organizations (Boadi et al., 2004a).

These data were used to create an annual cattle production model that takes into account regional and seasonal variations in production practices. The eight cattle subcategories were broken down into 38 distinct cattle production stages—29 for the Beef sector and 9 for the Dairy sector—observed throughout the different provinces of Canada (Table A3.4–2). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment. Further work on the Dairy sector was implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters. This update created a time series datum that better captures changes in production practices in the Dairy sector and introduced an analysis of changes in dairy nutrition considering more recent Canadian and North American research (Ellis et al., 2007; Ellis et al., 2010; Sheppard et al., 2011a; Sheppard et al., 2011b; Vanderzaag et al., 2013; Appuhamy et al., 2016; Chai et al., 2016; Jayasundara et al., 2016).

The feeding practices for Beef and Dairy sector livestock are detailed in the next section.

17 Tapscott B. 2015. Personal communication (e-mail from Tapscott B, OMAFRA, to Section Head, Agriculture, Forestry and Other Land Uses, dated September 16, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

Dairy Sector Production and Performance

Dairy production practices vary across the country because of differences in land prices, climate, forage availability and market access. They have also changed significantly between 1990 and the present. The predominant management practices for each province are reflected in the province-specific parameters entered into the IPCC Tier 2 equations for both enteric fermentation and manure management emissions.

Table A3.4–3 provides an example of production performance data collected for the Canadian Dairy sector, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model at the inception of the Boadi et al. (2004a) study. While the basic subcategory classes developed by Boadi et al. (2004a) were accurate for the mid-2000s when the Tier 2 model was populated, it was recognized that certain production parameters were not static over time and that these parameters could impact all aspects of emissions from the sector. Since 1990, with the increase in milk production in the dairy herd, there has also been a shift in the diet of an average dairy cow, both in the quantity and quality of feed consumed.

There are no consistent national data sources for complete dairy feed quality linked to dairy production and performance. However, certain regional and partial resources exist, specifically the feed quality database from Lactanet[18] for parts of Eastern Canada and Cost of Production[19] (COP) surveys for Quebec and Ontario. However, consistent milk production statistics do exist for the entire country. Production statistics identifying the relative proportions of the national dairy herd that fall into high, medium and low productivity classes and are linked to herd characteristics such as farm size are collected,managed and prepared for the inventory by Lactanet.

To develop parameters that link productivity with production practice, the feed quality database developed by Lactanet, consisting of feed data collected and analyzed for more than 2000 dairy herds in Quebec and Atlantic Canada, was used as a model to develop a matrix of animal diets that could be related to specific farm sizes and productivity classes. Feed composition, digestibility, crude protein content and some herd characteristics, such as lactation lengths and cattle weights, were grouped according to five categories of farm size and three categories of productivity class. The feed composition statistics required for Tier 2 calculations were attributed to provinces based on the proportions of their animal populations that fell into different farm size and productivity classes. As the data used in this analysis from Lactanet were collected between 2000 and 2010, further cost of production survey data were used as a

18 https://www.valacta.com/en-CA/library

19 cdc-ccl.gc.ca/CDC/index-eng.php?id=3941

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Table A3.4–2 **Cattle Production Stage Model**

Subcategory	Production Environment	Period of Year [a]	Province
Beef cows	Pregnant, confined	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Lactating, pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Pregnant, confined	Feb–Mar	MB
Beef cows	Lactating, pasture	Jan/Mar–Dec	MB
Breeding bulls	Mature, confined	Jan–Apr/Nov–Dec	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Mature pasture	May–Oct	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Mar–Apr	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Nov–Dec/Jan–Feb	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Birth to pasture	Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Pasture	Apr–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Heifer replacement	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background heifers	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background steers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher heifers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher steers	Oct–Dec/Jan–Mar	PE/NS/NB/ON/MB/SK/AB/BC
Heifer replacement	Young, not pregnant	Apr–May	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Early gestation	Jun–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Late gestation	Oct–Dec/Jan–Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher heifers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher steers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher heifers	Feedlot short-keep long-finish	April–Jul	NS/ON/MB
Finisher steers	Feedlot short-keep long-finish	April–Jul	NS/ON/MB
Background heifers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background steers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background heifers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Background steers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Finisher heifers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher steers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, confined	var [b]	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, pasture	var	NL/PE/NB
Dairy cows	Lactating, confined (after pasture)	var	PE
Dairy cows	Dry, low-quality feed	var	NL/PE/NS/NB/QC/ON/MB/SK/BC
Dairy cows	Dry, high-quality feed	var	MB/SK/AB/BC
Dairy cows	Dry, pasture	var	NL/ON
Dairy heifers	Confined (243 days year)	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy heifers	Pasture	May–Oct	NL/PE/NB/ON/SK
Dairy heifers	Confined (365 days year)	Jan–Dec	NB/ON/SK

Notes:

a. Actual period of the year could vary slightly from province to province.

b. Variable dependent on farm, province and animal cycles.

proxy to project changes in certain feed components, specifically the proportion of silage in diets relative to the proportion of hay for the period of 1990 to 1999.

A time series consisting of the annual weighted provincial averages for feed digestibility, lactation lengths and crude protein content in feed was transferred into the Boadi model structure. Furthermore, provincial cattle weights for dairy animals were modified based on average measurements included in the Lactanet database for each farm size and productivity class. The percentage change in cattle weight was used as an indicator of changes in body weight, mature weight and weight gain from the 2001 benchmark values established by Boadi et al. (2004a). The resulting dairy animal weight time series is also incorporated into the Tier 2 methodology.

Table A3.4–3 **Typical Characteristics of Dairy Production in 2001 in Canada**

Animal Category/Parameters	Production Characteristics [b]	Data Sources [c]
Dairy cows [a]		
Average weight, kg	634 (51)	Okine and Mathison (1991); Kononoff et al. (2000); Petit et al. (2001)
Mature weight, kg	646 (55)	
Conception rate, %	59.2 (7.3)	
Calves		
Birth weight, kg	41 (3.3)	
Average weight, kg	186 (18.5)	
Mature weight, kg	330.5 (37.6)	
Daily weight gain, kg/day	0.7 (0.3)	
Calf crop [d] %	93 (6)	
Replacement heifers		
Average weight, kg	461.6 (24.7)	
Beginning weight (1 year), kg	327.8 (31.0)	
Mature weight at calving, kg	602.1 (45.9)	
Mature weight, kg	646.1 (54.9)	
Daily weight gain, kg/day	0.77 (0.14)	
Replacement rate, %	32.3 (3.2)	Western Canadian Dairy Herd Improvement Services (2002)

Notes:

a. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian dairy production, as reported in the CRF.

b. The numbers in parentheses are the standard deviation.

c. Values with no reference were obtained from expert consultations (see Boadi et al., 2004b).

d. “Calf crop” is the percentage of the overwintering cows that produced a live calf.

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3.4–4), as documented by Lactanet,[20] which collects a sample of milk production representing more than two thirds of the Canadian dairy cow population for the 1999–2019 period and compiles and prepares the data for use in the inventory. These data represent the best estimate of actual milk production per average cow per province in Canada. However, from 1990 to 1998, this data set does not exist for all of Canada. The only data that are available from 1990 to 1998 for all of Canada are publishable data that were reported by Agriculture and Agri-Food Canada. The publishable data are collected for the most productive animals and the quantity of milk that is produced in the first 305 days of their lactation period. The time series of real milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable data and the management data from 1999 to 2007. The trend of increased milk production is reflected in the emission factor for dairy cows.

20 canwestdhi.com/publications.htm

Duration of Time in a Production Environment

It was assumed that cows that were dry (not lactating) during the summer months were on pasture; cows that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months. Lactation cycles were on average 320 days; however, cycles vary regionally and are based on herd productivity.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated in Boadi et al. (2004a) by dividing average gestation length by the regional average calving interval and subtracting the number of cows that are culled annually due to reproductive failure.

Ration Digestibility (DE%)

Digestibility of rations (DE%) was based on feed data in the Lactanet database and cost of production surveys. The values used in the Tier 2 calculations are weighted averages based on measured digestibility in the different diets associated with a specific farm size and productivity class from the data collected by Lactanet. For individual provinces not represented directly by Lactanet’s data, DE% values were obtained by multiplying the DE% by the proportion of animals in each farm size and productivity class for

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Table A3.4–4 **Average Milk Production from 1990 to 2019 at a Provincial Level**

	Average Milk Production (kg/head/day)									
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1990	21.0	20.9	21.0	20.8	20.3	21.7	22.1	22.2	23.2	24.3
1995	23.1	23.1	23.2	23.0	22.2	24.0	24.2	24.2	25.5	26.8
2000	27.4	26.1	26.8	26.4	25.5	26.5	27.9	27.7	29.0	30.0
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
2010	27.4	27.8	27.7	26.8	27.3	27.8	28.8	31.1	30.6	31.1
2011	27.9	28.5	28.3	27.0	27.4	28.0	28.3	30.1	30.2	30.7
2012	27.9	28.5	27.9	27.1	27.4	28.4	28.4	30.6	30.9	30.4
2013	29.6	29.7	29.1	28.5	28.7	30.2	30.7	32.0	32.8	32.7
2014	30.0	29.3	28.4	27.6	28.8	29.5	29.8	32.9	33.0	32.6
2015	30.3	29.4	28.9	27.3	28.7	30.1	30.6	33.1	34.2	33.0
2016	30.9	30.0	29.7	27.6	29.3	31.0	31.5	35.6	35.5	34.0
2017	30.5	31.3	30.8	28.4	29.8	31.3	31.5	35.0	34.6	32.2
2018	31.8	31.6	31.1	29.8	30.3	31.3	32.0	37.0	35.5	33.9
2019	34.9	33.1	32.0	30.2	31.2	32.5	33.2	36.4	35.7	34.3

Note:

Data source – Lactanet (2020)

each province. The provincial DE% time series was then inserted into the existing Tier 2 approach, replacing the fixed values from Boadi et al. (2004a).

Since 1990, the proportion of hay in feed has decreased, while the proportion of silages has increased. Silages typically have a higher feed value as the digestible portion of the feed is better preserved and, as a result, more of the feed is available for digestion by the animal. Furthermore, there has been a small overall increase in the amount of concentrates and supplements used in diets. Overall, DE% ranges from 69% to 72% for lactating cows, and 63% to 65% for dry cows, while heifers were assumed to have a diet similar to dry cows.

A3.4.1.1. Non-Dairy Cattle

Production Practices and Performance

Production practices for livestock reported under Non-Dairy Cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004a) characterized the predominant practices in 2001 for each province according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3.4–5 provide examples of production performance data collected for Canadian beef cattle, originally used as a QA verification of the data incorporated in the Tier 2 model.

Trends in carcass weights are used as an indicator of changes in mature weight from the 2001 benchmark values established by Boadi et al. (2004a) for the specific animal subcategories presented in Table A3.4–6. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2019). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3.4–2). Since 2003, beef cow carcass weights have remained more or less stable, but slaughter animal weights have continued to increase until recently when weights stabilized. In 2003, the Canadian beef cattle industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. After 2003, the slaughtered carcass weights of bulls had evidently increased due to the culling of older bulls. To provide an estimate more representative of the on-farm herd, the average live weights of bulls were retained at their 2002 value. From 2009 to 2018, the slaughter weights of bulls were used in the time series again. Bull weights were observed to decrease considerably in 2013. This observation was verified; in general, bull weights are prone to higher variability due to the low numbers being slaughtered on an annual basis.

Duration of Time in a Production Environment

Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) is assumed to enter the breeding herd (mature breeding bulls and beef cows) at 24 months of age. Slaughter heifers and steers at 12 months of age are either in feedlots or backgrounded. Animals scheduled for slaughter may be identified as either short-keeps or long-keeps. Short-keeps go directly to the feedlot to be slaughtered after 3 to 4 months, whereas long-keeps are typically backgrounded for 6 months before being sent to feedlots, where they are finished after 2 to 4 months.

Table A3.4–5 **Typical Characteristics of Beef Production in Canada in 2001 from Various Sources**

Animal Category/Parameters	Production Characteristics [a]	Data Sources [b]
Beef Cows		
Average weight, kg	603 (36)	Kopp et al. (2004)
Mature weight, kg	619 (52)	AAFRD (2001)
Milk, kg/day	7.3 (1.2)	Kopp et al. (2004)
Milk fat, %	3.6 (0.6)	Kopp et al. (2004)
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food (2000); AAFRD (2001)
Replacement Heifers		
Average weight, kg	478 (34)	
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.64 (0.14)	
Replacement rate, %	14.4 (3.1)	Manitoba Agriculture and Food (2000)
Bulls		
Yearling weight, kg	541 (18)	
Average weight, kg	940 (98)	
Mature weight, kg	951 (112)	
Daily weight gain, kg/day	1.0 (0.17)	
Calves (including Dairy Calves)		
Birth weight, kg	40 (3)	AAFRD (2001)
Wean weight, kg	258.4 (19.1)	Small and McCaughey (1999)
Age at weaning, days	215 (15)	
Daily Weight Gain, kg/day		
- Replacement heifers	0.67 (0.13)	Kopp et al. (2004)
- Backgrounder	0.98 (0.17)	
- Finisher	1.37 (0.12)	
Calf crop, %	95 (2.3)	
Heifer and Steer Stockers		
Average weight, kg	411 (47)	Kopp et al. (2004)
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.98 (0.16)	
Proportion to feedlot, %	65 (30)	
Feedlot Animals		
Average weight, kg		
- Direct finish	540 (25)	
- Background finish	562 (64)	
Mature weight, kg	630 (46)	
Finish weight, kg	609 (28)	
Daily weight gain, kg/day	1.37 (0.12)	

Notes:

Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.

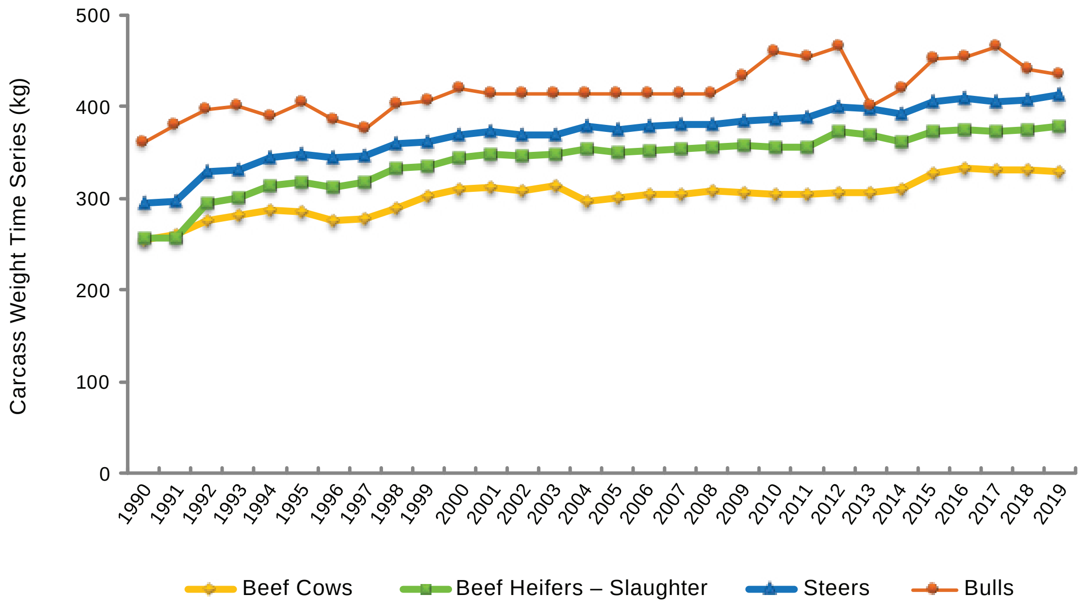
a. The numbers in parentheses are the standard deviations.

b. Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

Table A3.4–6 **Indicators of Live Body Weight Change Over Time for Cattle Subcategories**

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight.
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight.
Steers	Trends in steer carcass weight used as an indicator of live weight.
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weights are set constant to the 2002 live weight; 2009–Present uses carcass weight trend again.
Calves	No change
Dairy cows	Provincial trends in dairy cow productivity are used along with average body weight by productivity class as an indicator of live weight.
Dairy heifers	Trends in dairy cow live weight used as an indicator of dairy heifer live weight.

Figure A3.4–2 **Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada**



Ration Digestibility (DE%)

Forage DE% values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE% for Saskatchewan and Manitoba. Values from Alberta Agriculture, Food and Rural Development and the University of Alberta (2003) were used for Alberta, whereas values from the U.S. National Research Council (2001) were used to estimate DE% for British Columbia and the Eastern provinces. Overall, DE% ranged from 60% to 84%, depending on rations and feeding regimes.

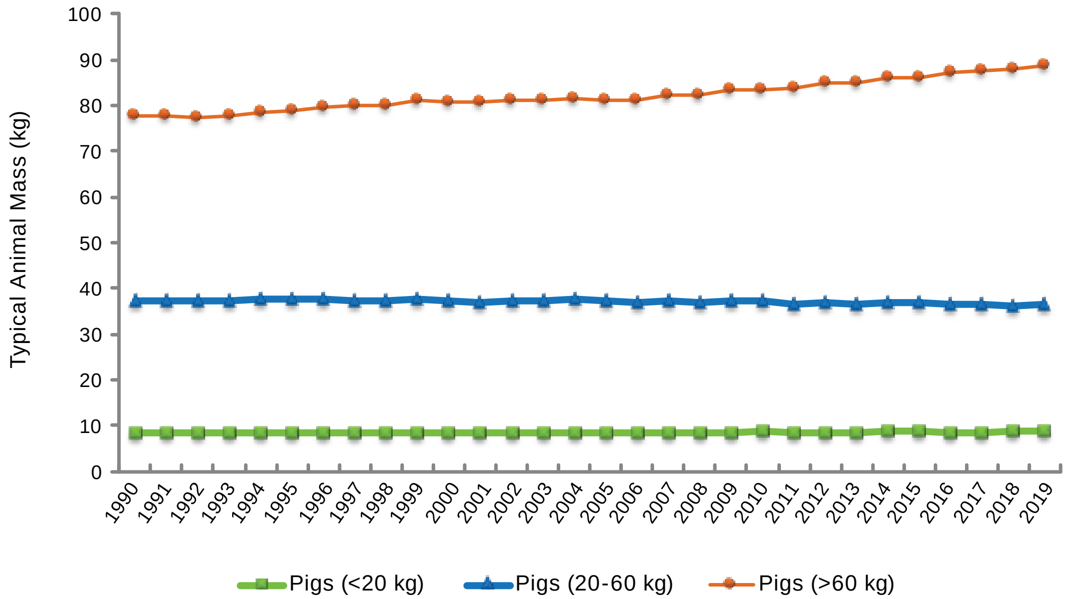
Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until two or three months of age. Therefore, enteric CH_4 emissions in these first few months are assumed to be zero.

A3.4.1.2. Swine

Production Performance

Trends in carcass weights are used as an indicator of changes in mature weight. Carcass weight data are collected and published by Statistics Canada as part of the quarterly Farm Cash Receipts (FCR) survey (Statistics Canada, n.d. [c]). Average cold-trimmed carcass weights are converted to live weights using the corresponding conversion factor (Agriculture and Agri-Food Canada, 2018). Since 1990, hog carcass weights have increased steadily from 77 kg to 100 kg (+30%), as a result of a change in production practices and genetics. Relationships between live weight and average daily weight gain, as well as changes in average daily weight gain over time by animal weight class, were developed based on data from the Prairie Swine Research Centre and combined with the time series of mature weights to develop a time series of typical animal mass for market swine. The typical animal mass for market swine varies by weight class (Figure A3.4–3) based on increased rates of growth and, in the case of the upper weight class, an increase in carcass weights since 1990. Animal mass for breeding animals was held constant using the default IPCC value.

Figure A3.4–3 **Typical Animal Mass for Swine, by Weight Class**



A3.4.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from the process of enteric fermentation is calculated using Equation A3.4–1 for all categories of livestock in Canada. CH_4 emissions reported under Enteric Fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3.4–8). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3.4–1

$$CH_{4EF} = \sum_{T}(N_T \times EF_{(EF)T})$$

CH_{4EF}	=	CH_4 emissions from the process of enteric fermentation for all animal categories
N_T	=	animal population for the T^th animal category or subcategory in each province
$EF_{(EF)T}$	=	emission factor for the T^th animal category or subcategory (Table A3.4–8 for cattle; for other animal categories, see Annex 6)

A3.4.2.1. Enteric CH_4 Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2006) Tier 2 equations for different subcategories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, heifer replacement, heifers > 1 year and steers > 1 year) based on stages of production. Tier 2 enteric fermentation estimates require an approximation of gross energy consumed (GE) calculated according to Equation A3.4–2.

Equation A3.4–2

$$GE = \left[\left[\frac{(NE_m + NE_a + NE_l + NE_p)}{(REM)}\right] + \left[\frac{NE_g}{(REG)}\right]\right] / \left[\frac{DE\%}{100}\right]$$

GE	=	gross energy, MJ/day
NE_m	=	net energy required for maintenance, MJ/day
NE_a	=	net energy required for activity, MJ/day
NE_l	=	net energy required for lactation, MJ/day
NE_p	=	net energy required for pregnancy, MJ/day
REM	=	ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g	=	net energy required for growth, MJ/day
REG	=	ratio of net energy available in a diet for growth to digestible energy consumed
$DE\%$	=	digestibility of the ration, %

All net energy estimates are applied according to equations in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). Due to the Canadian climate, Equation 10.2 from the Guidelines (Equation A3.4–3) was implemented for Non-Dairy Cattle.

Equation A3.4–3

$$Cf_i\ (in\ cold) = Cf_i + 0.0048 \times (20 - °C)$$

Cf_i = A coefficient that varies for each animal category relating weight to energy requirements for body maintenance, MJ/day/kg

$°C$ = Mean daily temperature during the winter season

The cold-adjusted Cf_i was derived by using the average temperature for the period October to April for each Canadian province, weighted based on the geographic location of non-dairy types of cattle (distributed at the ecodistrict scale) in the province. It was then corrected based on the percentage of animals kept in barns for different provinces, taken from Sheppard and Bittman (2012) and was applied to all production stages that occur during the winter months. Production stages that occur in both winter and summer, specifically finishing stages for steers and slaughter heifers, were averages of the default and the cold-adjusted Cf_i. As a result of this implementation, considering the different production stages of the animal, average annual Cf_i values varied between 0.43 for non-dairy cows in Manitoba, the coldest province, and 0.37 for non-dairy cows in Ontario and some of the Maritime provinces. Based on a weighting of production stages, the Cf_i would typically be 0.35, not considering the temperature effect. The lower Cf_i in Eastern Canada is due mainly to milder temperatures, but also to the practice of keeping animals in barns over winter, whereas in Western Canada, cattle are mainly kept outdoors. As a result, the impact of cold on the net energy of maintenance is largely observed in Western Canada.

Different stages of production require different consumption patterns to supply the necessary energy for specific animal products and environmental conditions and therefore have different GE values. For example, emissions reported under Dairy Cattle were estimated for two production categories: dry cows and lactating cows. Lactating cattle require high consumption rates (GE) for milk production. Dry cattle may also be confined or on pasture, which also modifies their required energy intake.

The total duration of time an animal spends in a production stage can also be variable, and a weighted average emission factor was therefore calculated. Criteria used in the weighting included duration of time spent in each production stage and relative percentage of the population in each stage of production. Furthermore, some net energy calculations may be modified based on a factor that takes into account the time that the energy is supplied within a production stage.

For each province, an emission factor ($EF_{(EF)}$) is calculated according to Equation A3.4–4. Provincial emission factors were weighted on the basis of the proportion of the provincial animal population relative to the national population to calculate a national emission factor for each subcategory, for each year in the time series (Table A3.4–8). For emission factors reported under Non-Dairy Cattle, the IPCC default methane conversion rate (Y_m) of 6.5% was used to calculate non-feedlot cattle emission factors and 3% was used for animals in feedlots.

The dairy Y_m factor was derived directly from production data and empirical CH_4 prediction equations developed from North American research. Briefly, the farm size by productivity matrix used to derive ration digestibility was also used to provide more detailed feed characteristics such as neutral detergent fibre, fat content and non-fibre carbohydrate content. These feed, herd and production characteristics separated by farm size and productivity class were inserted into 12 predictive methane equations, compiled from three scientific publications (Ellis et al., 2007; Ellis et al., 2010; Appuhamy et al., 2016). Gross energy for each production and farm size class was calculated according to Equation A3.4–2 based on the herd specific characteristics. Finally, the methane conversion rates (Y_m) were back-calculated from predicted methane emissions and calculated gross energy intake.

An average Y_m per productivity and farm size class was calculated based on the results of the 12 predictive equations. This value was then weighted for each province based on the proportional breakdown of the population of animals in each productivity and farm size class in the same way as a provincial digestibility value was derived. The Y_m that was derived varied between 5.9% for the lowest productivity classes and 5.4% for the highest productivity class. Weighted provincial Y_m values varied between 5.5% and 5.7%.

Dry matter intake (DMI) is based on the cattle production model and calculated at the provincial level based on regional trends and seasonal stages of production. Weighted national DMI (Table A3.4–7) for dairy cows has increased by 24% since 1990 in response to increased milk production per cow (Table A3.4–4), while DMI for dairy heifers decreased by 3% over this period due to increased feed digestibility resulting from changes in ration composition. For beef cattle, DMI is driven by trends in carcass weights (Figure A3.4–2).

Equation A3.4–4

$$EF_{(EF)T} = \sum_T \left[\frac{GE_P \times Y_{mP} \times 365}{55.65} \times TP_P \right]$$

$EF_{(EF)T}$ = annual emission factor for defined animal population T, kg/head/year

GE_P = gross energy for a given cattle stage of production P, MJ/day

Y_{mP} = methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m^3/kg

55.65 = energy content of methane, MJ/kg CH_4

TP_P = time within a stage of production P, days/year

Table A3.4–7 **Dry Matter Intake (DMI) by Cattle Subcategory, for Select Years from 1990 to 2019, estimated from Gross Energy (GE) Intake**

	DMI – (kg DM/head/day)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[a]	Steers[a]	Calves
1990	17	10	14	13	10	10	9	6
1995	17	10	15	14	11	11	10	7
2000	18	10	15	15	11	11	10	7
2005	18	10	15	15	11	11	10	7
2010	19	10	16	15	11	11	10	7
2011	19	10	16	15	11	11	10	7
2012	19	10	17	15	11	12	11	7
2013	19	10	15	15	11	12	10	7
2014	19	10	15	15	11	11	10	7
2015	20	10	16	15	12	12	11	7
2016	20	10	16	15	12	12	11	7
2017	20	10	17	15	12	12	11	7
2018	20	10	16	15	12	12	11	7
2019	21	10	16	15	12	12	11	7

Note:

a. Reported as kg/head/day; however, emissions are calculated based on time to slaughter.

A3.4.2.2. Verification of Parameter Selection Against Canadian Research

In 2011, an internal Tier 2 quality assurance/quality control (QA/QC) was carried out on the Enteric Fermentation source category (MacDonald and Liang, 2011). In this analysis, a review and compilation of Canadian literature related to methane production from the process of enteric fermentation were carried out. The results were then evaluated in light of the implementation of the 2006 IPCC Guidelines.

The 2011 analysis research measuring enteric fermentation processes in Canada indicates that the average measured methane conversion rates (Y_m) are 6.6% (±2.4) of gross energy (GE) for non-dairy cattle animals outside of feedlots, 3.2% (±1.9) of GE for non-dairy types of cattle on feedlots and 5.7% (±0.9) for dairy livestock (McCaughey et al., 1997, 1999; Boadi and Wittenberg, 2002; Boadi et al., 2002, 2004b; McGinn et al., 2004, 2008, 2009; Beauchemin and McGinn, 2005, 2006; Chaves et al., 2006; Kebreab et al., 2006; Ominski et al., 2006; Odongo et al., 2007; Eugène et al., 2008; Van Haarlem et al., 2008; Beauchemin et al., 2009; Ellis et al., 2010; Jayasundara et al., 2016). For the Non-Dairy Cattle category, these values agree broadly with the values published in the 2006 IPCC Guidelines. Recent work by Escobar-Bahamondes et al. (2016) suggests that further differentiation of Y_m factors by production subcategory is possible, which could aid in improving the accuracy of emission estimates. From the same compilation of research, the emission factor for the Non-Dairy Cattle category is observed to be 57 (±22) kg CH_4/head/year outside of feedlots and 56 (±24) kg CH_4/head/year in feedlots, and the average measured emission factor for the Dairy Cattle category is 130 (±34) kg CH_4/head/year.

Caution must be used in interpreting these values because this data set did not include animals in cold conditions and because the majority of studies focus on yearling heifers and steers. Also, the average value does not take into account the relative importance of different cattle subcategories to the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada for the Non-Dairy Cattle category (i.e., 60 to 70 kg CH_4/head/year) and Dairy Cattle category (i.e., 115 to 137 kg CH_4/head/year). A recent publication by Jayasundara et al. (2016) compiled literature data from 11 studies and found that Y_m factors for Canadian dairy livestock were on average 5.7 (±0.9)%. In the current Canadian cattle model, Y_m for dairy cows is varied over time and by province, averaging 5.5%–5.7% of GE, while a fixed Y_m of 6.5% is used for dry dairy cows, dairy heifers.

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that a bias that is introduced through the use of the Y_m values from the 2006 IPCC Guidelines is compensated for by the estimate of GE for specific animal subcategories.

Researchers from Canada have participated in some extensive reviews and validations of the IPCC Tier 2 enteric fermentation model comparing measured and observed emissions using Canadian data. In general, model analysis indicates that the IPCC Tier 2 model tends to underestimate high-emitting animals and overestimate low-emitting animals (Ellis et al., 2007, 2009, 2010).

Improvements to the dairy model in the 2018 national inventory report, in particular with the Y_m derived directly from empirical relationships from North American studies, assure that emission rates are consistent with recent measurements of CH_4 emissions, greatly improving the

Table A3.4–8 **CH_4 Emission Factors for Enteric Fermentation for Cattle in Select Years from 1990 to 2019**

Year	EF(EF)T (kg CH_4/head/year)[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8
2019	142.2	76.6	124.0	120.3	91.0	53.9	49.0	43.7

Notes:

a. Enteric emission factors are derived from Boadi et al. (2004b), modified to take into account trends in milk production in dairy cows and carcass weights for several beef cattle categories.

b. Reported as kg/head/yr; however, emissions are calculated based on time to slaughter.

accuracy of emission estimates. Similar approaches would significantly improve estimates for the Non-Dairy Cattle category, but data are still being compiled to carry out these studies. In general, it is difficult to improve Canadian estimates through updates of single parameters. Improving on the current model requires a comprehensive approach effectively linking regional animal production characteristics to animal productivity, as has been done for the Dairy Cattle category.

A3.4.2.3. Enteric CH_4 Emission Factors for Non-Cattle

For non-cattle animal categories, IPCC Tier 1 emission factors are used to calculate emissions (see Annex 6). When default emission factors are not available for the minor livestock categories, logical proxies are used to estimate emissions; swine emission factors are used for wild boars, and sheep emission factors are used for llamas and alpacas. These proxies are based on species similarities as well as similarities in production practices.

A3.4.2.4. Uncertainty

A comprehensive uncertainty analysis was carried out on all methodologies used in the calculation of methane from livestock for 2010. Uncertainty ranges (percentages) of means were rerun for the 2014 NIR submission and have not been rerun since that submission. In the analysis, a stochastic reproduction of the livestock CH_4 emission model was built in Mathematica© and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the IPCC Good Practice Guidance (IPCC, 2000). This analysis built on a recent study (Karimi-Zindashty et al., 2012). However, the Environment Canada stochastic model (ECSM) built in Mathematica© (1) applied the exact parameters and equations used in the Canadian inventory methodology based on the Good Practice Guidance (IPCC, 2000); (2) included uncertainty associated with populations and duration of production stages, which impact subcategory emission factors (Table A3.4–9); and (3) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3.4–9). The ECSM was run for the years 1990, 2005, 2010 and 2012. A trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012. The relative uncertainties from the previous analysis were applied to the current year's values. Uncertainty analysis on the revised dairy model, however, has not yet been carried out and reported uncertainty estimates are based on the Boadi et al. (2004a) methodology.

Currently, the data required to create probability distributions of the coefficients used in the agricultural IPCC Tier 2 models simply do not exist. Some of the default coefficients in Tier 2 equations are provided with an uncertainty range, often estimated by expert opinion; for other coefficients, ranges are taken from a few studies, often using methodologies that are not easily comparable. In general, the analysis of Rypdal and Winiwarter (2001) applies to the agricultural emission model as a whole, and it can be understood that large probability distributions are associated with default Tier 2 coefficients due to a lack of appropriate measurements and subsequent generalizations, uncertainties in measurements and an inadequate understanding of emission processes. This initial uncertainty analysis has applied a precautionary principle, and for coefficients with very little information, uncertainty bounds were conservative.

Uncertainties in populations of major animal categories, i.e., cattle, swine and sheep, were supplied directly by Statistics Canada based on biannual and quarterly survey statistics. For small provinces with few animals in certain categories, sample variance is large, as indicated by uncertain values of > ±50%. However, because the data were collected based on a sampling design proportional to population distributions, the overall uncertainty for major animal categories at the national level was low. National populations for non-dairy cattle types have the lowest uncertainty (±1.8% of the mean), with slightly higher uncertainty for swine (±2.6% of the mean), dairy cattle (±5.4% of the mean) and sheep (±6.0% of the mean).

All other animal population estimates are renewed only through the *Census of Agriculture*. To account for the increase in uncertainty due to the time that has elapsed since the census, a model was developed that estimated the increase in uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1996, 2001, 2006 and 2011. The uncertainties for populations in 2012 were estimated as the agricultural census uncertainty at the provincial level plus the 95% confidence interval for the linear regression multiplied by the number of years since the last census (one year). Due to the recent *Census of Agriculture*, the other animals tended to have lower population uncertainties in the 2012 analysis than the 2010–2011 uncertainties, similar to those animals for which population estimates are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for other animal categories ranged from ±2% of the mean for poultry to ±4% of the mean for bison; however, these animal categories contribute little to total emissions.

The parameters used in the calculation of Tier 2 emission factors for cattle can be divided into two categories: (1) those associated with cattle production and performance (see section A3.4.2 for detailed descriptions of parameters); and (2) those that are specific to the IPCC Tier 2 equations (see section A3.4.2 for details). For the most part, the uncertainty assigned to parameters associated with cattle production and performance is relatively low, as these estimates are collected on a provincial basis, from provincial experts, and are values that are generally known within the industry. The largest source of uncertainty in production practices is the duration and fraction of animal populations in specific production stages. This source of uncertainty is associated with the number of animals that are backgrounded and the duration of that backgrounding period. These are parameters that are highly dependent on prices and import/export markets, and therefore confidence in the values that are currently being used is low. A high level of uncertainty (30%) was applied to the number of animals backgrounded, and a non-symmetrical triangular distribution was applied to the duration of backgrounding as a precautionary approach to account for high levels of potential variability in these production practices. The uncertainty in production population fraction and the duration of production stages was not accounted for directly in Karimi-Zindashty et al. (2012).

The uncertainties for parameters used in IPCC Tier 2 equations were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who used the probability distributions either from Monni et al. (2007) or from the 2006 IPCC Guidelines. Two differences are notable: (1) digestible energy probability distributions became available from data supplied by Lactanet after the Karimi-Zindashty et al. (2012) study was completed, allowing the calculation of typical distributions of different types of feed; and (2) Karimi-Zindashty et al. (2012) used the 2006 IPCC methodology and therefore did not include the effects of weight loss on gross energy. A uniform distribution was therefore used in the ECSM analysis to account for the impact of incorporating an estimate of net energy mobilized through weight loss during lactation (NE_{mob}) that varied according to duration of weight loss between 0% and 20% of the lactation period. As this parameter has been removed from the 2006 IPCC Guidelines, this approach was an effective way to evaluate the overall impact of this parameter.

A trend analysis was carried out using the ECSM in which the uncertainty in the magnitude of the change in emissions over time was calculated. For the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. These parameters represent the elements of the calculation model that change over time, and therefore an estimate is available for a value in 1990 and in 2012 (noted by a superscript g in Table A3.4–9). The parameters in 1990 and 2012 are considered entirely independent and, as a consequence, for each calculation in the Monte Carlo simulation, a value was selected from the probability distribution for 1990 and 2012 independently. In contrast, other parameters used a value selected once from their probability distribution for the calculation of emissions in both 1990 and 2012. The parameters that were allowed to vary independently for the enteric fermentation process analysis were animal populations, milk production and fat content for dairy cows, and body weights for cattle. The relative uncertainty values for the trend analysis were applied to the 2013 results.

The summary results of the uncertainty analysis for emissions from the process of enteric fermentation are reported in Chapter 5, section 6.2.3. Briefly, the fixed range used in calculating uncertainty ranges for emissions from enteric fermentation is 39% (-17% to +22% of the mean) (see Chapter 5). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle; they lie within an uncertainty range of -19% to +22% of the mean emission factor for the Non-Dairy Cattle category and -16% and +21% of the mean emission factor for the Dairy Cattle category. In the case of other animals that use Tier 1 IPCC (2006) default emission factors, uncertainty ranges of ±50% were assigned, with the exception of swine, which was ±37% based on

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Monni et al. (2007). Relative to cattle, the Tier 1 emission factors for other animals have little impact on the total uncertainty because of the small contribution of other animal categories to total enteric fermentation emissions. Mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than calculated in the inventory database (roughly 2%). This difference is likely due to the introduction of the non-symmetrical triangular distribution that increased the length of backgrounding for slaughter heifers and steers and to the uniform distribution of the factor that defines energy released from weight loss during lactation in dairy cows.

The overall uncertainty for each estimate of each individual year changes little over time. The uncertainty range for emissions in 1990 and 2012 is 39% to 40%. Based on the trend analysis, over the long term, CH_4 emissions increased between the 1990 base year and 2012 by 9% to 19%, with a most likely value (MLV) of 15% (trend uncertainty 10%). Most of the increase in emissions is associated with the Enteric Fermentation category, which increased by 11% to 22%, with an MLV of 16%. To estimate the trend uncertainty reported in Chapter 5, the relative trend uncertainties from the previous analysis were applied to the current year's mean change in emissions. In general, this uncertainty analysis was consistent with other agricultural estimates of uncertainty. The paper by Monni et al. (2007) is, to our knowledge, currently the only one detailing agricultural CH_4 emission uncertainty with the use of IPCC Tier 2 methodology. The use of comparable probability distributions for IPCC Tier 2 default parameters provides comparability between the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Enteric Fermentation emissions from Finnish agriculture for different cattle subcategories as ranging from -22% to +29% of the mean to -29% to +39% of the mean. Rypdal and Winiwarter (2001) reported uncertainties for some European countries ranging from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but they used mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analysis in the field of agriculture.

The results of this uncertainty analysis were, of course, very similar to those produced by Karimi-Zindashty et al. (2012), who also observed an overall uncertainty range for enteric fermentation emissions of 39%, indicating that the uncertainty associated with the production stage duration and population fractions had little impact on the overall uncertainty. The incorporation of the uncertainty associated with weight loss during lactation did not increase overall uncertainty, but tended to skew the uncertainty distribution for Dairy Cattle category estimates towards higher emission estimates. The sensitivity analysis carried out by Karimi-Zindashty et al. (2012) indicated that the major drivers of uncertainty in emission estimates were associated with the default IPCC Tier 2 parameters, in particular the methane conversion rate (Y_m) and the factor associated with the net energy of maintenance (Cf_i), applied at the national scale. Uncertainty in the Tier 2 methodology may be reduced through the development of country-specific parameters at the regional scale for different animal categories. It is suspected that the recent revisions to the dairy model will have reduced the overall uncertainty of enteric emission estimates; however, further analysis is required to quantify the impact of improvements on the uncertainty estimates.

A3.4.3. CH_4 Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH_4 emission factors from manure management systems (IPCC, 2006), also referred to as animal waste management systems (AWMS). Equation A3.4–5 is used to calculate CH_4 emissions from the management of manure for all categories of livestock in Canada with the exception of deer and elk, rabbits, mules and asses, and fur-bearing animals, which were calculated using IPCC Tier 1 emission factors. Wild boar emission factors were calculated based on average swine Tier 2 parameters, but assuming only solid manure. Sources of animal population data are the same as those used in the reporting of Enteric Fermentation estimates and are listed in Table A3.4–1.

When default emission factors or country-specific information sources are not available for the minor livestock categories, logical proxies are used to estimate emissions. These proxies are based on species similarities as well as similarities in production practices. When proxies are used at a provincial level, weighted national values may not match between the native and proxy livestock categories due to differences in provincial populations used for weighting.

The following proxies and expert judgement are used for minor animal categories:

- Manure management system parameters from the Non-Dairy Cattle category are used to represent bison, including the maximum CH_4 producing potential (B_0) and provincial AWMS distributions.
- Provincial AWMS distributions for horses are used to represent mules and asses.
- Provincial AWMS distributions for the Non-Dairy Cattle category are used for the reporting of Deer and Elk, except that liquid systems are distributed to PRP based on expert judgement that deer and elk livestock manure is unlikely to be handled by liquid manure systems.
- Volatile solids for the Swine category are used to represent wild boars at a provincial level. The disaggregation of swine animal subcategories and scaling of VS with animal mass (section A3.4.3.6) are not used for this proxy relationship. Lastly, all manure from wild boar livestock is allocated to solid AWMS based on expert judgement.
- Sheep manure management system parameters are used to represent llamas and alpacas, including volatile solids (VS) and provincial AWMS distributions.

Total emissions from the minor animal categories Mules and Asses, Deer and Elk, Llamas and Alpacas, Mink, Foxes, Rabbits and Wild Boars represented less than 100 kt CO_2 eq in 2019 (<0.2% of total agricultural emissions), including direct and indirect emissions and emissions from application to agricultural soils. Changes to these proxies could not have a significant impact on emission estimates from the agricultural sector, and based on the insignificant impact of these animal categories on agricultural emissions, improvements to these animal categories are of the lowest priority in the agricultural inventory.

Equation A3.4–5

$$CH_{4MM} = \sum_{T} (N_T \times EF_{(MM)T})$$

CH_{4MM}	=	emissions for all animal categories
N_T	=	animal population for the T[th] animal category or subcategory in each province
$EF_{(MM)}T$	=	emission factor for the T[th] animal category or subcategory calculated according to Equation A3.4–6

To develop Tier 2 CH_4 emission factors representing manure management systems, country-specific inputs were required that take into account climate, livestock rations and the type of manure storage system included in Equation A3.4–6. The following equation represents an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

Equation A3.4–6

$$EF_{(MM)T} = VS_T \times 365 \times B_{0T} \times 0.67 kg/m^3 \times \sum_{ij} MCF_{ij} \times AWMS_{Tij}$$

$EF_{(MM)T}$	=	annual emission factor for defined animal population T, kg CH_4/head-year
VS_T	=	daily volatile solids excreted for an animal within the defined population T, kg/day
B_{0T}	=	maximum CH_4 producing potential for manure produced by an animal within defined population T, m^3/kg VS
MCF_{ij}	=	CH_4 conversion factor for each manure management system i in climate region j
$AWMS_{Tij}$	=	system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j, often referred to in IPCC documents as management system (MS)
0.67	=	conversion factor of m^3 CH_4 to kilograms CH_4

The following sections outline the sources of input values for VS, DE%, ASH, B_0, MCF and AWMS.

A3.4.3.1. Volatile Solids (VS)

Cattle (VS)

Volatile solids (VS) are the organic fraction of total solids in manure. The VS of manure was estimated using the digestibility (DE%) of dietary intake, manure ash content and gross energy (GE) consumed by a given animal subcategory, and the urinary energy (UE) fraction of the gross energy intake, according to the 2006 IPCC Guidelines.

For cattle subcategories, the GE depends on the cattle production model defined for estimating emissions from the enteric fermentation process (Boadi et al., 2004a), as shown in Equation A3.4–3. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3.4–7). Increases in milk production in dairy cows and carcass weight in beef cattle have increased VS with increased dry matter intake and, as a result, CH_4 emission factors over the time series; however, increases of DE% in dairy feed over time have moderated this effect for dairy cows.

Equation A3.4–7

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE \times GE)\right] \times \left(\frac{1 - ASH}{18.45\ MJ}\right)$$

VS	=	volatile solids excretion, kg/head/day
GE	=	gross energy consumed by a given animal, MJ/head/day
$DE\%$	=	digestibility of the ration, %
UE	=	urinary energy (unitless)
ASH	=	ash fraction of the manure, %

Swine (VS)

Volatile solids reported for the Swine category (Table A3.4–11) were estimated by first calculating provincial VS excretion based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE% and ASH derived from expert surveys. Typical animal mass was used to convert the temporally fixed VS into units of VS per 1000 kg body weight (kg VS/1000 kg animal mass/day), which was then applied to the full animal mass time series.

All Other Animals (VS)

Volatile solids for animal categories other than Dairy Cattle, Non-Dairy Cattle and Swine were calculated based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE% and ASH derived from expert surveys. The values for DMI, DE% and ASH taken

Table A3.4–9 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation**

Parameter Category	Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range[a]	Uncertainty Distribution Source and Notes	Spatial Allocation/Animal Category Allocation
Population Data[g]						
Cattle Biannual Surveys						
	Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[d]	Provincial/subcategory
	Non-dairy			±5% – ±73%		
Other Survey-based Populations						
	Swine	Statistics Canada (Tables 003-0004 and 003-0031)		±8% – ±89%		
	Sheep			±14% – ±80%		
Census of Agriculture						
	Goats	*Census of Agriculture* (Statistics Canada, 2012a)		±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	
	Poultry			±5% – ±12%		
	Bison			±18% – ±85%		
	Llamas and Alpacas			±16% – ±42%		
	Horses			±5% – ±16%		
Cattle Production Parameters and Performance						
	Milk production[g]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Fat content[g]	Valacta/Canwest DHI				
	Dairy herd efficiency[g]	Valacta/Canwest DHI				
	Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	
	Average daily gain (ADG)	Boadi et al. (2004b)				
	Pregnancy period	Boadi et al. (2004b)				
	Production stage duration	Boadi et al. (2004b)	normal except slaughter animals, triangular, non-symetric	±5%, Slaughter animals: MLV[e] from Boadi et al. (2004b) LB: 12% of MLV: UB: 25% of MLV	Expert opinion, Boadi et al. (2004b) – for feeder heifers and steers, a triangular distribution was assumed based on interpretation of potential market effects (Canfax Research Services, 2009)	Provincial/production stage subcategory, internal correlation[f]
	Production stage population fraction	Boadi et al. (2004b)	normal	±5% – ±30%		
Cattle Weight Estimates[g]						
	Live weight, 2001	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/production stage subcategory
	Mature weight, 2001	Boadi et al. (2004b)				
	Carcass weight	CBGA[b] and published AAFC[c] (1990–2010)				National/subcategory
Emissions Factors for Cattle (IPCC Tier 2 Equations)						
	Methane conversion rate (Y_m)		normal	Feedlot animals – ±30% Other animals – ±15%	Karimi-Zindashty et al. (2012) – IPCC (2006)	National/feedlot vs. non feedlot
Gross Energy for Cattle Calculation IPCC Tier 2 Equation A3-18						
	Digestible energy (DE)	Boadi et al. (2004b)	normal	Pasture ±9% Confined ±9% Background ±7.5% Prepared feed ±5.5%	Derived from raw data supplied by Valacta Dairy Services	Provincial/production stage subcategory
Net Energy for Cattle Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)						
	Animal activity coefficient (C_a)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
	Gender coefficient (C)		normal	±30%		
	Maintenance coefficient Cf_i			±30%		
	Lactation coefficient			±30%		
	Weight loss rate		normal	5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Weight loss duration		uniform	LB: 0 UB: 20% of lactation period.	Interpretation of differences between 2000 and 2006 IPCC Guidelines	
Non-cattle Emission Factors						
	Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category
	Other animals			±50%		

Notes:

a. Where differences in uncertainty exist for different provinces or animal categories, maximum and minimum uncertainties are given.

b. Canadian Beef Grading Agency.

c. Agriculture and Agri-Food Canada.

d. Personal communication. Plourde R, Statistics Canada, Livestock and Food Section, Ottawa, ON. April 4, 2010.

e. MLV = most likely value; LB = lower bound; UB = upper bound.

f. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.

g. Values that were allowed to vary independently during trend analysis.

from that survey were used to calculate VS for non-cattle livestock categories for each individual province (Equation A3.4–8). Confidence intervals were developed using a Monte Carlo simulation performed with Crystal Ball® (Decisioneering 2000), resulting in a probability distribution based on the variance in expert opinion and scientific literature (Table A3.4–10).

Table A3.4–10 **Mean Volatile Solids in Manure of Non-Cattle Animal Categories in 2019 and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean**

Animal Category	Mean Volatile Solids (kg/head/day)	95% Confidence Interval (%)
Sheep and Lambs [a]	0.60	31
Mature Horses	3.6	16
Goats	0.72	41
Bison	3.1	16
Wild Boars [b]	0.23	50
Poultry	0.02	20

Notes:

a. Llamas and alpacas are given the same values as sheep at the provincial level, and weighted based on the population of llamas and alpacas in each province.

b. The value for wild boars is calculated on the basis of the value for swine.

Table A3.4–11 **Mean Volatile Solids in Swine Manure in 2019**

Animal Category	VS (kg / 1000 kg body mass / day)	Typical Animal Mass (kg)	VS (kg/day)
Sows	1.57	198	0.31
Boars	1.57	198	0.31
Pigs (<20 kg)	10.78	8.7	0.09
Pigs (20–60 kg)	5.13	37	0.19
Pigs (>60 kg)	4.56	89	0.40

Equation A3.4–8

$$VS = \left[DMI \times 18.45 \times \left(1 - \frac{DE\%}{100}\right) + (UE \times DMI \times 18.45)\right] \times \left(\frac{1 - ASH}{18.45\ MJ}\right)$$

VS = volatile solids excretion, kg/head/day

DMI = dry matter intake, kg/head/day

$DE\%$ = digestibility of the ration, %

UE = urinary energy (unitless)

ASH = ash content of the manure, %

The following sections outline the data for estimating VS developed by Marinier et al. (2004).

Digestibility (DE%) and Dry Matter Intake (DMI)

The sources of information used for DE% for both the Dairy Cattle and Non-Dairy Cattle categories are detailed in section A3.4.1.1.

Broad regional differences in ration composition were identified for sheep, horses and swine livestock. Regional differences were not considered for goats or poultry livestock, since these data were not available.

Generally, rations for grazing livestock consist of roughage and grains. Diet digestibility will vary, with grains having a higher digestibility than roughage. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. A weighted estimate of DE% was calculated using the known approximate DE% for grains and roughage for each animal type and the distribution of grain and roughage usage by province (Table A3.4–12). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle animal categories was determined through consultation with experts and published values (Table A3.4–13).

Table A3.4–12 **Approximate Ration Digestibility (DE%) for Selected Livestock Subcategories and Data Sources**

Animal Category	DE (%)	Data Sources[a]
Goats	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chickens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horses	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horses	60	L. Warren, Colorado State University

Note:

a. Data source – Expert consultations (Marinier et al., 2004).

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Table A3.4–13 **Dry Matter Intake for Selected Livestock**

Animal Category	DMI (kg/head/day)	Data Sources
Sheep and Lambs		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	W. Whitmore, Manitoba Agriculture and Food
Replacement Lambs	1.2–1.5	NRC (1985)
Market Lambs	1.3–1.6	NRC (1985)
Horses		
Mature Idle Horses	7.4–11	NRC (1989); L. Warren, Colorado State University
Mature Working Horses	7.4–13.7	NRC (1989); L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
Swine		
Starters (5–20 kg)	0.55–0.72	C. Wagner-Riddle, University of Guelph
Growers (20–60 kg)	1.4–2.1	J. Patience, Prairie Swine Centre
Finishers (60–110 kg)	2.1–3.3 [a]	M. Nyachoti, University of Manitoba; C. Pomar, Agriculture and Agri-Food Canada
Sows	2.28	C. Wagner-Riddle, University of Guelph
Boars	2.0–2.5	M. Nyachoti, University of Manitoba; NRC (1998)
Goats		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
Poultry		
Laying Hens	0.072–0.11	S. Leeson, University of Guelph; D. Korver, University of Alberta
Broilers	0.085–0.088	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	0.023–0.53	Hybrid (2001)

Notes:

Data source – Expert consultations (Marinier et al., 2004).

a. Calculated as 3.5% of body weight.

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3.4–14 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

Table A3.4–14 **Manure Ash Content for Selected Livestock and Data Sources**

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goats	8	IPCC (2000)
Horses	4	IPCC (2000)
Laying Hens	10	Marinier et al. (2004)
Chickens	7	Marinier et al. (2004)
Turkeys	5	Marinier et al. (2004)
Swine	5	Marinier et al. (2004)
Wild Boars	5	(Taken from Swine)

A3.4.3.2. Maximum CH_4 Producing Potential (B_0)

The B_0 is defined as the maximum volume of CH_4 that can be produced from 1 kg of VS loaded into a manure management system and is expressed as m^3/kg VS loaded. The values published in the 2006 IPCC Guidelines were used for all animals. For bison, the values of the Non-Dairy Cattle category were used.

A3.4.3.3. Animal Waste Management System (AWMS) Distribution Factor

The AWMS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable published information on the distribution of manure management systems in Canada.

Anaerobic treatment lagoons and daily spread are not typically used for manure storage in Canada. Though some examples may exist, they cannot be quantified and, for this reason, are currently considered non-significant and are not estimated. The existence of these types of systems was not identified in the expert consultation carried out by Marinier et al. (2004) or across Farm Environmental Management Surveys, which are the sources of AWMS allocation data for Canada. Therefore, the amount of manure treated by these systems is assumed to be negligible. Earthen storage systems exist in Canada, but in these storage systems, solids are removed regularly when the storage systems are emptied on an annual basis and there is no long-term accumulation and anaerobic treatment of solids in the lagoon, as is the case with “anaerobic treatment lagoons” as defined by the IPCC guidelines.

Dairy

For the Dairy Cattle category, a relationship between farm size and time spent on pasture, in exercise yards and in barns was developed from Sheppard et al. (2011) for each province. The proportion of manure excreted in each of these locations is assumed to be equal to the time spent in each area. Time spent on pasture was found to decrease with increasing farm size, and the fraction of manure deposited on pasture decreased on average from 19% in 1990 to 16% in 2016 due to a shift towards larger farm operations.

For manure deposited in barns, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship to farm size, for Eastern and Western Canada respectively, derived from the survey data. Liquid system use increased from 17% in 1990 to 64% in 2011, the most recent survey year, while solid manure is assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. A portion of total solid manure is composted, while the remainder is disaggregated into two solid AWMS sub-systems based on survey data: pack and pile. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey compiled in Sheppard et al. (2011a). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

Swine

For swine, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship with farm size and was modelled based on provincial farm sizes from the *Census of Agriculture*. Liquid system use increased from 80% in 1990 to 97% in 2011, the most recent survey year included, while solid manure was assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. Solid manure was disaggregated into two solid AWMS sub-systems: Pack and Pile, based on survey data. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey (Sheppard et al., 2010b). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

All Other Animals

A survey of experts on the topics of manure management and animal production was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004). National averages of results are summarized in Table A3.4–12. Briefly, among the dominant animal production categories across the country, poultry manure is stored as solid manure, and beef cattle manure is equally distributed between solid storage and deposition on pasture, with the exception of British Columbia and Manitoba, where the majority of manure is deposited on pasture.

For minor livestock categories where the default IPCC Tier 1 methodology is used to estimate manure management CH_4 emissions, AWMS distributions are reported in CRF tables for consistency with reporting of manure management N_2O emissions (see A3.4.4.1), but are not incorporated in the calculations.

A3.4.3.4. Methane Conversion Factor (MCF)

The MCF describes the proportion of B_0 that is attained, depending on the storage system and climate region. The values published in the 2006 IPCC Guidelines were used for all animals, with the exception of poultry. Where a range of temperature dependent MCFs were available, the value for cool climate and average annual temperature of 12ºC was used.

For poultry animals on liquid manure management systems, an MCF that was consistent with all other livestock liquid manure management systems was used, as storage methods for liquid poultry manure in Canada do not differ significantly from storage systems used in dairy or swine production.

For the Dairy Cattle and Swine categories, MCF values from the 2006 IPCC Guidelines were assigned to each AWMS subsystem (section A3.4.3.3). In liquid subsystems, the Liquid/Slurry MCF value of 20% (without crust) or 13% (with crust) was used for Tank and Earthen Basin, while Pit Storage Below Animal Confinements was used for Slatted Floor systems (MCF=20%). For solid subsystems, the Drylot MCF was used for Pack, while the Solid Storage MCF was used for manure heaps. For Dairy Cattle, the Drylot MCF was also used for Exercise Yards. A full list of MCF values by livestock and manure system can be found in Annex 6.4.

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Table A3.4–15 **Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (per Animal Category, Based on the Distribution of Animal Populations in 2019)**

Animal Category	Liquid Systems	Solid Storage and Drylot	Pasture, Range and Paddock	Other Systems
Non-Dairy Cattle	5.3	45	45	4.2
Dairy Cattle	64	18	16	2.9
Poultry	7.0	92	0.6	0.6
Sheep and Lambs	0.1	34	66	0.02
Llamas and Alpacas [a]	0.03	28	72	0.02
Swine	97	3	0	0
Goats	0	42	58	0
Horses	0	31	68	0.7
Bison	0.2	46	50	4.0
Deer and Elk [b]	0	47	50	3.5
Fur-Bearing Animals [c]	0	100	0	0
Mules and Asses [d]	0	32	68	0.7
Wild Boars [c]	0	100	0	0

Notes:

Totals may not add up to 100% due to rounding.

a. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs, at the provincial level.
b. Identical distributions to non-dairy cattle, except that liquid systems are distributed to pasture, range and paddock (PRP).
c. Assumed 100% solid manure.
d. Assumes that manure handled by AWMS is the same for mules and asses as for horses.

Table A3.4–16 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2019**

	$EF_{(MM)T}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers [a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter [b]	Steers [b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0
2019	39	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:

a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
b. Reported as kg/head/year, but emissions are calculated based on time to slaughter.

A3.4.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors that are developed to calculate CH_4 emissions from manure management systems vary by animal subcategory and over time (Table A3.4–16). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission factor time series was derived for cattle to reflect (1) the increase in milk productivity of dairy cows, (2) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (3) the change in live weight of beef cattle as explained in sections A3.4.1, A3.4.3.4 and A3.4.1.1, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, use of liquid manure management systems and high dietary intake for sustained milk production. Dairy emission factors have more than doubled since 1990 due to the increasing use of liquid manure management systems. Beef cattle emission factors are lower, reflecting their lower rates of confinement, lower GE and the fact that the majority of manure is managed in a solid form with a low MCF.

A3.4.3.6. Swine Manure Management CH_4 Emission Factors

Swine emission factors are developed to calculate CH_4 emissions from manure management systems and vary by animal subcategory and over time (Table A3.4–17).

A provincial emission factor time series was derived for swine to reflect (1) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (2) changes in the growth rates and live weights of market swine by weight class, as explained in sections A3.4.3.4 and A3.4.1.2, respectively. The swine emission factor is first calculated using VS derived from Marinier et al. (2004), and incorporating the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). The annual VS excretion rates are then recalculated using animal mass from the Marinier survey year, and expressed as VS per 1000 kg animal mass. Lastly, VS is scaled over time using the swine TAM time series.

Emission factors for pigs in the low-weight and middleweight classes decrease slightly over time due to increases in the rate of weight gain and increases in the methane conversion factor. In contrast, a steady increase in the upper-weight class emission factor reflects increases in live weight. A small decrease in the emission factor for sows over time is the result of proportional changes to provincial animal populations, leading to an overall decrease in VS.

A3.4.3.7. Manure Management CH_4 Emission Factors for All Other Livestock

Manure management system emission factors for animals other than swine and cattle vary by animal subcategory but are constant over time (Table A3.4–18). For the largest other animal categories—sheep and poultry—growth stages for animals are taken into account. Emission factors for sheep, lambs, goat, horses, bison, llamas and alpacas, and poultry are calculated using the 2006 IPCC Tier 2 methodology. Volatile solids are derived from Marinier et al. (2004); however, since this report was based on the 2000 IPCC Guidelines, the emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). Proxies are used for very minor livestock categories that account for less than 0.2% of total agricultural emissions, as described in A3.4.3.

Emission factors for other minor categories tend to be low due to the large portion of manure that is deposited either on pasture, range or paddock or in solid form in pens and holding yards. Default Tier 1 IPCC emission factors from Table 10.15 of Chapter 10 of the 2006 IPCC guidelines are used for deer and elk, foxes, mink, rabbits, and mules and asses, and represent less than 0.1% of total agricultural emissions.

Table A3.4–17 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2019**

	$EF_{(MM)T}$ (kg CH_4/head/year)				
Year	Boars	Sows	Pigs (< 20 kg)	Pigs (20-60 kg)	Pigs (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0
2019	7.0	7.0	2.1	4.2	9.2

Table A3.4–18 **2019 CH_4 Emission Factors for Manure Management for All Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars [a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and Asses	0.76
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.10

Note:

a. Emission factor based on swine VS, assuming 100% solid manure.

A3.4.3.8. Verification of Parameter Selection Against Canadian Research

The Manure Management source category was a part of a Tier 2 QA/QC for the Agriculture sector for the 2011 submission (MacDonald and Liang, 2011), including a review and compilation of Canadian literature related to methane production from manure storage.

Few studies have measured emissions from manure storage or quantified the characteristics of manure and manure storage strategies that influence emissions in Canada. Observed emission factors are highly variable, as are measurement techniques. The methodological variability makes comparison of specific parameters used in Tier 2 calculations extremely difficult. When the liquid storage MCF was estimated from *in-situ* measurements, it varied from greater than 100% (suggesting that B_0 is also underestimated) to as low as 14% in the case of swine, and from 4% to 62% for dairy with no mitigation measures in place (Kaharabata et al., 1998; Massé et al., 2003, 2008; Wagner-Riddle et al., 2006; Laguë et al., 2005; Park et al., 2006, 2010; VanderZaag et al., 2009, 2010). Some studies exist in Canada on emissions from solid manures and other storage methods (composting) (Pattey et al., 2005; Xu et al., 2007; Hao, 2007; Hao et al., 2001b, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology makes comparisons to IPCC parameters difficult.

Godbout et al. (2010) carried out an analysis on a small sample set from Eastern Canadian farms and suggested that the B_0 values for Swine, Non-Dairy Cattle and Dairy Cattle category livestock were 0.47–0.42, 0.21–0.19 and 0.35–0.30 m^3 CH_4 kg^{-1} VS, respectively. The values for Non-Dairy Cattle and Swine are consistent with IPCC default values, though dairy manure is the exception, with observed B_0 being 50% higher than the default value. In VanderZaag et al. (2018) B_0 for raw manure from two dairy farms was found to be 0.248 (SD=2) and 0.247 (SD=6). Further analyses of B_0 are required for a wider range of regions and production practices.

Quantities of volatile solids stored in the manure management systems for different animal categories tend to be consistent with quantities estimated in inventory calculations. The variability observed in studies is therefore likely linked to a combination of differences in measurement methodology, variability in manure characteristics (B_0) and differences in a number of physical and biochemical factors for each experimental situation that are not taken into account in the IPCC Tier 2 model. These factors include temperature, manure composition, storage dimension, storage duration and storage cleaning procedures—all of which may influence emissions from manure storage (Pattey et al., 2005; Laguë et al., 2005; Park et al., 2006, 2010; Wagner-Riddle et al., 2006; Massé et al., 2008; VanderZaag et al., 2009, 2010). Furthermore, these factors are not controlled in research, making comparisons even more difficult. More standardized factorial research is required in order to understand the relative weight of factors that influence emissions from manure storage and to refine estimation methodology.

Based on current research results, no specific bias can be determined in results for manure management systems, as there is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems.

Desjardins et al. (2018) measured CH_4 flux for full farm systems, including emissions from both manure management and enteric fermentation processes using an aircraft-based platform and compared top-down estimates with a bottom-up footprint adjusted inventory estimate of emissions for an agricultural region in eastern Ontario, Canada. They concluded that when a wetland area in the flux footprint was less than 10%, the top-down and bottom-up estimates were within the measurement error. They noted, however, that top-down CH_4 fluxes significantly over-estimated methane emissions when contributions from wetlands were not considered in the potential sources. Fine-scale mapping of wetlands was required to effectively quantify natural methane emission sources. Where estimates from the two methods were inconsistent, the discrepancy was related to both increasing fractional area of wetlands in the flux footprint and increasing surface temperature.

A3.4.3.9. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management systems were included in the comprehensive uncertainty analysis discussed in section A3.4.2.4. As was the case with the enteric fermentation process, the analysis built on the recent study by Karimi-Zindashty et al. (2012) and applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3.4–19). Data on the probability distributions of the coefficients used in the agricultural manure management IPCC Tier 2 models are scarce, and expert opinions were the main source of probability distributions, particularly those compiled in the Marinier et al. (2004) report. As was the case with the method for enteric fermentation, the relative uncertainty for the 2012 analysis was applied to the current year and no new uncertainty analysis was carried out for the changes to the model for dairy cattle livestock.

Population uncertainty for major animal categories was identical to that discussed in section A3.4.2.3, and the distributions used to define uncertainties can be found in Table A3.4–9.

The parameters used in the calculation of Tier 2 manure management system emission factors for all animals can be divided into two categories: those associated with volatile solid calculation and those specific to the calculation of IPCC Tier 2 emission factors. The confidence intervals assigned to coefficients used in the calculation of volatile solids were relatively small compared to parameters used in the calculation of emission factors. With the exception of the ash content of manure, parameters tend to be under 10%, largely because parameters such as DMI and DE% are values with which producers are very familiar and which can provide some degree of confidence. In the case of cattle, volatile solids vary according to the gross energy (GE) of consumption and are subsequently similar in variability to the enteric fermentation emission factor (±19%).

The probability distributions for coefficients used in IPCC Tier 2 equations used to calculate the emission factors were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who derived the distributions either from expert opinion within the Marinier et al. (2004) report or directly from the 2006 IPCC Guidelines. The uncertainty for B_0 was taken from Marinier et al. (2004), but no reliable source was available for the estimate of

Table A3.4–19 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management**

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Volatile Solid Calculations (Equation A3.4–6 and A3.4–7)						
Dry Matter Intake (DMI)						
- Swine		Triangular			National/Subcategory	Marinier et al. (2004)
	Boars		1.2–3.4	2.28		
	Sows		2.0–2.5	2.25		
	Pigs < 20 kg		0.55–0.72	0.68		
	Pigs 20–60 kg		0.63–2.1	1.75		
	Pigs > 60 kg		2.1–3.3	2.7		
- Poultry						
	Laying hens		7.4–9.9	9.85		
	Broilers		0.085–0.088	0.086		
	Turkeys		0.23–0.53	0.27		
- Other livestock						
	Sheep		1.2–3.0	2		
	Lambs		1.2–1.6	1.35		
	Goats		1.4–2.3	1.75		
	Horses		7.4–9.9	9.85		
	Buffalo		6.8–10.1	8.43		
Ash						
- Cattle		Triangular	3.9–11	8	National/Category[b]	Marinier et al. (2004)
- Swine			3.9–11	4.8–5.1		
- Poultry	Laying hens		3.9–11	10		
	Broilers		3.9–11	7		
	Turkeys		3.9–11	5		
- Other livestock						
	Sheep		3.9–11	8		
	Lambs		3.9–11	8		
	Goats		3.9–11	8		
	Horses		3.9–11	4		
	Buffalo		3.9–11	8		

Table A3.4–19 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management** (cont'd)

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Digestible Energy (DE)						
-Cattle		Normal	Pasture ±9%/ Confined ±9% /Background ±7.5%/Prepared feed ±5.5%		Provincial/Production subcategory	Derived from raw data supplied by Valacta Dairy Services
-Swine			±9%		Provincial/Category	
-Poultry	Laying hens		±5.5%		National/Subcategory	
	Broilers					
	Turkeys					
-Other livestock						
	Sheep		±9%		Provincial/Category	
	Lambs				Provincial/Category	
	Goats				Provincial/Category	
	Horses				Provincial/Category	
	Buffalo				Provincial/Category	
Emission Factor Calculation (Equation A3.4–5)						
Methane Conversion Factor (MCF)						
	All Animals	Normal	±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum Methane Producing Potential (B_0)						
	Dairy cattle	Triangular	0.1–0.24	0.24	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Non-dairy cattle		0.19–0.33	0.19		
	Swine		0.32–0.48	0.48		
	Poultry		0.24–0.39	0.32		
	Sheep and lambs		0.19–0.36	0.19		
	Goats		0.15–0.19	0.18		
	Horses		0.30–0.36	0.3		
	Buffalo		0.19–0.33	0.19		
Animal Waste Management Systems (MS)[d]						
	Dairy cattle	Triangular	LB: MLV-10% UB: MLV+25%	MLV from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[c] Liquid systems allowed to vary to non-symmetric triangular distributions
	Swine		LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)		
	Non-dairy cattle	Normal	±17%			Marinier et al. (2005). Internally correlated variable[c]
	Poultry					
	Sheep and lambs					
	Goats					
	Horses					
	Buffalo					

Notes:

MLV = most likely value; LB = lower bound; UB = upper bound

a. Most likely value when triangular distribution, normal distributions given as simple ±%.

b. Ash for swine varies among some provinces.

c. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.

d. Values that vary independently during trend analysis.

uncertainty around the MCF. In the current study, a large uncertainty range was used (±45% of the mean) based on expert opinions. However, the choice of this value simply indicates that our confidence in the MCF value is low. The actual value of the total uncertainty estimate for manure management systems must therefore be taken within the context that it is highly dependent on a value and a probability distribution function that is highly uncertain.

In contrast with the Karimi-Zindashty (2012) study, the current analysis was based on a provincial distribution of manure management systems, and uncertainty ranges were estimated from values observed in different provincial and national reports (Koroluk and Bourque, 2003; BPR-Infrastructure, 2008) and surveys (Sheppard et al., 2009, 2010, 2011; Sheppard and Bittman, 2011). In the case of dairy cattle livestock, the lower bound for liquid manure management systems was based on a comparison between reports that suggested that manure treated by liquid systems could vary by as much as 10% above or below the Marinier et al. (2005) estimate. Furthermore, it was reported that there has been a continual movement towards liquid manure systems over time. Therefore, the upper bound was set as 25% based on the rate of adoption of liquid systems from BPR-Infrastructure (2008) and the number of years that have passed since the survey by Marinier et al. (2005). In the case of swine animals, liquid manure management systems' upper bounds were fixed at 100%. Other manure management systems' lower bounds for all animal types were 0, also tending to skew probability distributions. This approach resulted in non-symmetrical distributions for all manure management systems. While this approach increased the uncertainty of each individual manure management system, relative to the Karimi-Zindashty study, it likely reduced its impact on the national emission uncertainty because the manure systems were disaggregated to the provincial level, and the total manure management systems were held to 100% of total manure management systems.

The trend analysis carried out using the ECSM quantified the uncertainty in the magnitude of the change in emissions over time for manure management systems. As was the case for the enteric fermentation method, for the long-term trend, emissions for 1990 and 2013 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. A more detailed description of the trend analysis is found in section A3.4.2.4. The parameters that were allowed to vary independently for the manure management system trend analysis were animal populations, milk production and fat content in dairy cattle animals, body weights in beef cattle and AWMS (noted by a superscript g in Table A3.4–9 and superscript e in Table A3.4–19). Before 2004, lower boundaries for liquid AWMS were calculated based on the rate of adoption of liquid systems and the number of years that have passed since the survey by Marinier et al. (2005), as in the case of upper boundaries. This approach resulted in non-symmetrical distributions for all manure management systems; and for the trend analysis, it also modified the symmetry of probability distributions around liquid systems between the base year and the current year. Trend uncertainty for the 2018 inventory was based on the 2012 trend analysis.

The summary of results of the uncertainty analysis on emissions reported under Manure Management is reported in Chapter 5. Briefly, the uncertainty range used to derive the uncertainty reported in Chapter 5 for the 2014 emissions from manure management is 60% (-32% to +27% of the mean). As was the case with the enteric fermentation results, emission factors account for the majority of uncertainty. Emission factors lie within an uncertainty range of -34% to +62% for the Non-Dairy Cattle category and a range of -60% to +50% for Dairy Cattle. The emission factors for the Swine category, the largest single contributor to manure management emissions, lie within an uncertainty range of -51% to +43%. All other animals contribute little to the emission totals, i.e., 0.19 Mt CO_2 eq within an uncertainty range of 0.13 (-35% of the mean) to 0.23 (+15% of the mean). Overall, as was the case with enteric fermentation results, mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than those calculated from non-stochastic models and tend to be slightly skewed towards the lower boundary, indicating a tendency towards higher emissions. However, mean emissions from swine and other animals estimated using the stochastic model are slightly lower than emissions estimates, and the distribution of emission estimates tends to be slightly skewed towards the upper boundary, indicating a tendency towards lower emissions. This skewed distribution is evident when looking at the range of uncertainty around the emission factors (e.g. 34% to +62% for Non-Dairy Cattle). The asymmetry of the uncertainty range is likely due to a combination of the skewed probability distributions for manure management systems and the same factors that influenced the distribution of enteric fermentation emission estimates for cattle, specifically the skewed distributions for backgrounding of slaughter animals and the uniform distribution used for net energy mobilized from weight loss during lactation in Dairy Cattle.

Based on the trend analysis, there has been no detectable increase in emissions from manure management since 1990, where change from 1990 could range from a decrease of 10% to an increase of 8%, though it is most likely that there has been an increase in emissions of roughly 5.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle livestock in Ontario in 1990, the triangular distribution used around the percentage of manure treated in liquid manure management systems had a lower boundary of 16%, a most likely value of 40% and an upper boundary of 42%; in 2010, the lower boundary was 37%, the most likely value was 40% and the upper boundary 59%. The use of a skewed distribution indicating a higher probability that fewer animals were raised on liquid manure management systems in the past balances the increase in animal populations. As a result, it is improbable overall that there is an increase in manure management emissions over time, particularly from cattle.

The uncertainty range of the analysis carried out in 2012 was slightly smaller than that of the previous analysis (2%), likely due to a combination of lower uncertainty for census animal populations and modifications in the uncertainty bounds around AWMS systems with the addition of two years from the time of the original survey. Overall, the uncertainty range around manure management emissions produced by this analysis is slightly smaller than the data reported by Karimi-Zindashty et al. (2012), as the proportions of manure treated by different manure management systems were distributed to the provincial level in this analysis, whereas a national average was used in the 2012 publication. Monni et al. (2007) estimated CH_4 manure management emission factor uncertainty to be roughly ±30% based strictly on expert opinion. As was the case with enteric fermentation, Karimi-Zindashty et al. (2012) demonstrated that most uncertainty in the manure management model is associated with the use of default IPCC model parameters that are applied at the national level, specifically the MCF. By deriving MCF factors for different regions and different storage structures, uncertainty would be significantly reduced. Further work on uncertainty will focus on the development of trend uncertainty and the refinement of probability distributions around country-specific parameters already existing in the model. As the MCF factor is driving uncertainty for the Manure Management category, it is not suspected that changes to the dairy or swine models would have a large impact on the national manure management uncertainty. However, the introduction of a time series of AWMS for the Dairy and Swine sectors may play an important role in influencing the trend uncertainty for manure management system emissions.

A3.4.4. N_2O Emissions from Manure Management

N_2O emissions from manure management systems result from mineralization of organic materials, and the nitrification and denitrification of mineral nitrogen directly and indirectly.

A3.4.4.1. Direct N_2O Emissions from Manure Management

Three factors are required to estimate N_2O emissions from manure management systems using the IPCC Tier 1 method: (1) N excretion rates for various animal categories and subcategories, (2) types of AWMS and (3) emission factors associated with manure management systems.

As previously described in section A3.4.3, default emission factors or country-specific information sources are sometimes used for minor livestock categories as logical proxies based on species similarities when no other information is available. The following proxies and expert judgement are used in the calculation of N_2O emissions, in addition to those already listed in A3.4.3:

- The nitrogen excretion rate for Swine is used to represent wild boars.
- The nitrogen excretion rate for Sheep is used to represent lambs, as well as llamas and alpacas.
- The nitrogen excretion rate for Buffalo is used to represent bison.
- The nitrogen excretion rate for Other Cattle is used to represent Deer and Elk.

Nitrogen Excretion Rates for Various Domestic Animals

For the Dairy Cattle category, the Tier 2 methodology from the 2006 IPCC guidelines is used. Nitrogen intake from feed has increased steadily since 1990 in order to meet the protein requirements of increased milk production (Table A3.4–4) and, as a result, a corresponding increase in dairy cow N excretion rates (Table A3.4–20) was calculated.

For the Non-Dairy Cattle category, annual live weights (see section A3.4.1.1) were multiplied by the IPCC default N excretion rate (IPCC, 2006) to produce a time series of manure N excretion rates (Table A3.4–20).

For the Swine category, distinct parameters were used to estimate N excretion from subcategories of breeding animals and market animals. In the case of market

Table A3.4–20 **Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)**

(kg N/head/year)								
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter [a]	Steers [a]	Calves
1990	107	72	88	58	45	45	48	27
1995	110	72	99	65	50	55	57	27
2000	114	73	103	70	54	60	61	27
2005	116	73	102	68	52	61	61	26
2010	123	76	113	69	53	62	63	27
2011	122	76	112	69	53	62	64	27
2012	122	76	114	69	53	65	65	27
2013	126	76	99	69	53	64	65	27
2014	125	76	103	70	53	63	64	27
2015	123	76	111	74	56	65	66	27
2016	123	76	112	75	58	66	67	27
2017	121	76	114	75	57	65	66	26
2018	122	76	108	75	57	65	67	26
2019	122	76	107	74	57	66	68	26

Notes:

N excretion rate for non-dairy cattle is 0.31 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

a. Values are adjusted for the life-span of slaughter animals.

swine, increases in growth rates and live weights were used to develop a country-specific time series of animal mass per production stage, which was multiplied by an N excretion rate derived from Table 10.19 in the 2006 IPCC guidelines. For breeding animals, the IPCC default N excretion rate was multiplied by the IPCC default animal mass.

Annual manure N excretion rates for all other types of animals vary by livestock category according to IPCC Tier 1 default values (IPCC, 2006). Poultry have high excretion rates (Table A3.4–22), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison have the highest N excretion rates due to their size. Tier 1 default values for fur-bearing animals and rabbits have exceptionally high excretion rates relative to their size (Table A3.4–22), but are understood to be based on breeding stock and attribute all manure produced on the farm to the breeding stock.

Table A3.4–21 **Time Series of Manure N Excretion Rates for Swine (kg N/head/year)**

(kg N/head/year)					
Year	Sows	Boars	Pigs (<20 kg)	Pigs (20–60 kg)	Pigs (>60 kg)
1990	17	17	1.6	7.3	15.0
1995	17	17	1.7	7.3	15.2
2000	17	17	1.7	7.3	15.6
2005	17	17	1.7	7.2	15.7
2010	17	17	1.7	7.2	16.2
2011	17	17	1.7	7.1	16.2
2012	17	17	1.7	7.1	16.4
2013	17	17	1.7	7.1	16.5
2014	17	17	1.7	7.2	16.6
2015	17	17	1.7	7.1	16.7
2016	17	17	1.7	7.1	16.9
2017	17	17	1.7	7.1	16.9
2018	17	17	1.7	7.0	17.0
2019	17	17	1.7	7.1	17.2

Notes:

N excretion rate for breeding swine is 0.24 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

N excretion rate for market swine is 0.53 kg N-1000 kg^{-1}-day^{-1} and was calculated based on market value of 0.24, overall swine excretion of 0.50, and weighting proportion indicated in the footnote of Table 10.19. Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Table A3.4–22 **Manure N Excretion Rates for All Other Animals**

Animal Categories	N Excretion Rate [a] (kg N/1000 kg/day)	Average Body Weight [b] (kg)	Annual Manure N (kg N/head/year)
Sheep	0.42	27	4.1
Lambs	0.42	27	4.1
Goats	0.45	64	10.5
Horses	0.3	450	49.3
Llamas and Alpacas	0.42	112	17.2
Bison	0.32	580	67.7
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8
Elk and Deer	0.31	120	13.6
Wild Boars [c]	0.5	61	11.1
Foxes	12.1	1.8	7.9
Mink	4.6	1.8	3.0
Rabbits	8.1	1.6	4.7
Mules and Asses	0.3	245	26.8

Notes:

a. Data source – IPCC (2006).
b. For buffalo, average live weight was taken from the U.S. NIR.
c. Equivalent to overall swine excretion rate of 0.50 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N_2O emissions. Less-aerated systems, such as liquid systems, generate little N_2O, whereas drylots produce more. However, there is little scientific information in Canada specifying amounts of N_2O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Annex 6, were used to estimate emissions. For livestock from the Dairy and Swine sectors, weighted N_2O emission factors are calculated using the proportion of manure in each AWMS subsystem (see section A3.4.3.3) and the corresponding default emission factors (Annex 6), to produce a time series of N_2O emission factors by AWMS.

Table A3.4–15 summarizes the distribution of manure management systems in Canada by animal category. N_2O emissions from manure on pasture, range and paddock systems are not included under the Manure Management category, as they are reported under the Agricultural Soils category (section A3.4.5.1). Animal population data are detailed in section A3.4.1.

Direct N_2O emissions from manure management are estimated using the IPCC Tier-1 method (Equation A3.4–9), as follows:

Equation A3.4–9

$$N_2O_{D(mm)} = \sum_{i} \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T}\right) \times EF_{AWMS} \times \frac{44}{28}$$

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	population for the Tth animal category or subcategory in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3.4–20 for cattle and Table A3.4–22 for non-cattle), kg N/head/year
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 6), kg N_2O-N/kg N
$44/28$	=	coefficient converting N_2O-N to N_2O

A3.4.4.2. Indirect N_2O Emissions from Manure Management

During animal manure storage and handling, losses of N occur through the following indirect pathways: (1) volatilization of manure N as NH_3 and NO_x and subsequent re-deposition and (2) leaching and runoff of N. Leaching is estimated only for the Dairy and Swine sectors, where country-specific information on the fraction of nitrogen loss due to leaching and runoff was available. These losses of manure N can result in N_2O emissions (Equation A3.4–10 and Equation A3.4–11).

In the case of the Dairy and Swine sectors, the introduction of a manure management time series that considered a wider variety of manure storage conditions results in changes in the fraction of manure N that is lost over the reporting period (Table A3.4–23). A shift from solid manure storage to liquid, an increase in the number of covered manure storage systems and, in the case of the Dairy sector, a shift in time in pasture, resulted in a decrease in the proportion of total N lost to the environment over time.

Equation A3.4–10

$$N_2O_{G(mm)} = \sum_{i} \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{GasMS(T,AWMS)}\right) \times EF_4 \times \frac{44}{28}$$

$N_2O_{G(mm)}$	=	indirect N_2O emissions due to NH_3 volatilization for managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–20 for cattle and Table A3.4–22 for non-cattle), kg N/head/year
$Frac_{GasMS(T,AWMS)}$	=	fraction of managed manure N for livestock category, T that volatilizes as NH_3 and NO_x in the manure management system, AWMS (see Table A3.4–23 and Table A3.4–24)
EF_4	=	emission factor from atmospheric deposition of N, 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilized) (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–23 **Total N, NH_3- and NO_x-N Losses Associated with Various Livestock and Manure Management Systems**

Animal Category	Manure Management Systems	$Frac_{(LossMS)}$ (%) [a]	NH_3-N and NO_x-N Loss (%) [a, b, c] ($FRAC_{GasMS}$)
Non-Dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range	-	20 (5–50)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range	-	20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range	-	20 (5–50)
Elk and Deer	Solid Storage	15 (5–20)	12 (5–20)
Wild Boars	Solid Storage	15 (5–20)	12 (5–20)
Foxes	Solid Storage	15 (5–20)	12 (5–20)
Mink	Solid Storage	15 (5–20)	12 (5–20)
Rabbits	Solid Storage	15 (5–20)	12 (5–20)
Mules and Asses	Solid Storage	15 (5–20)	12 (5–20)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range	-	20 (5–50)

Notes:

a. Numbers in parentheses indicate a range.

b. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).

c. Leaching loss from pasture, range and paddock is reported under indirect N_2O emissions from agricultural soils and is calculated using the same parameters as manure N spread to agricultural soils.

Equation A3.4–11

$$N_2O_{L(mm)} = \sum_{i}\sum_{AWMS}\left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{LeachMS(T,AWMS)}\right) \times EF_5 \times \frac{44}{28}$$

$N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year

$N_{i,T}$ = population for livestock category or subcategory, T in province i

$N_{i,AWMS}$ = percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)

$N_{EX,T}$ = N excretion rate for livestock category or subcategory, T (see Table A3.4–20 for cattle, Table A3.4–21 for swine, and Table A3.4–22 for all other livestock), kg N/head/year

$Frac_{LeachMS(T,AWMS)}$ = fraction of managed manure N losses for dairy (see Table A3.4–24) and swine (see Table A3.4–25) and other livestock (see Table A3.4–23) for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS

EF_5 = emission factor from N leaching and runoff, 0.0075 kg N_2O-N/(kg N leaching/runoff) (IPCC, 2006)

$44/28$ = coefficient converting N_2O-N to N_2O

Table A3.4–24 **Total N, NH_3- and NO_x-N Losses Associated with Dairy Cattle and Manure Management Systems**

	$Frac_{(LossMS)}$ (%)			Leaching Loss (%) ($Frac_{LeachMS}$)			NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)		
Year	Liquid	Solid	Other [a]	Liquid	Solid	Other	Liquid	Solid	Other
1990	12	23	0	0	3	0	11	16	0
1995	12	23	0	0	3	0	11	16	0
2000	13	23	0	0	3	0	11	16	0
2005	13	23	37	0	3	7	12	16	23
2010	10	23	35	0	3	5	9	17	24
2011	10	23	35	0	3	5	8	17	24
2012	10	23	35	0	3	5	8	17	24
2013	10	23	35	0	3	5	8	17	24
2014	10	23	35	0	3	5	8	17	24
2015	10	23	35	0	3	5	8	17	24
2016	10	23	35	0	3	5	8	17	24
2017	10	23	35	0	3	5	8	17	24
2018	10	23	35	0	3	5	8	17	24
2019	10	23	35	0	3	5	8	17	24

Note:

a. Other in the case of Dairy Cattle refers only to composting of solid manures.

Table A3.4–25 **Total N, NH_3- and NO_x-N Losses Associated with Swine Manure Management Systems**

	$Frac_{(LossMS)}$ (%)		Leaching Loss (%) ($Frac_{LeachMS}$)		NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)	
Year	Liquid	Solid	Liquid	Solid	Liquid	Solid
1990	23	31	0	3.3	21	23
1995	23	31	0	3.3	21	23
2000	23	31	0	3.4	21	23
2005	23	31	0	3.3	21	23
2010	20	30	0	3.1	19	23
2011	19	30	0	3.0	18	23
2012	20	30	0	3.0	18	23
2013	20	30	0	3.0	18	23
2014	20	30	0	2.9	18	23
2015	20	30	0	2.9	18	23
2016	20	30	0	2.9	18	23
2017	20	30	0	2.9	18	23
2018	20	30	0	2.9	18	23
2019	20	30	0	2.9	18	23

A3.4.5. N_2O Emissions from Agricultural Soils

Emissions of N_2O from agricultural soils consist of direct and indirect emissions. N_2O emissions that result from anthropogenic N inputs occur through direct pathways, i.e., from the soils to which the N is added, and indirect pathways through (1) volatilization of inorganic N fertilizers and manure N as NH_3 and NO_x and subsequent deposition, and (2) leaching and runoff of N.

Nitrogen is allocated to the landscape according to the following procedure: (1) region-specific N application rates are calculated for each crop type; (2) a "recommended" amount of nitrogen is allocated to each of 405 ecodistricts in Canada based on the application rate and the area of each crop type within the ecodistrict; (3) the total amount of manure N available to be applied to agricultural soils is calculated based on the population of livestock within the ecodistrict; (4) biosolids are applied to select crop types according to remaining "recommended" N, after subtracting the available manure N from step 3; (5) Manure N is applied to crops in each ecodistrict, according to remaining crop requirements following biosolids application; (6) the amount of organic N applied (manure + biosolids) is subtracted from the initial "recommended" amount to calculate the amount of "theoretical" crop N requirements not met by organic sources alone; and (7) the amount of "theoretical" N is scaled to match total provincial fertilizer sales reported by Statistics Canada, and this corrected amount represents inorganic N fertilizer applied to each ecodistrict.

A3.4.5.1. Direct N_2O Emissions from Agricultural Soils

Direct sources of emissions from agricultural soils include inorganic N fertilizers, organic N fertilizers, urine and dung deposited on pasture, range and paddock by grazing animals, crop residues, mineralization associated with loss of soil organic matter and cultivation of organic soils. Tillage practices, summerfallow and irrigation can also influence soil N_2O emissions. The N_2O emission factors for most of the direct emission sources are country-specific and incorporate the influence of moisture regimes, landscape position and soil texture on rates of N_2O production and emission (Rochette et al., 2008).

The approach involves determining base emission factors "EF_{BASE}" for each of 405 ecodistricts,[21] using long-term growing season precipitation and potential evapotranspiration. The EF_{BASE} is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_{BASE} (Equation A3.4–12).

Equation A3.4–12

$$EF_{BASE} = EF_{CT,\frac{P}{PE}=1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

EF_{BASE} = a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}

EF_{CT} = emission factor, estimated at actual P/PE in an ecodistrict, kg N_2O-N kgN^{-1} (see Figure A3.4–3)

$EF_{CT,\,P/PE=1}$ = emission factor of 0.017 estimated at P/PE = 1, kg N_2O-N kgN^{-1}

F_{TOPO} = fraction of the ecodistrict area in the lower section of the toposequence—see Rochette et al. (2008)

P = long-term mean precipitation from May to October in an ecodistrict, mm

PE = long-term mean potential evapotranspiration from May to October, mm

Base N_2O Emission Factor (EF_{BASE})

Nitrous oxide is produced mainly during denitrification and is therefore greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, N_2O emission factors have been shown to increase with increased rainfall (Dobbie et al., 1999) and climate-variable emission factors have been used in estimating soil N_2O inventory (Flynn et al., 2005). Similarly, this methodology estimates emission factors including winter and spring thaw emissions at the ecodistrict level as a function of the ratio of the long-term normals of precipitation over potential evapotranspiration (P/PE) from May to October (Figure A3.4–4). The EF_{BASE} factors were determined using the same approach as for the determination of the IPCC Tier 1 emission factor by Bouwman (1996), i.e., EF_{BASE} = slope of the "N_2O emissions versus N fertilizer rate" relationship. The EF_{BASE} was estimated for the three regions where field N_2O measurements are available: Quebec-Ontario; the Brown and Dark Brown soil zones of the Prairies; and the Grey and Black soil zones of the Prairies. The soil N_2O emissions versus fertilizer N relationship determined for the Quebec-Ontario region has a similar slope (0.012 kg N_2O-N kgN^{-1}) (Gregorich et al., 2005) and fit (r^2 = 0.43) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairies region, low and variable N_2O emissions were measured across the range of N fertilizer rates (Brown and Dark Brown soils = 0.0016 kg N_2O-N kgN^{-1}; Grey and Black soils = 0.008 kg N_2O-N kgN^{-1}). These observations suggest that soil N_2O production in the Prairies region is not limited by mineral N availability, but rather by the low denitrification activity under well-aerated soil conditions. Despite the uncertainty in the determination of emission factors in the Prairies region, this approach is deemed a valid option to account for the influence of moisture limitations on N_2O emissions in that region.

To account for a topographical effect, an EF_{BASE} of 0.017 kg N_2O-N kgN^{-1} (EF_{BASE} at P/PE = 1) was used for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types. Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based on the observations that N_2O emissions are greater in lower sections of the landscape, where intermittently saturated soil conditions are favourable to denitrification (Corre et al., 1996, 1999; Pennock and Corre, 2001; Izaurralde et al., 2004). The fraction of the landscape occupied by such lower sections (F_{TOPO}) was applied to concave portions of the landscape (i.e., lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and where they are imperfectly and poorly drained with mottles[22] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine the proportional distribution of different landforms (such as lower sections) in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to which F_{TOPO} would be applied to derive N_2O emission estimates (Rochette et al., 2008).

21 "Ecodistrict" represents one level within Canada's National Ecological Framework. The country includes 1027 ecodistricts, characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna.

22 Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. Prevalence, size and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods.

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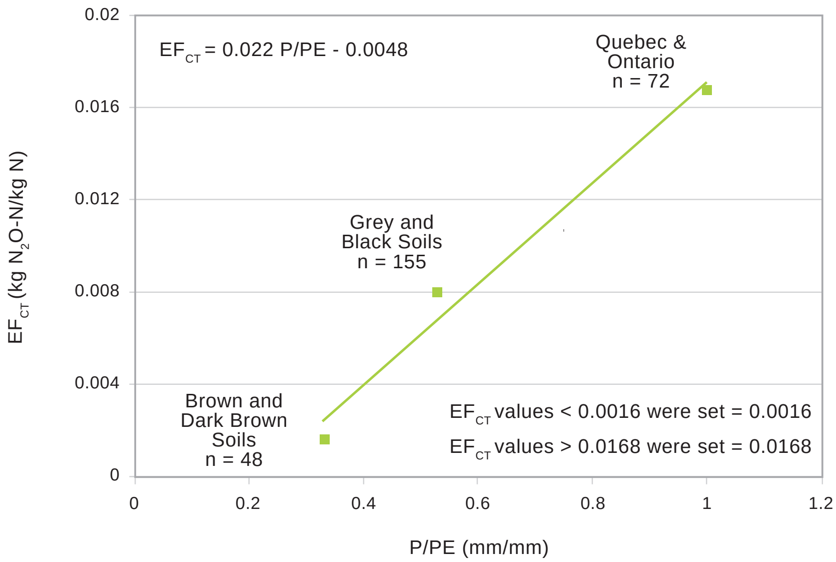
Figure A3.4–4 **EF_{CT} as a Function of Long-Term Ratio of Precipitation over Potential Evapotranspiration (P/PE) from 1971 to 2000**



N_2O Emissions During Winter and Spring Thaw

Field measurements of N_2O flux using chambers in Eastern Canada are usually made during the snow-free period (Gregorich et al., 2005). Average annual snowfall in Eastern Canada varies between 1.0 and 4.5 m (Environment Canada, 2002). Snowmelt water in the spring creates wet soil conditions that often stimulate N_2O production (Grant and Pattey, 1999; Wagner-Riddle and Thurtell, 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al., 2007). Limiting emission estimates to the snow-free period therefore underestimates total annual N_2O emissions in that region. Rochette et al. (2008) reported mean N_2O emissions during the winter and spring thaws in southern Ontario to be 1.2 kg N_2O-N ha^{-1} (Wagner-Riddle et al., 2007; Wagner-Riddle and Thurtell, 1998); these emissions were added to emissions calculated through the relationship between EF_{CT} and P/PE shown in Figure A3.4–4.

Emissions of N_2O during spring thaw also occur on the Prairies, but are usually lower than in Eastern Canada (Lemke et al., 1999). Chamber flux measurements used to estimate EF_{CT} on the Prairies include spring thaw emissions, because low snow accumulation in the region allows chamber deployments during that period. Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required on the Prairies.

There are 958 weather stations in the AAFC-archived weather database.[23] These stations (80º00′N–41º55′N, 139º08′W–52º40′W) located across Canada (758 stations) and the United States (200 stations) were used to interpolate precipitation and potential evapotranspiration from May to October from 1971 to 2000 to the ecodistrict centroids. The Meteorological Service of Canada, Environment and Climate Change Canada provided the Canadian weather data.

Soil Texture and N_2O Emissions

Soil texture does not directly influence N_2O production in soils. However, it correlates with several physical and chemical parameters that control N_2O production and transport in the soil profile (Arrouays et al., 2006; da Sylva and Kay, 1997; Minasny et al., 1999). Consequently, soil texture-related variables often correlate with N_2O emissions from agricultural soils (Hénault et al., 1998; Corre et al., 1999; Chadwick et al., 1999; Bouwman et al., 2002a; Freibauer, 2003).

The impact of soil texture on N_2O emissions from agricultural soils was incorporated in the emission factor using a ratio factor ($RF_{TEXTURE}$) defined as the ratio of N_2O emissions on soils of a given textural class to the mean emissions from soils of all textures (Equation A3.4–13). A value of 0.8 was assigned to the $RF_{TEXTURE-COARSE}$ and $RF_{TEXTURE-MEDIUM}$ and 1.2 for $RF_{TEXTURE-FINE}$ (Rochette et al., 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Quebec, Ontario and the Atlantic provinces. The assumption of a low influence of soil texture on N_2O emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairies region, where low soil water content results in low N_2O emissions, regardless of the soil texture.

23 Gameda S. Personal communication, Agriculture and Agri-Food Canada (2006).

Equation A3.4–13

$$RF_{TEXTURE,i} = (RF_{TEXTURE\text{-}FINE,i} \times FRAC_{TEXTURE\text{-}FINE,i}) + (RF_{TEXTURE\text{-}COARSE,i} \times FRAC_{TEXTURE\text{-}COARSE,i}) + (RF_{TEXTURE\text{-}MEDIUM,i} \times FRAC_{TEXTURE\text{-}MEDIUM,i})$$

$RF_{TEXTURE,i}$	=	a weighted soil texture ratio factor of N_2O for an ecodistrict i for Ontario, Quebec and the Atlantic provinces
$RF_{TEXTURE\text{-}FINE,i}$	=	a ratio factor of N_2O for fine-textured soils for an ecodistrict i
$FRAC_{TEXTURE\text{-}FINE,i}$	=	fraction of fine-textured soils in an ecodistrict i
$RF_{TEXTURE\text{-}COARSE,i}$	=	a ratio factor of N_2O for coarse-textured soils for an ecodistrict i
$FRAC_{TEXTURE\text{-}COARSE,i}$	=	fraction of coarse-textured soils in an ecodistrict i
$RF_{TEXTURE\text{-}MEDIUM,i}$	=	a ratio factor of N_2O for medium-textured soils for an ecodistrict i
$FRAC_{TEXTURE\text{-}MEDIUM,i}$	=	fraction of medium-textured soils in an ecodistrict i

Organic Nitrogen Fertilizers

N_2O emissions from organic N sources include emissions from the application of sewage sludge (biosolids), manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology was used for estimating N_2O emissions from organic N fertilizers.

Equation A3.4–14

$$N_2O_{ON} = \sum_i (N_{ON-CROPS,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

N_2O_{ON}	=	emissions from organic nitrogen fertilizer applied to cropland, kg N_2O/year
$N_{ON\text{-}CROPS,i}$	=	organic nitrogen (i.e., biosolids and animal manure) applied as N fertilizers on cropland in ecodistrict i, kg N yr^{-1}
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
$44/28$	=	coefficient converting N_2O-N to N_2O

Manure Nitrogen

The methodology is based on the quantity of manure N produced by domestic animals (see section A3.4.4.1) and country-specific $EF_{BASE,}$ taking into account the moisture regime and topographic conditions at the ecodistrict level. Manure was allocated to crops preferentially, based on a modified version of Yang et al. (2011), in order to better reflect practices and to ensure consistency in Canada's manure allocation methodology used in environmental indicators in Canada. Estimates of N_2O emissions from this source are calculated using Equation A3.4–14, in combination with our organic N sources.

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–15. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3.4–15

$$N_{MAN-CROPS,i} = \sum_i (N_T \times N_{EX,T}) \times (1 - N_{PRP,T}) \times (1 - FRAC_{(LossMS,T)})$$

$N_{MAN\text{-}CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kgN yr^{-1}
N_T	=	population for animal category or subcategory T, heads
$N_{EX,T}$	=	N excretion rate for animal category or subcategory (Table A3.4–20 and Table A3.4–22)
$N_{PRP,T}$	=	fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3.4–15)
$FRAC_{(LossMS,T)}$	=	fraction of manure N loss during storage and handling (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3.4–23 and Table A3.4–24)

Animal population data sources are detailed in section A3.4.1. Annual livestock population data from each animal category or subcategory at the provincial level are disaggregated into ecodistricts based on the livestock population distribution reported from the *Census of Agriculture*. Between two consecutive census years, livestock population proportions at the ecodistrict level are interpolated.

Biosolids Nitrogen

Data on the production and management of biosolids were derived from an Environment Canada–commissioned report (Cheminfo Services Inc., 2017). The data set was generated through a combination of telephone surveys and reports by the municipal wastewater treatment services in 33 Census Metropolitan Areas (CMAs) and from municipal and provincial environment departments/ministries across Canada. This survey represented only 63% of the Canadian population based on the wastewater treatment plants (WWTPs) located in CMAs and did not include PEI and the three Canadian territories. The data were compiled at five-year intervals (1990–2015) and had gaps and inconsistencies owing to a lack of complete management information and changes in provincial regulations on biosolids. Nevertheless, these data are the only known source for a quantitative analysis of biosolids available at a national scale.

Biosolids production data were produced through a series of analytical steps (Figure A3.4–5, Table A3.4–26). First, a provincial-level per capita model was constructed to establish a "baseline biosolids production." Production was assumed to be directly proportional to the population of a geographical area. Different spatially scaled roll-ups of Statistics Canada population estimates were evaluated for best fit of the data. Population estimates used for testing included CMA populations, aggregated CMA populations and provincial populations. Upon regression analysis, the provincial population-based model was chosen based on the strength of the correlation coefficients. Fortunately, the data generated using this approach were not significantly different from the data reported during the years that Cheminfo Services Inc. (2017) was doing the reporting. Therefore, the smoothed annual provincial biosolids production was derived using the linear model. For PEI, annual estimates for biosolids production were developed based on expert opinion and using a national average per capita figure (22.5 kg / person/yr). This analysis created a complete time series of biosolids production at a provincial scale.

Secondly, the regional rates of land application of biosolids (dry tonnes) were derived using the proportions reported in Cheminfo Services Inc. (2017) adjusted for federal, provincial and municipal regulations, bylaws and restrictions (Table A3.4–26). At the federal level, the regulations imposed by the CCME were applied. Afterwards, provincial restrictions based on the nutrient content of the biosolids and any restrictions on the frequency of biosolids application to lands were incorporated (Table A3.4–26).

Biosolids are typically subject to various digestion and decomposition methods in WWTPs prior to land application. These methods have significant implications for the nutrient content of the biosolids and therefore influence the emission potential when land-applied. Accordingly, as the final step, a combination of survey results and literature analyses was used to identify the major digestion processes, and estimates from Dad et al. (2018) were used to establish the nutrient content of the biosolids.

Figure A3.4–5 **Schematic Details of the Procedures and Data Sources Used to Determine the Time Series of Biosolids Production at a Provincial Scale**

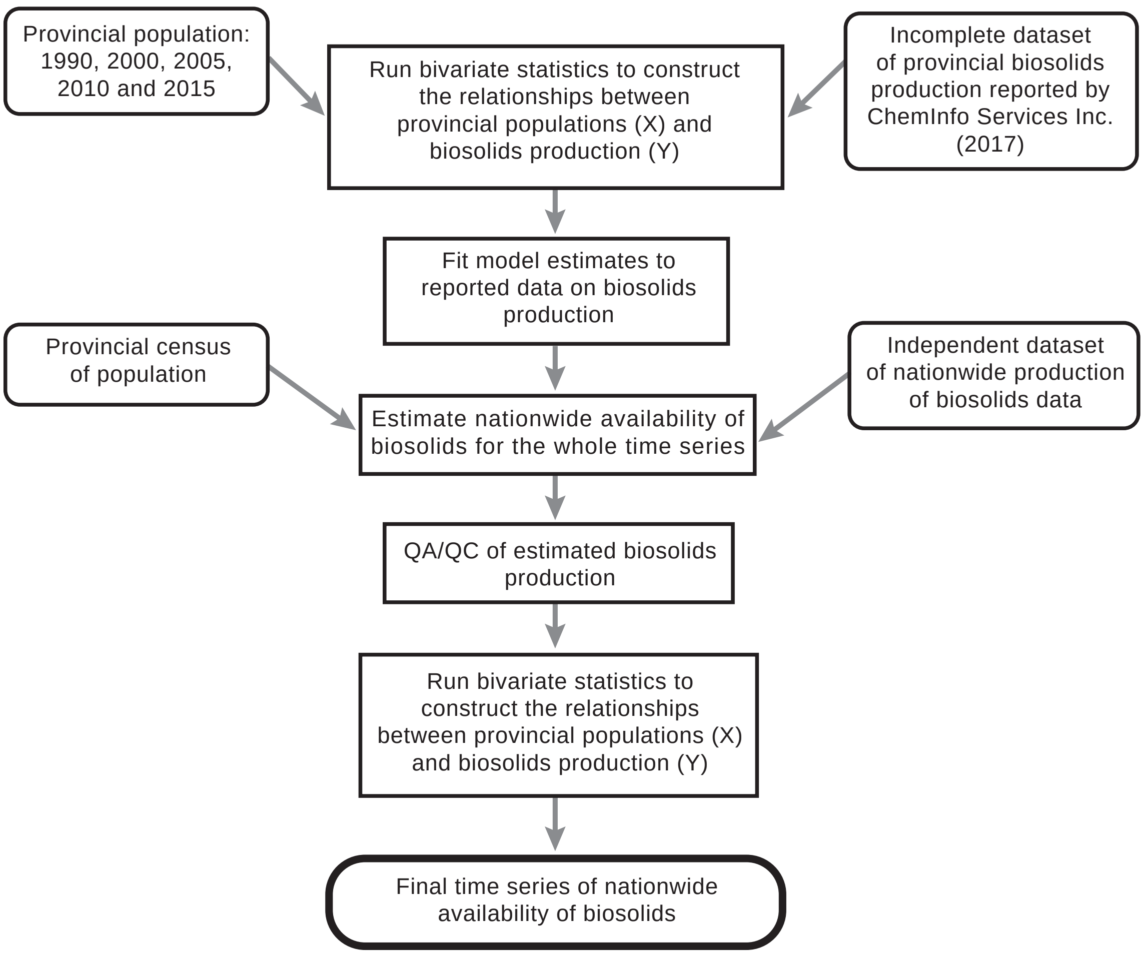


Table A3.4–26 **Data Sources Used for Determination of Annual Biosolids Production and Characteristics at the Provincial Scale**

Category	Data source	Notes/Comments
Biosolid Production	Cheminfo Services Inc. (2017)	Survey data for biosolid production and fractions that are land-filled, incinerated, land applied, and land-reclamation.
CMA population	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710013501	Statistics Canada. Population estimates, July 1, by census metropolitan area and census agglomeration, 2016 boundaries.
Provincial population	https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E	Statistics Canada. Census Profile 2016
Federal and provincial regulations	https://www.ccme.ca/files/Resources/waste/biosolids/pn_1446_biosolids_leg_review_eng.pdf	CCME. A Review of the Current Canadian Legislative Framework for Wastewater Biosolids.
Biosolids—fractions by digestive processes	Cheminfo Services Inc. (2017)	British Columbia commissioned work.
	Hydromantis Ltd. (2007). GPS-X 5.0 software. General Purpose Simulator — default parameters.	
	Environmental Dynamics Inc. (2017). Beneficial Reuse of Biosolids Jurisdictional Review.	
Nutrient content of biosolids under varied digestion/treatment processes	Dad et al. (2018)	

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Quality Control and Quality Assurance

For the production data, quality control was conducted at the provincial and national levels. To verify the validity of our data, comparisons were made between the estimated values against independent data points available from literature and from other data sources at the national level. Our data reasonably reflected the production volume of biosolids at the provincial level and represented the changes in provincial regulations that occurred at specific years (Table A3.4–27). At the national level, the data aligned well with the national figures (Figure A3.4–6).

Allocation of Biosolids to Ecodistricts and Crops

The amount of biosolids applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–16. Human population was used as a proxy to distribute provincial land-applied biosolids N to the ecodistrict spatial scale. In order to avoid over-application of N in an ecodistrict, a correction procedure was implemented to coordinate the application of manure and biosolids with recommended crop application rates per ecodistrict. First, the total amount of manure N within each ecodistrict was subtracted from the total amount of N required for crop growth, and compared with the amount of biosolids N initially allocated to the ecodistrict. In cases where biosolids N exceeded remaining crop N requirements, the required amount was applied and the excess N was reallocated to other ecodistricts in the province. Next, biosolids N was applied to select crops within each ecodistrict as per provincial and municipal regulations and bylaws limiting the application of biosolids. The amount of biosolids N applied to each crop in a given ecodistrict was then subtracted from the initial crop N requirements, and the modified parameter was used to distribute manure N to crops, following the manure application methodology.

Table A3.4–27 **Performance Statistics of Estimated Production Data Against Reported Figures at Provincial CMA and City Scale**

Location	Reported Production (kt)	Estimated Production (kt)	% Deviation	Year	Source
Calgary CMA, AB	20.5	23	12.2	Annually	EDI (2017)
City of Edmonton, AB	18	15.6	13.33	1990 to 2004	City of Edmonton (2012)
Halifax CMA, NS	30	13	56.67	Since 2014	EDI (2017)
City of North Battleford, SK	3.5	0.6	82.86	2003–2004	EDI (2017)
City of Toronto, ON	55	64	16.36	Since 2007	AECOM (2009)
City of Kelowna, BC	36.4	3.7	89.84	Since 2006	EDI (2017)

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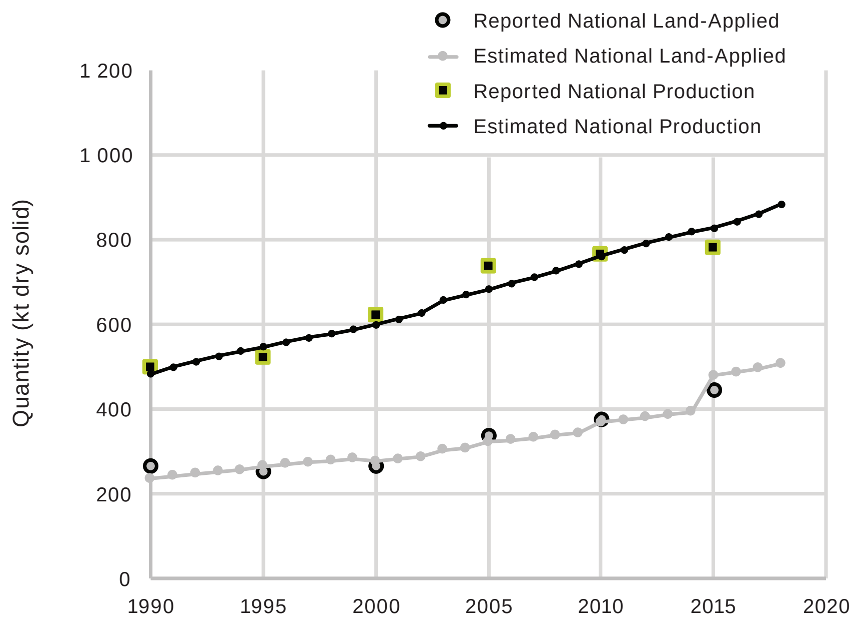
Figure A3.4–6 **National Biosolids Production (kt dry solid) Versus the Estimated Total Biosolids Production**



Equation A3.4–16

$$N_{BIO-CROPS,i} = \sum_i \left[Prod_p \times Frac_{LAND} \times Frac_{POP,i} \times \sum (TN_k \times Frac_{TYPE,k}) \times Frac_{CROP,im}\right]$$

$N_{BIO\text{-}CROPS,i}$ = biosolids applied as N fertilizer on cropland in ecodistrict i, kg N/year

$Prod$ = Biosolids production by province, p (kg)

$Frac_{LAND}$ = Fraction of provincial biosolids that are land-applied

$Frac_{POP,i}$ = Fraction of provincial human population in each ecodistrict i

TN_k = Total nitrogen content (%) by biosolids type k

$Frac_{TYPE,k}$ = Fraction of each biosolids treatment type k

$Frac_{CROP,im}$ = Fraction of biosolids N applied to crop type m, in ecodistrict i

Inorganic Nitrogen Fertilizers

The method for estimating N_2O emissions from inorganic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3.4–17 is used to estimate N_2O emissions by ecodistrict. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

Equation A3.4–17

$$N_2O_{SFN} = \sum_i \left(N_{FERT,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

N_2O_{SFN} = emissions from inorganic N fertilizers, kg N_2O yr^{-1}

$N_{FERT,i}$ = inorganic N fertilizer consumption in ecodistrict i, kgN yr^{-1}; N_{FERT} at an ecodistrict level is estimated using Equation A3.4–18

$EF_{BASE,i}$ = a weighted average of emission factors at ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}

$RF_{TEXTURE,i}$ = soil texture N_2O ratio factor for ecodistrict i

$44/28$ = coefficient converting N_2O-N to N_2O

Data for inorganic N fertilizer sales are available by province only and were disaggregated to the ecodistrict level. The approach (Equation A3.4–18) was based on the assumption that the amount of inorganic N fertilizers applied (N_{APPLD}) is equal to the difference between recommended N rates (N_{RCMD}) and manure N available for application on cropland ($N_{MAN\text{-}AV,CROPS}$).

Equation A3.4–18

$$N_{APPLDP,i} = N_{RCMD,i} - N_{MAN\text{-}AV,CROPS,i}$$

$N_{APPLDP,i}$ = total N fertilizer potentially applied in ecodistrict i, kgN yr^{-1}

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kgN yr^{-1}

$N_{MAN\text{-}AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kgN yr^{-1}

Based on the work of Yang et al. (2007), N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in an ecodistrict (Equation A3.4–19).

Equation A3.4–19

$$N_{RCMD,i} = \sum_{ij} (CROPA_{ij} \times N_{RECRT,ij})$$

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kgN yr^{-1}

$CROPA_{ij}$ = area of crop type j in ecodistrict i, ha

$N_{RECRTij}$ = recommended annual N application rate for crop type j in ecodistrict i, kgN ha-yr^{-1}

$N_{MAN\text{-}AV,CROPS}$ was calculated as the sum of all manure N from all farm animals (Equation A3.4–20) in the ecodistrict as follows:

Equation A3.4–20

$$N_{MAN\text{-}AV,CROPS,i} = N_{MAN\text{-}CROPS,i} \times (1 - UNAV)$$

$N_{MAN\text{-}AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kgN yr^{-1}

$N_{MAN\text{-}CROPS,i}$ = total amount of manure N applied as fertilizers to cropland in ecodistrict i, kgN yr^{-1}

$UNAV$ = fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al., 2007)

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLD} is adjusted in each ecodistrict as follows:

Equation A3.4–21

$$N_{FERT,i} = N_{APPLDi} \times \left[\frac{N_{SALESp}}{\sum_{i}^{n} N_{APPLDi}} \right]$$

N_{FERTi} = total fertilizer N actually applied to all crops in ecodistrict i, kg

$\sum_{i}^{n} N_{APPLDi}$ = total fertilizer N potentially applied to all crops in all ecodistricts in a province, kg

N_{SALESp} = total amount of fertilizer N sold in province p, kg

For years between census years (census years were 1991, 1996, 2001, 2006 and 2011), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLD} and N_{FERT} at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased since 1990, from 1.2 Mt to 2.6 Mt N, mainly because of the intensification of cropping systems from 1991 to 1997 and increased conversion from perennial to annual crops due to favourable grain prices since 2007 (Figure A3.4–7).

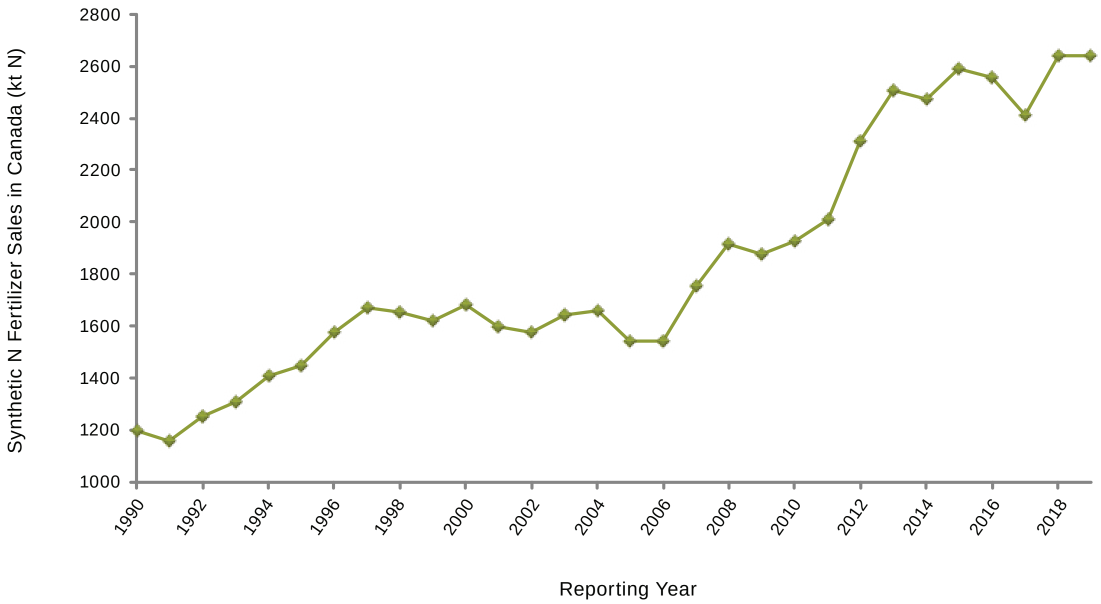
From 1990 to 2002, Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[24] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada, n.d. [b]).

Urine and Dung Deposited on Pasture, Range and Paddock by Grazing Animals

Canada uses a country-specific method for estimating N_2O emissions from urine and dung deposited on pasture, range and paddock by grazing animals. The N_2O emission factors for all livestock types were determined on the basis of a research project carried out between 2009 and 2011 for dairy cows in Eastern Canada and for beef cattle in Western Canada. Results from dairy manure in Eastern Canada are available in Rochette et al. (2014). Results from beef manure in Western Canada are summarized in Table A3.4–26 (Lemke et al., 2012). In comparison with the IPCC default EF for major livestock (2%), emission factors were 3.2 times lower in Eastern Canada and 46.5 times lower in Western Canada. Lower emission factors observed on the Canadian Prairies compared with the more humid climate in Eastern Canada are consistent with the findings of Rochette et al. (2008), who reported that moisture deficit—defined as the ratio of precipitation to potential evapotranspiration during the growing season—is a major contributing factor for

24 Available online at http://www.statcan.gc.ca/daily-quotidien/150213/dq150213f-eng.htm.

Figure A3.4–7 **Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2019**



N_2O emissions on arable cropland in Canada. For Ontario, Quebec and the Atlantic provinces, N_2O EFs are 0.0078 kg N_2O-N/kg N for fine-textured soil, 0.0062 kg N_2O-N/kg N for medium-textured soil and 0.0047 kg N_2O-N/kg N for coarse-textured soil (Rochette et al., 2014). A weighted N_2O EF based on soil texture is calculated for each ecodistrict based on Equation A3.4–13, assuming 75% of excreted N in urine (Rochette et al., 2014). In Western Canada, the N_2O EF is 0.00043 kg N_2O-N/kg N (Table A3.4–28). N_2O emissions are calculated using a fixed emission factor-based approach (Equation A3.4–22).

Equation A3.4–22

$$N_2O_{PRP} = \sum_{T,i}\left[\left(N_T \times N_{EX,T} \times N_{PRP,T} \times EF_{PRP,i}\right)\right] \times \frac{44}{28}$$

N_2O_{PRP}	=	emissions from urine and dung deposited on pasture, range and paddock from grazing animals, kg N_2O/year
N_T	=	animal population of category or subcategory T in a province, heads
$N_{EX,T}$	=	annual N excretion rate for animal category or subcategory T, kg N/head-year (Table A3.4–20 and Table A3.4–22)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3.4–15)
$EF_{PRP,i}$	=	emission factor for manure N deposited by animals on pasture, range and paddock in ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

Animal population data and data sources are detailed in section A3.4.1.

Crop Residue Decomposition

The transformation (nitrification and denitrification) of the N released during the decomposition of crop residues results in N_2O emissions into the atmosphere. A country-specific Tier 2 method similar to that for inorganic and organic N fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3.4–23, Equation A3.4–24 and Equation A3.4–25. The amount of N contained in the aboveground crop residues subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see section A3.4.7).

Equation A3.4–23

$$N_2O_{RES} = \sum_{i}\left(N_{RES,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O yr^{-1}
$N_{RES,i}$	=	total amount of crop residue N that is returned to soils for ecodistrict i, excluding N losses due to residue burning, kgN yr^{-1} (see Table A3.4–24)
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN yr^{-1}
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–28 **Emissions of Nitrous Oxide from Beef Urine and Dung on Pasture in Western Canada**					
Site	Treatment	Flux	Target N Rate	Standard Deviation	Emission Factor
		kg N ha^{-1}			kg N_2O-N kg^{-1}N
Swift Current, Saskatchewan	Control	0.07		0.04	
	Dung	0.07	500	0.05	0.000002 ± 0.00003
	Urine	0.79	750	1.56	0.001 ± 0.002
Lacombe, Alberta	Control	0.59		0.33	
	Dung	0.50	500	0.41	0 ± 0.0002
	Urine	0.72	750	0.58	0.0002 ± 0.0003
Overall mean					
	Dung				0 ± 0.0001
	Urine				0.0006 ± 0.0012

Note:

Unpublished data (Lemke et al., 2012); urine and dung applied in spring, summer and fall, and repeated one more time along with three replicates, and N_2O flux measurement frequency varied from three times a week immediately after urine and dung application down to once in four weeks depending on the intensity of the flux and weather conditions.

Equation A3.4–24

$$N_{RES,i} = \sum_{T,i}\left[P_{T,i} \times FRAC_{RENEW,T,i} \times \left(R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T}\right)\right]$$

$N_{RES,i}$ = total amount of crop residue N that is returned to soils for ecodistrict i, excluding N losses due to residue burning, kg N yr^{-1}

$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1} (see Equation A3.4–25)

$FRAC_{RENEW,T,i}$ = fraction of total area under crop T that is renewed annually in ecodistrict i

$R_{AG,T}$ = ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM) kg^{-1}

$N_{AG,T}$ = N content of above-ground residues for crop T, kg-N kg-DM^{-1}

$R_{BG,T}$ = ratio of below-ground residues to harvested yield for crop T, kg DM kg^{-1}

$N_{BG,T}$ = N content of below-ground residues for crop T, kg-N kg-DM^{-1}

Equation A3.4–25

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^{n}\left(A_{T,i} \times Y_{T,i}\right)} \times P_{T,p} \times \left(1 - H_2O_T\right)$$

$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1}

$A_{T,i}$ = area under crop type T in ecodistrict i, ha

$Y_{T,i}$ = average crop yield for crop type T in ecodistrict i, kg ha-yr^{-1}

$\sum_{=1}^{n}\left(A_{T,i} \times Y_{T,i}\right)$ = sum of total production for crop type T over all ecodistricts in a province

$P_{T,p}$ = total crop production for crop type T in province p, kg DM yr^{-1}

H_2O_T = water content of crop T, kg kg^{-1}

Statistics Canada collects and publishes annual field crop production data by province (Statistics Canada, n.d. [h]). Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chickpeas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003). Statistics Canada survey data are based on the *Census of Agriculture* (COA), and therefore general revisions to the survey time series may occur when COA data are modified due to refinements of the calibration model or other changes. Survey data are also occasionally revised by Statistics Canada due to error correction, and alignment with other supply and disposition statistics such as exports.

Mineralization Associated with Loss of Soil Organic Matter

The amount of N in mineral soils that is mineralized in association with loss of soil organic matter as a result of changes to land management practices can result in additional N_2O emissions from the Cropland Remaining Cropland category. A database containing soil organic carbon and N for all major soils in Saskatchewan (a data set of about 600) was used to derive an average C:N ratio of 11 with a standard deviation of 1.9. The C:N ratio of agricultural soils is considered to be consistent among regions. The 2006 IPCC Guidelines propose a range of C:N ratios from 8 to 15. A country-specific method is used for emission estimates (see Equation A3.4–26 and Equation A3.4–27).

Equation A3.4–26

$$F_{SOM} = \sum_{LM}[(\Delta C_{Mineral,LM} \times \frac{1}{R}) \times 1000]$$

F_{SOM}	=	the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices, kg N
$\Delta C_{Mineral,\ LM}$	=	average annual loss of soil organic carbon for each land management practice (LM), Mg C
R	=	C:N ratio of the soil organic matter (11.0±1.9)

Equation A3.4–27

$$N_2O_{FSOM} = \sum_i (F_{SOM,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

N_2O_{FSOM}	=	emissions associated with loss of soil organic matter due to changes in land management practices, kg N_2O/year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kg-N^{-1} yr^{-1}
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
$44/28$	=	coefficient converting N_2O-N to N_2O
$F_{SOM,i}$	=	the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices for ecodistrict i, kg N

Activity data on soil organic carbon loss at an ecodistrict level over the time series that is reported in the LULUCF Cropland Remaining Cropland category are used for soil N_2O estimates associated with the loss of soil organic matter.

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3.4–28).

Equation A3.4–28

$$N_2O_H = \sum_i (A_{OS,i} \times EF_{HIST}) \times \frac{44}{28}$$

N_2O_H	=	emissions from cultivated histosols, kg N_2O yr^{-1}
$A_{os,i}$	=	area of cultivated organic soils in province i, ha
EF_{HIST}	=	IPCC default emission factor for mid-latitude organic soils, 8.0 kg N_2O-N/ha-year (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

Areas of cultivated histosols at a provincial level are not collected as part of the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils in Canada was 16 kilohectares (Liang et al., 2004) and remains constant over time.

Change in N_2O Emissions from Adoption of No-Till and Reduced Tillage

This category is specific to Canada and does not derive from additional N inputs such as fertilizer, manure and crop residue, but rather is implemented as modifications to EF_{BASE} due to the switch from conventional to conservation tillage practices—namely no-till (NT) and reduced tillage (RT).

Field studies in Quebec and Ontario showed that NT practices increased N_2O emissions, whereas on the Prairies, the opposite was observed (Gregorich et al., 2005). To quantify the impact of tillage practices on N_2O emissions, a tillage ratio factor (F_{TILL}), defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), is used (Rochette et al., 2008):

Equation A3.4–29

$$N_2O_{TILL} = \sum_i \left[(N_{FERT,i} + N_{MAN-CROPS,i} + N_{RES,i}) \times \left(EF_{BASE,i} \times FRAC_{NT-RT,i} \times (F_{TILL} - 1)\right)\right] \times \frac{44}{28}$$

N_2O_{TILL}	=	change in N_2O emissions resulting from the adoption of NT and RT, kgN_2O yr^{-1}
$N_{FERT,i}$	=	inorganic fertilizer N consumption in ecodistrict i, kgN yr^{-1}
$N_{MAN-CROPS,i}$	=	amount of manure N applied as fertilizers to cropland in ecodistrict i, kg-N yr^{-1}
$N_{RES,i}$	=	amount of crop residue N that is returned to soils for ecodistrict i, kgN yr^{-1}
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kg-N-yr^{-1}
$FRAC_{NT-RT,i}$	=	fraction of cropland on NT and RT in ecodistrict i
F_{TILL}	=	a ratio factor adjusting EF_{BASE} due to the adoption of NT and RT: F_{TILL} = 1.1 in Eastern Canada; F_{TILL} = 0.8 on the Prairies (Rochette et al., 2008)
$44/28$	=	coefficient converting N_2O-N to N_2O

The fraction of cropland under NT and RT ($FRAC_{NT-RT}$) for each ecodistrict was derived from the *Census of Agriculture* and is identical to that used in the LULUCF Cropland Remaining Cropland category for NT and RT practices (see section 4 – Cropland in Annex 3.5). These data are published at the census agricultural region, census division, and provincial and national levels. Annual $FRAC_{NT-RT}$ between two consecutive census years is interpolated.

N_2O Emissions Resulting from Summerfallow

Summerfallow is a farming practice typically used on the Prairies to conserve soil moisture by leaving the soil unseeded for an entire growing season of a crop rotation. During the fallow year, no fertilizer or manure is applied. Several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature and available carbon and N. Field studies have shown that N_2O emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette et al., 2008). In order to account for these emissions not captured by the default IPCC input-driven approach, the following country-specific method is used to estimate the effect of summerfallow on N_2O emissions. During a crop year, direct N_2O emissions from a given field are summarized as follows:

Equation A3.4–30

$$N_2O_{CROP} = N_2O_{BACK} + N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

N_2O_{CROP}	=	emissions from a cropped rotation, kg N_2O yr^{-1}
N_2O_{BACK}		the background soil N_2O emissions that are not due to crop residue-N, inorganic fertilizer-N or manure-N additions
N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O yr^{-1}
N_2O_{MAN}	=	emissions from organic N fertilizers, kg N_2O yr^{-1}
N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O yr^{-1}

In the absence of external N inputs, N_2O emissions during the fallow year (N_2O_{FALLOW}) can be seen as consisting of: (1) background emissions that would have occurred regardless of fallow (N_2O_{BACK}); and (2) emissions due to the modifications to the soil environment by the practice of summerfallow ($N_2O_{FALLOW\text{-}EFFECT}$):

Equation A3.4–31

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW\text{-}EFFECT}$$

N_2O_{FALLOW}	=	emissions due to the effect of summerfallow, kg N_2O yr^{-1}
N_2O_{BACK}	=	background emissions, kg N_2O yr^{-1}
$N_2O_{FALLOW\text{-}EFFECT}$	=	emissions due to modifications to the soil environment resulting from summerfallow, kg N_2O yr^{-1}

Since N_2O emissions are estimated to be equal during fallow and cropped years ($N_2O_{CROP} = N_2O_{FALLOW}$) and assuming that N_2O_{BACK} is the same in cropped and fallow situations, $N_2O_{FALLOW\text{-}EFFECT}$ can be empirically estimated as follows:

Equation A3.4–32

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{FALLOW\text{-}EFFECT}$$

N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O
N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O
N_2O_{MAN}	=	emissions from organic N fertilizers, kg N_2O
$N_2O_{FALLOW\text{-}EFFECT}$	=	emissions occurring under fallow land, kg N_2O

The N_2O emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, inorganic N fertilizers and organic N fertilizers) to the area of the ecodistrict under summerfallow:

Equation A3.4–33

$$N_2O_{FALLOW} = \sum_i \left[\left(N_2O_{SFN,i} + N_2O_{RES,i} + N_2O_{MAN,i}\right) \times FRAC_{FALLOW,i}\right]$$

N_2O_{FALLOW}	=	emissions from summerfallow, kg N_2O
$N_2O_{SFN,i}$	=	emissions from inorganic N fertilizers in ecodistrict i, kg N_2O
$N_2O_{RES,i}$	=	emissions from crop residue decomposition in ecodistrict i, kg N_2O
$N_2O_{MAN,i}$	=	emissions from organic N fertilizers in ecodistrict i, kg N_2O
$FRAC_{FALLOW,i}$	=	fraction of cropland in ecodistrict i that is under summerfallow

Estimates of N_2O_{SFN}, N_2O_{RES} and N_2O_{MAN} at an ecodistrict level are those derived from inorganic N fertilizers, organic N fertilizers and crop residue N. The fraction, $FRAC_{FALLOW}$, is derived from the *Census of Agriculture* for each ecodistrict and is identical to that used in the LULUCF Cropland Remaining Cropland category for the summerfallow practice (see section 4 – Cropland in Annex 3.5). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

N_2O Emissions Resulting from Irrigation

Higher soil water content under irrigation increases N_2O emissions by increasing biological activity and reducing soil aeration (Jambert et al., 1997). Accordingly, highest N_2O emissions from agricultural soils in the northwestern United States (Liebig et al., 2005) and Western Canada (Hao et al., 2001a) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing N_2O emissions under irrigated and non-irrigated conditions are lacking in Canada. Therefore, an approach was used based on the assumptions that: (1) irrigation water stimulates N_2O production in a way similar to rainfall;

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(2) irrigation is applied to eliminate any moisture deficit such that “precipitation + irrigation water = potential evapotranspiration”; and (3) the effect of irrigation on N_2O emissions is in addition to effects of the non-irrigated area within an ecodistrict. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was accounted for using an EF_{BASE} estimated at a P/PE = 1 (EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of an ecodistrict:

Equation A3.4–34

$$N_2O_{IRRI} = \sum_i [(N_{FERT,i} + N_{MAN-CROPS,i} + N_{RES,i}) \times (0.017 - EF_{BASE,i}) \times FRAC_{IRRI,i}] \times \frac{44}{28}$$

N_2O_{IRRI}	=	emissions from irrigation, kg N_2O yr^{-1}
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kgN yr^{-1}
$N_{MAN-CROPS,i}$	=	amount of organic N fertilizers applied to the cropland in ecodistrict i, kgN yr^{-1}
$N_{RES,i}$	=	amount of crop residue N that is returned to the cropland in ecodistrict i, kgN yr^{-1}
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN-yr^{-1} for ecodistrict i
$FRAC_{IRRI,i}$	=	fraction of irrigated cropland in ecodistrict i
$44/28$	=	coefficient converting N_2O-N to N_2O

The fraction $FRAC_{IRRI}$ is derived from the *Census of Agriculture* for each ecodistrict (see section 4 – Cropland in Annex 3.5). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

Table A3.4–29 **Coefficients for Crop Type, Inorganic N Fertilizers, Method of Fertilizer Application, Soil Chemical Properties and Climate Developed by Bouwman et al. (2002b)**

Conditions where coefficient used		Coefficients
Crop Type	Annual crops	-0.045
	Perennial crops	-0.158
Fertilizer Type	Urea	0.666
	Urea ammonium nitrate	0.282
	Anhydrous ammonia	-1.151
	Other N sources	-0.238
Method of Application	Broadcast onto surface	-1.305
	Incorporated	-1.895
Soil Chemical Properties	Soil pH<7.25	-1
	Soil pH 7.25 ~ 8.5	-0.608
	Soil CEC <250 mmol kg^{-1}	0.0507
	Soil CEC >250 mmol kg^{-1}	0.0848
Climate	Temperate	-0.402

A3.4.5.2. Indirect N_2O Emissions from Agricultural Soils

Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from volatilization and redeposition of inorganic and organic N. The emission calculation is shown in Equation A3.4–35.

Equation A3.4–35

$$N_2O_{VD} = \sum_i [(N_{FERT\,TN,i} \times FRAC_{GASF\,NT,i}) + (MAN_{PRP,iT} \times FRAC_{GasMS-PRP,T}) + (N_{MAN-CROPS,i} \times FRAC_{GASM,i})] \times EF_4 \times \frac{44}{28}$$

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N_2O yr^{-1}
$N_{FERT,\,TN,i}$	=	inorganic N consumption for each type of N fertilizers including urea, urea ammonium nitrate, anhydrous ammonia and others in ecodistrict i, kg N yr^{-1}
$FRAC_{GASF\,NT,i}$	=	fraction of inorganic N fertilizers applied to soils that volatilizes as NH_3-N, kg NH_3-N kgN^{-1}, determined by a country-specific method in an ecodistrict i (see Equation A3.4–17)
$MAN_{PRP,iT}$	=	amount of urine and dung N excreted on pasture, range and paddock by animal category or subcategory T in an ecodistrict i, kg N yr^{-1}
$FRAC_{GasMS-PRP,T}$	=	fraction of volatilized manure N deposited on pasture, range and paddock by animal category or subcategory T: 0.2 kg (NH_3-N + NO_x-N) kgN^{-1} (IPCC, 2006) for all livestock categories except Dairy Cattle (Table A3.4–34)
$N_{MAN-CROPS,i}$	=	organic N fertilizers applied on cropland in ecodistrict I, kgN yr^{-1} (see Table A3.4–32)
$FRAC_{GASM,i}$	=	fraction of volatilized organic N fertilizers in ecodistrict i: 0.2 kg (NH_3-N + NO_x-N) kgN^{-1} for all livestock (IPCC, 2006) except the Dairy Cattle and Swine categories (Table A3.4–32).
EF_4	=	emission factor due to volatilization and redeposition: 0.01 kg N_2O-N kgN^{-1} (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

A country-specific method was used to estimate ammonia emissions from inorganic N application. The method for deriving ammonia emission factors closely follows the approach of Sheppard et al. (2010a), who applied the regression model developed by Bouwman et al. (2002b) to derive regionally specific emission factors for different ecoregions in Canada. This model derives ammonia emission factors based on the type of inorganic N fertilizers, degree of incorporation into soil, crop type and soil chemical properties (Equation A3.4–36).

Equation A3.4–36

$$FRAC_{GASF\ TN,\ i} = 100 \times EXP^{(sum\ of\ relevant\ coefficients)}$$

$FRAC_{GASF\ TN,\ i}$	=	ammonia emission factor for each type of inorganic N fertilizer in ecodistrict i, %
sum of relevant coefficients	=	coefficients for crop type, type of inorganic N fertilizers, method of N application, soil chemical properties and climate, unitless (see Table A3.4–29)
100	=	conversion of fraction to percent
EXP	=	exponential

The method of application for each type of inorganic N fertilizers for Eastern and Western Canada is provided in Sheppard et al. (2010a). Soil properties, pH and cation exchange capacity (CEC) are derived from CANSIS soil polygon information and are based on fractional distributions of soil series having pH < 7.25 and CEC < 250 me/kg, pH < 7.25 and CEC > 250 me/kg, pH > 7.25 and CEC < 250 me/kg, and pH > 7.25 and CEC > 250 me/kg. Statistics Canada (n.d. [b]) has collected and published annual inorganic N fertilizer sales data including urea, urea ammonium nitrate, anhydrous ammonia and others. The application of this equation results in spatially specific emission factors for inorganic N fertilizers applied to annual crops. Provincial averages by fertilizer type (Table A3.4–30) are calculated based on the spatial distribution of soil chemical properties and climate for each individual ecodistrict in each province and, as a consequence, the fraction ($FRAC_{GASF}$) of ammonia volatilized by province varies slightly from year to year based on fertilizer sales (Table A3.4–31). More detail on methods of estimating ammonia emission factors from inorganic N fertilizers can be found in Sheppard et al. (2010a), and simplifications used to convert monthly emissions calculated in the original publication to an annual estimate are documented in Liang (2014). Briefly, based on the data provided in Sheppard et al. (2010a), it is assumed that inorganic N fertilizers are applied in either spring or fall when temperatures are similar. Therefore, a single temperature representing annual applications per ecoregion is used to estimate emissions. According to this approach, the fraction of fertilizers emitted during fertilizer application ranges from roughly 5% to a maximum of 10% (Table A3.4–31), depending on the year and province.

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Table A3.4–30 **Ammonia Emission Factors of Inorganic Nitrogen Fertilizers Applied to Annual Crops Weighted Based on Soil Properties for Each Province (%)**

	Annual			
Province	Urea	Anhydrous NH_3	UAN	Other
AB	5	4.2	3.8	5.4
BC	4.8	4	3.7	5.2
MB	5.8	4.9	4.5	6.3
NB	7.4	3.9	4.5	4.5
NL	7.4	3.9	4.5	4.5
NS	7.3	3.9	4.4	4.4
ON	8.2	4.4	5	4.9
PE	7.3	3.9	4.4	4.4
QC	7.4	4	4.5	4.5
SK	5.1	4.2	3.9	5.5

Table A3.4–31 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized / kg inorganic fertilizer N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.08	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.07	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2011	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2012	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2013	0.06	0.09	0.07	0.06	0.08	0.07	0.08	0.06	0.07	0.06
2014	0.06	0.09	0.06	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.07	0.07	0.05	0.07	0.06
2016	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2017	0.06	0.09	0.07	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2018	0.06	0.08	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2019	0.06	0.08	0.07	0.06	0.07	0.08	0.07	0.05	0.07	0.06

Table A3.4–32 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized/ kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.10	0.16	0.20	0.19	0.20	0.18	0.18	0.17	0.15
1995	0.13	0.09	0.16	0.19	0.19	0.19	0.18	0.18	0.17	0.15
2000	0.12	0.09	0.15	0.18	0.19	0.18	0.17	0.18	0.16	0.14
2005	0.11	0.08	0.14	0.17	0.19	0.16	0.17	0.18	0.15	0.13
2010	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2015	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2016	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2017	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2018	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2019	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12

Leaching and Runoff

A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching and runoff of inorganic and organic N fertilizers, and crop residue N from agricultural soils:

Equation A3.4–37

$$N_2O_L = \sum_i \left[\left(N_{FERT,i} + N_{MAN-CROPS,i} + MAN_{PRP,i} + N_{RES,i}\right) \times FRAC_{LEACH,i} \times EF_5\right] \times \frac{44}{28}$$

N_2O_L = emissions from leaching and runoff of N, kgN_2O yr^{-1}

$N_{FERT,i}$ = inorganic N fertilizers applied for ecodistrict i, kg N

$N_{MAN\text{-}CROPS,i}$ = organic N fertilizers applied for ecodistrict i, kg N

$MAN_{PRP,i}$ = urine and dung deposited on pasture, range and paddock for ecodistrict i, kgN

$N_{RES,i}$ = crop residue N for ecodistrict i, kg N

$FRAC_{LEACH,i}$ = fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below

EF_5 = leaching/runoff emission factor: 0.0075 kg N_2O-N kgN^{-1} (IPCC, 2006)

$44/28$ = coefficient converting N_2O-N to N_2O

Determining the Fraction of Nitrogen that is Leached ($FRAC_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. In some farming systems of southern British Columbia, high N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year (Paul and Zebarth, 1997; Zebarth et al., 1998). Those farming systems, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0 to 37 kg N/ha, representing between 0% and 20% of N inputs. Leaching losses in most of the Prairies region may be smaller due to lower precipitation and lower N inputs on a per area basis. Based on a long-term experiment in central Alberta, Nyborg et al., (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

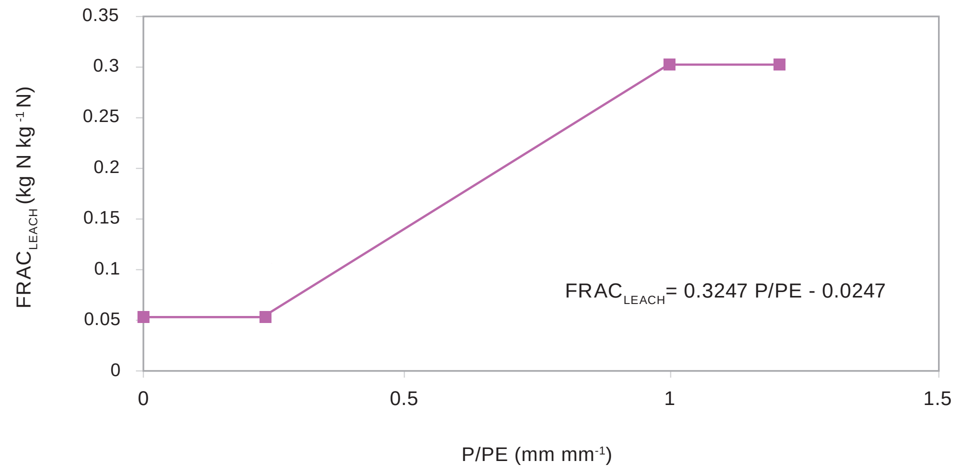
The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairies region of Canada, or as high as 0.3 in humid regions (IPCC, 2006) of Eastern Canada. Accordingly, it was assumed that $FRAC_{LEACH}$ would vary from 0.05 to 0.3, depending on the ecodistrict.

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value of 0.3 (IPCC, 2006) was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged from 0.23 to 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the two-end points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3.4–8).

Data sources for N_{FERT}, $N_{MAN\text{-}CROPS}$, MAN_{PRP} and N_{RES} (section A3.4.5.1) at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database) were used to calculate $FRAC_{LEACH}$ at an ecodistrict level.

Figure A3.4–8 **Determination of the Ecodistrict $FRAC_{LEACH}$ Values**



A3.4.6. Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodologies used in the calculation of N_2O from livestock and agricultural soils for 2010 (Karimi-Zindashty et al., 2014). The analysis has not yet been published, and limited depth of analysis could be carried out due to the size of the Canadian N_2O model and the upper limits of the data processing capability of the Analytica software. However, the analysis did provide the uncertain bounds around the principal emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for the current year. In the analysis, a stochastic reproduction of the complete N_2O emission model was built in Analytica© at the ecodistrict scale, and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the Good Practice Guidance (IPCC, 2000). A sensitivity analysis was carried out to identify the parameters that contributed most to different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: (1) those associated with information at the ecodistrict scale, (2) provincial-scale data and (3) IPCC/national-scale parameters (Table A3.4–33). The majority of national-scale parameters are taken directly from the 2006 IPCC Guidelines (IPCC, 2006) or from the original country-specific methodological development work carried out by Rochette et al. (2008), derived either analytically

Table A3.4–33 **Fractions of Swine N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized / kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.22	0.14	0.28	0.23	0.28	0.21	0.28	0.26	0.15
1995	0.13	0.22	0.12	0.27	0.23	0.27	0.21	0.27	0.25	0.13
2000	0.13	0.22	0.11	0.26	0.23	0.25	0.20	0.26	0.25	0.12
2005	0.12	0.22	0.11	0.25	0.23	0.24	0.20	0.25	0.24	0.12
2010	0.12	0.21	0.11	0.24	0.23	0.23	0.20	0.25	0.24	0.12
2011	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2012	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2013	0.13	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2014	0.13	0.21	0.11	0.24	0.22	0.25	0.20	0.25	0.24	0.13
2015	0.13	0.21	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.13
2016	0.13	0.21	0.11	0.25	0.23	0.25	0.20	0.25	0.24	0.13
2017	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13
2018	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13
2019	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13

Table A3.4–34 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from Deposition on Pasture, Range and Paddock, in 2019, at a Provincial Scale**

Province	Implied EF (kg NH_3-N volatilized / kg manure N)
AB	0.035
BC	0.042
MB	0.036
NB	0.039
NL	0.036
NS	0.039
ON	0.042
PE	0.039
QC	0.036
SK	0.036

or through expert opinion based on a panel of four experts in agricultural GHG emissions. Provincial-scale parameters include fertilizer sales and characteristics of crop production, the source of uncertainty being the Statistics Canada survey uncertainty and expert opinion on characteristics of crop production. The uncertainty of livestock populations and management parameters for animal categories were identical to that discussed in sections A3.4.2.4 and A3.4.3.9; the distributions used to define uncertainties can be found in Table A3.4–9 and Table A3.4–19. Landscape-scale parameters were derived from the agricultural soil landscape parameter database developed by AAFC and used in the production of cropland estimates for LULUCF. Specific landscape-parameter uncertainty was based on the general rules used in the production of uncertainty estimates for cropland carbon, which postulates that the uncertainty of a parameter at the landscape scale is inversely proportional to the relative size of the landscape unit, i.e., smaller parameters associated with smaller ecodistricts have greater uncertainty. The bounds of the uncertainty for different parameters varied. For example, uncertainties around animal distribution was ±30% for small ecodistricts and ±5% for large ecodistricts, whereas for the fraction of lowland soil in a given ecodistrict, variability was bounded as ±10% for small ecodistricts and ±1.25% for large ecodistricts. The current analysis does not include new country-specific emission factors for N_2O emissions from animal manure deposited on pasture, range and paddock, but does include the analysis of emissions considering the 2006 IPCC Guidelines leaching emission factor.

The summary results of the uncertainty analysis on emissions of N_2O are reported in Chapter 5. The relative uncertainty range for N_2O emissions from agricultural sources is 56% (-27% to +29% of the mean). Most uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the estimate of indirect emissions uncertainty of 126% (-58% to +68% of the mean). The emissions are skewed to the lower end of the emission probability distribution, because emission factor uncertainty is bounded by zero and emission factor variability is expressed as a factor on the lower scale; a change from 1% to 0.2% has a smaller impact on total emissions than a change from 1% to 5% at the upper end of the probability distribution. The uncertainty range of direct N_2O emissions from agricultural soils is 69% (-31% to +38% of the mean). There have been few complete studies of uncertainty from emissions of N_2O in the literature. In a study directly comparable to this particular uncertainty analysis, Monni et al. (2007) estimated that total N_2O emissions in Finland ranged from -50% to +70% of the mean emission estimate. Their methodology included a mixture of country-specific and default Tier 1 methodology to produce emission estimates. In a recent study of uncertainty in the United Kingdom, Milne et al. (2013) observed high uncertainty ranges for direct, indirect and total N_2O emissions, specifically -56% to +140%, -91% to +370%, and -55% to +110%, respectively. Our parameter uncertainty was similar to that used by the UK researchers, but it is suspected that the high degree of spatial disaggregation in the Canadian N_2O model resulted in slightly lower overall uncertainty. The uncertainty associated with the fraction of emission(s) from inorganic N fertilizers would be reduced from ±200% by the IPCC default (IPCC, 2006) given the country-specific approach applied in this submission. However, because the uncertainty associated with EF_4 (N volatilization and re-deposition) is ±400% (IPCC, 2006), it is unlikely that the overall uncertainty of N_2O emissions would decrease.

Sensitivity analysis indicated that indirect EF uncertainties were the largest contributors to overall uncertainty. Uncertainty of direct soil emissions was dominated by the use of uncertainty in the Tier 1 emission factor for emissions from pasture, range and paddock (PRP), the slope of P/PE regression equation and the emission factor modifier for tillage and texture (RF_{TILL}, RF_{TEXT}). The EF for solid manure systems was the largest source of uncertainty in the estimate of N_2O emissions from AWMS. Reduction of uncertainty will require the replacement of Tier 1 default emission factors and modifiers in the methodology.

Table A3.4–35 **Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions**

Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value [b]	Uncertainty Distribution Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data [a]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication
N excretion	2006 IPCC Guidelines	Normal	±50%	IPCC default	
$FRAC_{GAS}/FRAC_{LOSSMS}$		Triangular	IPCC default	IPCC default	See Table 10.22/10.23 of 2006 IPCC Guidelines
AWMS emission factor		Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	2006 IPCC Guidelines variable depending on the manure storage type
Crop characteristics					
H_2O content	Janzen et al. (2003)	Normal	±15%		Expert consultation
Relative DM allocation of residue (product, aboveground and belowground)					
$FRAC_{Renew}$ (duration)					
N concentration in residue (aboveground and belowground)					
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al., 2008	Normal	Intercept ±54% Slope ± 21%		Expert consultations
$FRAC_{LEACH}$ calculation parameters			Intercept ±54% Slope ±21%		
F_{TILL}			±100%		
$RF_{TEXTURE}$			±30%		
EF_{LEACH}	2006 IPCC Guidelines	Triangular	0.002–0.12	0.025	2006 IPCC Guidelines
EF_{VD}			0.002–0.05	0.01	
EF_{HIST}			2–24	8	
Provincial – Scale Parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from common usage in AAFC [c] literature and modelling studies	Normal	±15%		Expert consultation
Provincial fertilizer sales	Statistics Canada	Normal	±15%		Interpretation of data quality evaluation in Statistic Canada Report
Ecodistrict – Scale Parameters					
P and PE	Weather Station Data	Normal	5–15%		Based on individual weather station data, 30-year average
Total ecodistrict area	AAFC [c] geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1990–2011	Normal	Function of Relative Ecodistrict Size: maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter		Based on the uncertainty methodology used in the carbon quantification methodology for croplands
Crop areas					
Animal population distribution to ecodistrict					
FTOPO (proportion of lowland soils in ecodistrict)					
Extent of organic soils					
Irrigated soil area					
Annual soil texture					
Perennial soil texture					

Note:

a. Uncertainty associated with most livestock parameters can be found in section A3.4.2.4 and section A3.4.3.8, and the distributions used to define uncertainties can be found in Table A3.1–7 and Table A3.2–8.

b. Reported where applicable when using a triangular distribution.

c. Agriculture and Agri-Food Canada.

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A3.4.7. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, for convenience and as a means of disease control through residue removals, although expert opinion suggests that this practice has declined in recent years because of soil quality and environmental issues.

Field burning of agricultural residues emits CH_4 and N_2O. The quantity of crop residue burning in Canada can be estimated as follows:

Equation A3.4–38

$$Q_{BURN} = \sum_{T}(PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

Q_{BURN}	=	quantity of crop residue burned from crop T for each province, Mg dry matter yr^{-1}
$PRODUCTION_T$	=	total production of crop T, Mg yr^{-1}
$MOISTURE_T$	=	moisture content of the product from crop T, fraction
$RatioAR/P_T$	=	ratio of above-ground crop residue to the crop product for crop T, unitless
PCB_T	=	percent of crop residue that is subject to field burning for crop T, fraction
$RATIO_{SCALE}$	=	a scaling factor or an intensity factor adjusted for burning in 2006, unitless

Data collected in 2001 and 2006 by Statistics Canada through its Farm Environmental Management Survey (FEMS)[25] include crop residue burning. The type of crop and the extent of crop residue burning for each province were only available for 2006; these data were collected in FEMS and are summarized in Table A3.4–36. To establish a complete time series of activity data, additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al., 2008). Thus, a crop that was subject to field burning in 2006 was also assumed to be subject to field burning for the entire time series.

The intensity of crop residue burning in each province for 1991, 1996 and 2001 was adjusted as a ratio based on the average burning for 2006. Janzen et al. (2003) report basic characteristics of crops, such as moisture content of crop product and ratio of aboveground crop residue to crop product. Annual production of each crop subject to residue burning is available (Statistics Canada, n.d. [h]).). Other parameters, such as fraction of biomass actually burned, and emission factors required for emission estimates, were obtained from the 2006 IPCC Guidelines.

N_2O and CH_4 emissions from crop residue burning are estimated using the following equation:

Equation A3.4–39

$$EMISSION_{BURN} = \sum(Q_{BURN,i} \times C_F \times G_{EF}) / 1000$$

$EMISSION_{BURN}$	=	emissions of N_2O or CH_4 from the burning of crop residues for Canada (kt N_2O or CH_4)
Q_{BURNi}	=	quantity of crop residue burned from province i, Mg, dry matter yr^{-1}
C_F	=	fuel efficiency (IPCC, 2006), unitless
G_{EF}	=	emission factor (IPCC, 2006), 0.00007 kg N_2O or 0.0027 kg CH_4/kg of dry matter burned
1000	=	converting Mg to kt

25 Available at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044.

Table A3.4–36 **Burning of Crop Residues by Crop Types in 2006**

	Spring Wheat	Winter Wheat	Oats	Barley	Mixed Grains	Flaxseed	Canola
	% of Crop Residue Burned (by Weight)						
AB	0	0	0	0	0	8	0
BC	0	0	0	0	0	0	0
MB	2	3	3	1	0	17	1
NB	0	0	1	0	0	0	0
NL	0	0	0	0	0	0	0
NS	33	0	0	0	0	0	0
ON	0	0	0	1	2	0	0
PE	3	0	0	1	0	0	0
QC	0	0	1	0	0	0	0
SK	0	0	0	0	0	15	1

Table A3.4–37 **Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006**

	1991	1996	2001	2006
	% of Crop Residue Burned (by Weight)			
AB	0.8	0.7	0.2	0.2
BC	0	0	0	0
MB	12.6	10.1	8.9	2.3
NB	0.5	0.5	0.5	0.5
NL	0	0	0	0
NS	0.5	0.5	0.5	0.5
ON	0.7	0.7	0.7	0.3
PE	0.4	0.4	0.4	0.4
QC	0.4	0.4	0.4	0.3
SK	8.1	5.8	3.9	1.5

Note:

Data for 2001 and 2006 were extracted from FEMS 2001 and FEMS 2006, collected by Statistics Canada; data for 1991 and 1996 were gathered through consultations by Coote et al. (2008).

A3.4.8. CO_2 Emissions from Liming and Urea Fertilization

A3.4.8.1. CO_2 Emissions from Liming

Limestone (C_aCO_3) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of CO_2 release varies with soil conditions and the types of compounds applied. In most cases, lime is applied repeatedly. Thus, for the purposes of the inventory, it is assumed that the annual rate of lime is in near equilibrium with the consumption of lime in previous years. Emissions associated with lime application are calculated from the amount of lime applied annually.

The amount of C released as a result of limestone application is calculated using the default IPCC Tier 1 approach (IPCC, 2006).

Equation A3.4–40

$$CO_2 - C\ Emission = \sum(M_{Limestone/dolomite,i} \times EF_{Limestone/dolomite})$$

$CO_2 - C\ Emission$ = annual C emissions from lime application, Mg C yr^{-1}

$M_{Limestone/dolomite,i}$ = annual amount of limestone and dolomite consumption in province i, Mg yr^{-1}

$EF_{Limestone//dolomite}$ = 0.12, limestone emission factor or 0.13 dolomite emission factor

The quantity of lime and dolomite used for agricultural purposes is not collected through the *Census of Agriculture* by Statistics Canada, but rather through Natural Resources Canada's *Canadian Minerals Yearbook* (1990 to 2006). For more recent years, this information is only available on request.[26] This data source provides a consistent and complete time series of activity data on agricultural lime consumption in Canada. As this data source provides no information on the ratio of dolomite to limestone, the ratio from data collected through consultation with the Canadian Fertilizer Institute was used.

The 95% confidence limits associated with annual lime consumption data were estimated to be ±30%. This uncertainty was assumed to include the uncertainty of lime sales, the uncertainty of when lime sold is actually applied, and thus the uncertainty in the timing of emissions. The uncertainty in the emission factor was assumed to be -50% based on the 2006 IPCC Guidelines.

A3.4.8.2. CO_2 Emissions from Urea Fertilization

When urea or urea-based nitrogen fertilizer is applied to soil to augment crop production, CO_2 is released upon hydrolysis as follows:

$$(NH_2)_2CO + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$

In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$. CO_2 emissions from urea fertilization can be estimated using Equation A3.4–41:

Equation A3.4–41

$$CO_2 - C\ Emission = \sum(M_{Urea,i} \times EF_{Urea})$$

$CO_2 - C\ Emission$ = annual C emissions from urea application, Mg C yr^{-1}

$M_{Urea,i}$ = annual amount of urea fertilization, Mg yr^{-1}

EF_{Urea} = 0.20, emission factor

Statistics Canada collects and publishes annual fertilizer shipment data, including urea and urea ammonium nitrate (Statistics Canada, n.d. [b]). The uncertainty estimate associated with the emissions is assessed based on simple error propagation using survey uncertainty of ±15% for the activity data and an uncertainty of -50% associated with the EF specified in the 2006 IPCC Guidelines.

26 [NRCan] Natural Resources Canada. 2007–2016. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

A 3

A3.5. Methodology for the Land Use, Land-Use Change and Forestry Sector

The Land Use, Land-Use Change and Forestry (LULUCF) sector of the inventory includes estimates of greenhouse gas (GHG) emissions and removals associated with managed lands and with the conversion of land from one category to another.

As in Chapter 6, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon (C) stock changes, emissions and removals in all forest-related categories, including Forest Land, Forest Land converted to other land uses and Land Converted to Forest Land, is briefly described in section A3.5.2; this description is not repeated under the Forest Land Converted to Cropland, Forest Land Converted to Wetlands and Forest Land Converted to Settlements subcategories. Section A3.5.3 describes the approach for estimating emissions associated with the use and disposal of harvested wood products (HWP) from wood harvested in Canada and section A3.5.4 describes the methods used to quantify the effect of management practices on agricultural land for the Cropland category. Likewise, the sections on the Grassland (A3.5.5), Wetlands (A3.5.6) and Settlements (A3.5.7) categories focus on category-specific estimation methodologies.

A3.5.1. Spatial Framework for LULUCF Estimate Development and Area Reconciliation

Canada's monitoring system for LULUCF draws on the close collaboration among several scientists and experts in different disciplines. Early on, it was recognized that the approaches, methods, tools and data that are available and most suitable for monitoring human activities in one land category are not always appropriate for another. Differences exist in the spatial framework specific to each land category, and these differences create a risk that activity data and estimates would be spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners contributing to the LULUCF sector to ensure the highest possible consistency and spatial integrity of inventory estimates.

The LULUCF sector of the GHG inventory reports information in 18 reporting zones (Chapter 6, Figure 6–1). These reporting zones are essentially the same as the ecozones of the National Ecological Framework, a hierarchical, spatially consistent national ecosystem classification (Marshall et al., 1999). For the purpose of reporting LULUCF estimates, three ecozones are split into smaller land units: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones, and the Prairies ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Land and water areas for each reporting zone are compiled according to McGovern (2014) and reported annually in Chapter 6.

Analysis units are the finest level of spatial resolution and are specific to each estimation system. In managed forests, the analysis units are the geographic intersection of reporting zones (Chapter 6, Figure 6–1) and provincial/territorial forest management units. For the purpose of this assessment, managed forests were classified into 607 analysis units across 12 provinces and territories; Nunavut was excluded because there is no managed forest area in this northern region (Table A3.5–1). Changes in the number of spatial analysis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modification of administrative boundaries, timber areas and parks can result in units that do not meet the criteria for separate analysis; these units are therefore regrouped.

The most suitable spatial framework for GHG monitoring of cropland are the polygons of the Soil Landscapes of Canada[27] (SLC). A soil landscape describes a group of soils and their associated landscapes and provides information, such as surface form, slope, typical soil C content under native and dominant agricultural land use, and water table depth. Soil landscapes are spatially associated with SLC polygons (the analysis units) that may contain one or more distinct soil landscape components. SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national classification system within

27 Available online at http://sis.agr.gc.ca/cansis.

Table A3.5–1 **Spatial Analysis Units of Managed Forests**

Province/Territory	Number of Analysis Units
Newfoundland and Labrador	24
Prince Edward Island	1
Nova Scotia	1
New Brunswick	1
Quebec	129
Ontario	52
Manitoba	70
Saskatchewan	40
Alberta	181
British Columbia	65
Yukon	13
Northwest Territories	30
Nunavut	0
Canada	**607**

which ecosystems of various scales can be described, monitored and reported on (Marshall et al., 1999). The 12 353 SLC polygons are nested in the next level of generalization (1027 ecodistricts), which are further grouped into 194 ecoregions and 15 ecozones. SLC polygons span in the order of 1000 to 1 000 000 hectares (ha) and are appropriate for mapping at the scale of 1:1 million.

Analysis units for estimating the areas of forest converted to other land uses are the result of the spatial intersection of forest conversion strata (Figure A3.5–6) with ecological and administrative boundaries. Forest conversion strata were developed on the basis of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires analysis units to be as consistent as possible with respect to the patterns of forest conversion and large enough to provide an acceptable sample size, given the predetermined sampling rate.

The analysis units of different land-use categories can overlap. Most often, the exact location of events within a unit is not known. Therefore, the activity data pertaining to different land-use categories cannot be harmonized at the level of analysis units. The spatial harmonization is conducted within 60 reconciliation units (RUs), which are derived from the spatial intersection of reporting zones with provincial and territorial boundaries. Quality control and quality assurance procedures are conducted at the level of analysis units during estimate development and at the level of RUs during estimate compilation.

A3.5.2. Forest Land and Forest-related Land-Use Change

A3.5.2.1. Carbon Modelling

The estimation of C stock changes, emissions from and removals by managed forests, forest conversion to other land uses and land converted to forest land is conducted with version 3 of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) (Kurz et al., 2009), the most recent of a family of models whose development dates back to the late 1980s (Kurz et al., 1992). The model integrates forest inventory information (stand age, area and species composition), curves of merchantable volume over age, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of C transfers between pools and exchanges with the atmosphere that are associated with ecosystem processes and various events.

The ecosystem processes modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litterfall, non-disturbance tree mortality and decomposition. The CBM-CFS3 also models events, such as management activities, forest conversion and natural disturbances. Management activities represented are clear-cut, shelterwood harvest, seed tree harvest, selection harvest, commercial thinning, precommercial thinning, salvage logging, residential firewood harvest and the burning of harvest residues. Different practices of forest conversion are also simulated, including controlled burning.

The forest C pools represented in the CBM-CFS3 can be matched with the Intergovernmental Panel on Climate Change (IPCC) forest C pools (Table A3.5–2). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual ecosystem process events are simulated as C transfers between C pools executed at each time step (annually) in every inventory record (Figure A3.5–1). During annual processes, C is taken up in the biomass pool and some biomass C is transferred to dead organic matter (DOM) pools. The decay of DOM results in C transfer to another DOM pool (e.g., stem snags to medium deadwood pool), to a slow soil pool or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al. (2009). Rates of C transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be either very high (e.g., 95% for hardwood foliage) or very low (e.g., < 1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C and exhibit temperature sensitivity according to defined Q_{10} relationships; the decay rates vary between 50% (very fast DOM pools, such as dead fine roots) and 0.0032% (slow soil pool).

Growth is simulated as an annual process. Each of the records (roughly 3 million) in the 607 analysis units of the forest inventory is associated with a yield curve that defines the dynamics of gross merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ between provinces and territories. Curve libraries for each province and territory in Canada are similar to those used by resource management agencies in the forest planning processes and are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of gross merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al., 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for each province/territory, ecozone, leading species or forest type. Finally, below-ground biomass pools are estimated using regression equations (Li et al., 2003). Mean annual increments are not used in this derivation.

Modelling of C transfers triggered by disturbances is based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as disturbances. The impact of a disturbance is represented by a disturbance matrix, which specifies, for one or more disturbance types, the proportion of C in each ecosystem pool that is transferred to other pools, released to the atmosphere or transferred to Harvested Wood Products (Figure A3.5–2). In the current submission, the simulation uses a total of 191 disturbance matrices. The number of different disturbance matrices is dependent on the availability of activity data (e.g., the spatial and temporal resolution

Table A3.5–2 **Forest Carbon Pools in IPCC and CBM-CFS3**

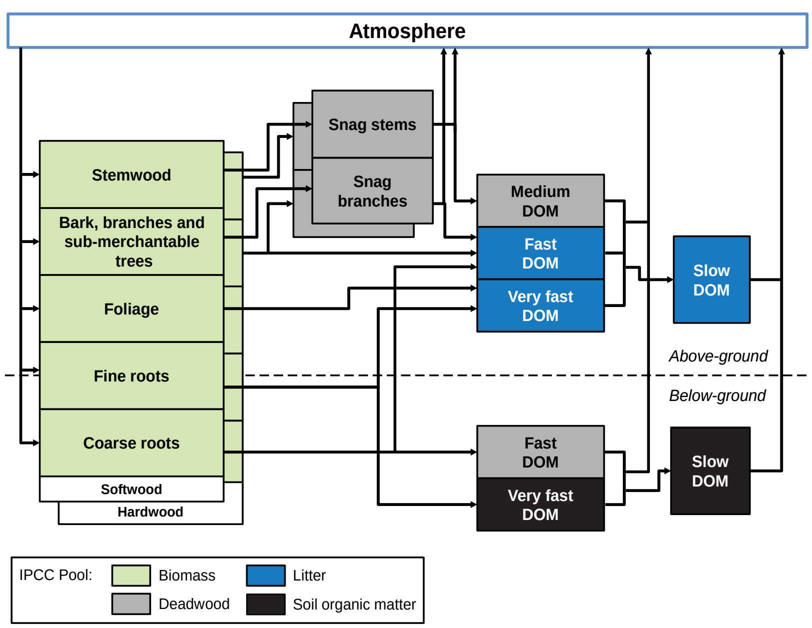
IPCC Carbon Pools		Pool Names in CBM-CFS3
Living Biomass	Above-ground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots Coarse roots
Dead Organic Matter (DOM)	Deadwood	Above-ground fast Below-ground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag
	Litter	Above-ground very fast Above-ground slow
Soils	Soil organic matter	Below-ground very fast [a] Below-ground slow Black carbon [b] Peat [b]

Notes:

a. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.

b. Black carbon and peat are currently not estimated.

Figure A3.5–1 **Carbon Pools and Transfers Simulated by the CBM-CFS3**



Note: Source – White et al. (2008), updated of disturbance data) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance.

Within disturbed lands, the amount of C emitted as CO_2 from each pool at the time of disturbance, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone. There are therefore no CO_2 emission factors applicable to all disturbances of a given type, such as fires. With a few exceptions, the proportion of total C emitted in each C-containing GHG (CO_2, CO and CH_4) due to fire is constant: 90% of C is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al., 1998; Kasischke and Bruhwiler, 2003).

Carbon emissions emitted as CO oxidize in the atmosphere resulting in indirect CO_2 emissions. Amounts of C emitted as CO and indirect CO_2 are calculated by multiplying total C by, respectively, 28/12 and 44/12. More details on the reporting of these indirect CO_2 emissions can be found in Chapter 6 and Annex 7.

While the CBM-CFS3 can model C fluxes at various spatial scales, generating national estimates involves harmonizing, integrating and ingesting vast quantities of data from a large variety of sources. The next section documents the key data sources used for this submission.

A3.5.2.2. Forest drainage

Forest drainage is used to lower the water table, thereby improving soil aeration and promoting root development and tree growth on low-productivity organic soils. A consultation with forestry industry experts and an extensive literature review carried out in 2015 and 2016 suggested that the only province in Canada where operational drainage of organic soils for forestry occurred was Quebec (Gillies, 2016). This management activity occurred from the 1980s through to the mid-2010s on a small percentage of peatlands corresponding to three RUs (11, 12 and 15) on both private and public lands. Forest drainage has progressively declined since 2003 due to the end of government subsidies and changes to Quebec's forest management tenure.

Data on forest drainage were compiled from a combination of historical documents, consultations and provincial statistics to develop a time series from 1980–2018 of annual peatland areas drained for forestry on both private and publicly owned forests of Quebec. Provincial statistics (Gouvernement du Québec, 2018) were reported by administrative region (AR) for 1994–2008 and by province for 1986–1993 and for 2009–2017. Drainage data for 1980–1985 were assumed to be constant, resulting in a cumulative area drained equivalent to the 1986 value reported by Quebec statistics, which was also consistent with values cited in

Figure A3.5–2 **Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-Cut Harvest and Salvage Logging Applicable in All Ecozones Except Those in Alberta and Quebec**

	13	14	15	16	17	18	19	24	25	Products
1. Softwood merchantable					0.15					0.85
2. Softwood foliage	1									
3. Softwood others			1							
4. Softwood sub-merchantable			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merchantable					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood sub-merchantable			1							
11. Hardwood coarse roots			0.5	0.5						
12. Hardwood fine roots	0.5	0.5								
13. Above-ground very fast soil C	1									
14. Below-ground very fast soil C		1								
15. Above-ground fast soil C			1							
16. Below-ground fast soil C				1						
17. Medium soil C					1					
18. Above-ground slow soil C						1				
19. Below-ground slow soil C							1			
20. Softwood stem snag					0.5					0.5
21. Softwood branch snag			1							
22. Hardwood stem snag					0.5					0.5
23. Hardwood branch snag			1							
24. Black C								1		
25. Peat									1	

Hillman (1987). Given the absence of drainage activity data for 2018 (Gouvernement du Québec, 2018) and the fact that there were no areas drained in 2016 and 2017, drained areas were assumed to be zero after 2017. Estimates of drained areas by AR (1994–2008) were allocated to the three RUs by overlaying the AR to create a spatially weighted area average that was applied to the provincial values for all years.

Emissions of CO_2, CH_4 and N_2O from drained organic soils were calculated using a Tier 1 method and emission factors from Tables 2.1, 2.2 and 2.3, respectively, of the 2013 Wetland Supplement to the 2006 IPCC Guidelines (IPCC, 2014). Emission factors are associated with the temperate (RUs 11 and 12) and boreal (RU 15) climate zones. The fraction of area covered by ditches was also determined using the default values for drainage ditches from Table 2.3 of the 2013 Wetland Supplement (IPCC, 2014).

A3.5.2.3. Data Sources

Managed Forest Land

Canada's forests are classified as "managed" or "unmanaged" based on the occurrence of management activities for timber or non-timber and on the level of protection against disturbances (Figure A3.5–3). Managed forests occur within all provinces and territories of Canada, with the exception of Nunavut (Figure A3.5–4). The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots and any other land in the Forest category where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The procedures are documented in Stinson et al. (2011).

The model tracks managed forest lands disturbed by harvesting before and after 1990, lands affected by various natural disturbances since 1990 and lands not affected by any disturbances since 1990. Lands not affected by disturbances since 1990 are broken down into stands originating after harvesting or following stand-replacing wildfires prior to 1990. All areas of land in 1990 that were not identified as being of harvest origin were assumed to be of wildfire origin (given that insect disturbances are not stand replacing). These distinctions are used to separate stands dominated by anthropogenic and natural emissions and removals (see section A3.5.2.4).

Forest management activities are documented in the National Forestry Database[28] and additional information on specific activities is obtained directly from provincial and territorial forest management agencies. The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provide essential information—notably detailed forest inventory data, details on forest management activities and practices, disturbance information including prevention or control, regional yield tables (volume / age curve), site indices—and regional expertise (Table A3.5–3). The forest inventory data in Canada's National Forest Inventory

28 National Forestry Database, available online at http://nfdp.ccfm.org/en/index.php.

Figure A3.5–3 **Decision Tree for the Determination of Managed Forest Area**

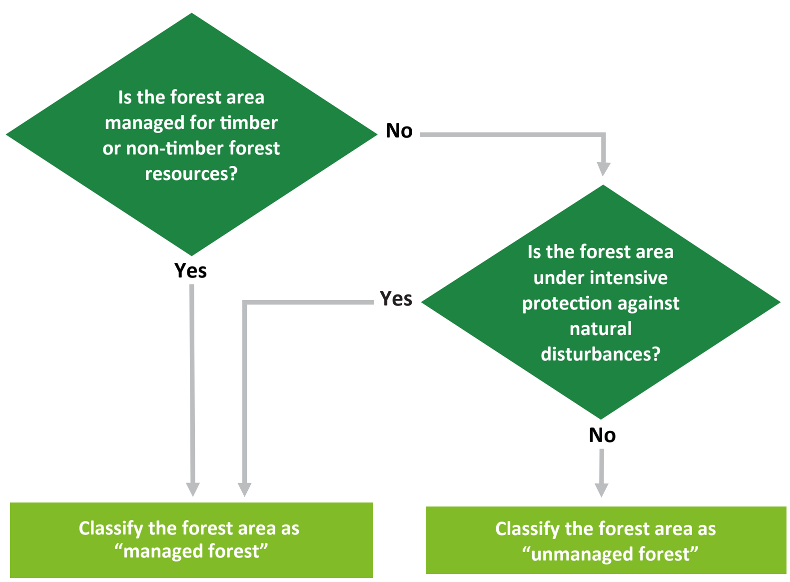


Table A3.5–3 **Main Sources of Information and Data, Managed Forests**

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Climate data	CFS	Analysis units	1961–1990 normals	McKenney et al., 2001
Forest inventories and merchantable volume data[a]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	https://nfi.nfis.org/index.php
	Newfoundland	Analysis units	1991–2006	Provincial experts
	Prince Edward Island	Analysis units	2000	Provincial experts
	Nova Scotia	Analysis units	2006	Provincial experts
	Quebec	Analysis units	2000	Provincial experts
	Ontario	Analysis units	2000	Provincial experts
	Alberta[b]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	2011	Provincial experts
Conventional harvest data[c]	National Forestry Database	Provincial boundaries	1990–2018	http://nfdp.ccfm.org/
	National Forestry Database	Analysis units	1990–2016	http://nfdp.ccfm.org/
Slash burning	National Forestry Database and British Columbia	Provincial boundaries	1990–2018	Provincial experts and http://nfdp.ccfm.org/
Residential firewood harvest data	Energy Sector data for residential firewood use	Reconciliation Units	1990–2019	Sections A3.1.4.1.4 and A3.5.3
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2017	Atlantic Forestry Centre and Pacific Forestry Centre
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Quebec	Spatially explicit	1985–2018	Provincial experts; https://www.donneesquebec.ca/recherche/fr/dataset/donnees-sur-les-perturbations-naturelles-insecte-tordeuse-des-bourgeons-de-lepinette
	Manitoba	Spatially explicit	1985–2019	Provincial experts and provincial forest health aerial overview surveys; National Forest Pest Strategy Information System
	Saskatchewan	Spatially explicit	1985–2019	Provincial experts; National Forest Pest Strategy Information System
	Alberta	Spatially explicit	1985–2019	Provincial experts; Alberta Forest Health Aerial Overview
	British Columbia	Spatially explicit	1990–2019	Provincial experts; BC Forest Insect and Disease Survey; BC Aerial Overview Survey
	Yukon	Spatially explicit	1994–2005	Provincial experts; Yukon Forest Health Aerial Overview
	Northwest Territories	Spatially explicit	1985–2019	Provincial experts; Northwest Territories Forest Health Survey
Fire data	National Burned Area Composite	Spatially explicit	2004–2018	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially explicit	1959–2003	http://www.nrcan.gc.ca/node/13159
Drainage data[d]	Quebec	Province of Quebec boundaries	1980–1985	Provincial experts; historical records; Hillman, 1987; Gillies, 2016
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	1986–1994	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Administrative regions of Quebec	1994–2008	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	2008–2018	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres

Notes:

a. Forest inventory B5:F36 and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or from provincial experts where specified.

b. Alberta's forest inventory database comprises provincial forest inventory for the province's Forest Management Areas, and CanFI inventory for the remainder of the managed forest landbase.

c. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories, 2019 harvest data are estimated by assuming them to be equal to 2018 values.

d. No new drainage activity has been registered in the Province of Quebec since 2016.

(CanFI 2001) were used for New Brunswick, Manitoba, Saskatchewan, Yukon and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, Ontario, British Columbia and Alberta. A series of "method papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al., 2011).

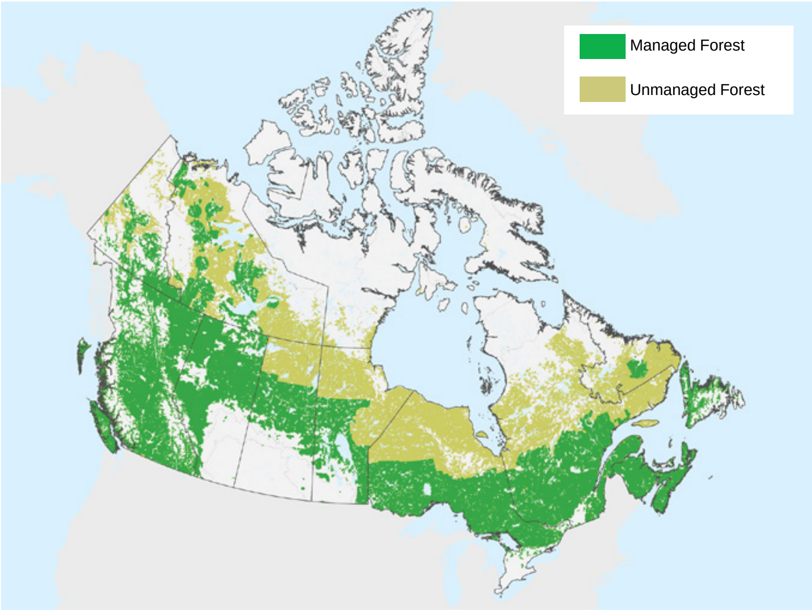
Activity data for the burning of harvest residues ("slash") are obtained from the National Forestry Database for all regions except specific areas of British Columbia where expert opinion is used.[29]

Collection of firewood for residential heating is a common practice in Canada, with an estimated 93% of annual firewood taken from forested lands and the rest from agricultural woodlands and urban trees. Improvements implemented in this inventory submission to estimate the

29 In British Columbia, expert opinion indicates that the proportion of areas harvested using clear-cut where slash burning is applied is 15% on the coast and 50% for the rest of the province.

A3

Figure A3.5–4 **Lands with Managed and Unmanaged Forests in Canada**



impact of this activity on the C balance of Canadian forests include the development of a set of rules to disaggregate these volumes into several components (Hafer et al. 2020, Doyon et al., 2019): softwood, hardwood and mixedwood collected from the forested lands, woody biomass collected from croplands, urban trees from settlement lands, pellets and manufactured logs (the latter four components modelled under Harvested Wood Products, see A3.5.3). For the forested-land target components and based on survey data, a list was developed for the spatial analysis units within each RU from which the firewood to be collected should be taken.

Regional firewood harvest practices in Canada and regionally-differentiated disturbance matrix parameters were implemented in the CBM-CFS3 model for three conceptual "firewood collection zones": (i) Mixedwood-Acadian (MWA), comprised of the Atlantic Maritime and Mixedwood Plains ecozones; (ii) agricultural (AGR), comprised of the Subhumid- and Semi-arid Prairie ecozones; and (iii) boreal-montane (BOR), comprised of all other forest ecozones. Firewood collection in both the MWA and AGR zones is assumed to be via light thinning (30% removal), while firewood collection in the BOR zone is assumed to be via clear-cut harvesting (85% removal). Inventory records selected for firewood collection are disturbed in decreasing order of total snag content, to ensure that a reasonable (though unspecified) proportion of the firewood is collected as dead wood

Data on biomass used as residential firewood are obtained from surveys of residential wood use and origin. Sections A3.1.4.1.4 and A3.5.3 of the present report provide additional information on these surveys and the methodology used to convert the consumption and use data collected to volumes of firewood. Areas specifically attributed to firewood harvest are defined by the model based on those volume estimates.

Areas disturbed by wildfires were extracted from the Canadian National Fire Database for the years 1990 to 2003 and from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) for the years 2004 to the current inventory year (Table A3.5–3). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data prepared by the Canadian Forest Service and combined with data provided by resource management agencies from across Canada. The NBAC provides complete mapping of wildfires using medium-resolution remote sensing data when available; data from resource management agencies are given second priority; and low-resolution remote sensing data are used only where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3.5–3), which record the area impacted by the disturbance and assign an impact severity class that indicates the degree of tree mortality or defoliation. The area of impact is assigned to the appropriate analysis unit and host species within it, and the severity of the impact is reflected in the parameters of the disturbance matrix applied (Kurz et al., 2009).

Areas drained for forestry (Table A3.5–3) on private and publicly owned forests in Quebec are estimated using historical documents, consultations and Quebec statistics. Spatial allocation by RU was performed using Quebec statistics.

A3.5.2.4. Quantifying Anthropogenic Emissions and Removals

Interannual variations and trends in emissions and removals from managed forests in Canada are dominated by the impact of wildfires and periodic forest insect outbreaks, making it difficult to detect trends due to human actions in the forest (Kurz et al., 2008a,b; Stinson et al., 2011; Kurz et al., 2013).

The IPCC does not currently provide default methods for separating anthropogenic emissions and removals from those occurring due to natural disturbances, although it has recognized the issues of reporting emissions from natural disturbances for some countries (IPCC, 2010). Furthermore, the IPCC (2010) has encouraged countries that use Tier 3 methodologies to work towards the development of new approaches that can improve the identification of anthropogenic emissions and removals. The CBM-CFS3 model now has the capability to track and separate emissions and removals in managed forest stands dominated by the impact of anthropogenic activities from those in which emissions and removals result from a significant natural disturbance that has masked the legacy of human management and affected the commercial value of the stand.

The management and natural disturbance history of each individual stand (inventory record) in the managed forest area is used to assign stands to two groups. Emissions and removals are identified as being anthropogenic when (i) a stand's growth trajectory has been significantly modified by human intervention—this definition includes commercial clear-cut and partial harvest, commercial and pre-commercial thinning, salvage logging, site preparation, and rehabilitation and planting on stands that have undergone both stand replacement and partial natural disturbances; and (ii) regardless of its origin, a stand has attained commercial maturity and therefore is actively considered within forest management planning scenarios (eligible to be scheduled for harvest). Once a stand originating from natural disturbance has reached this age, emissions and removals are switched to the reported category.

In contrast, emissions and removals resulting from natural disturbance are defined as originating from (i) stands that have been affected by a stand replacing natural disturbance up to the period that stands reach commercial maturity, or (ii) stands that have been affected by partial disturbance resulting in reduced standing biomass until that stand has attained pre-disturbance equivalent biomass. Only partial disturbances causing more than 20% mortality are included in the natural disturbance category.

In the initial implementation of this approach in the 2017 NIR, a fixed value of 60 years was assumed to be generally applicable to represent a minimum return period to commercial maturity across Canada. Since the 2018 NIR, regionally specific return periods based on differences in forest management practices, species distributions and stand dynamics among regions have been used.

To develop regionally representative definitions of commercial maturity, a questionnaire was distributed to provinces and territories in March 2017. The objective of this consultation process was to document forest management practices across Canada, with a focus on the treatment of naturally disturbed forest stands in operational planning. As such, work with provincial experts provided a minimum return period to commercial maturity ranging from 45 to 99 years, with an average of 76 years. In most cases, provincial agencies defined species-specific commercial maturity based on the maximum mean annual increment of species-specific yield curves for a high productivity site class in a given region. Other provincial agencies used empirical data based on observed regional minimum harvest ages or an age to achieve a specific piece size. Based on the species-specific commercial age, a weighted minimum return period was determined for each reporting zone using the proportional breakdown of the commercial species that were attributed a minimum operable age, or minimum harvest age, in that area. Greater detail on the methodological approach used to track anthropogenic emissions and removals can be found in Kurz et al. (2018).

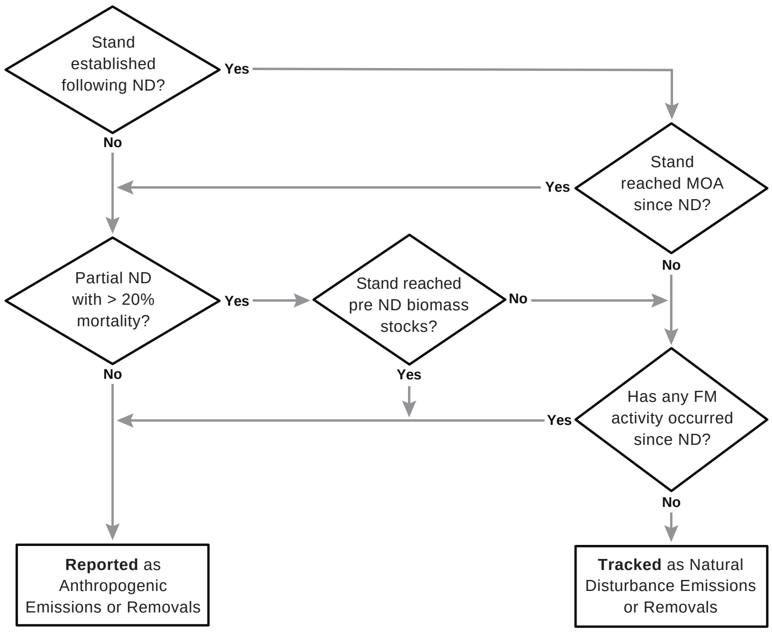
In the current modelling framework, partial natural disturbances occur mainly due to insect infestations. In these cases, above-ground biomass recovery was used to define a recovery period, as the growth trajectory of the stand is only temporarily modified. Stands subject to insect disturbances causing less than or equal to 20% biomass mortality are not deemed to be dominated by natural disturbances; at this low mortality level, disturbances are considered agents that contribute to stand density reductions.

This improvement in the reporting approach ensures that emissions from stands affected by uncontrollable natural disturbances and the subsequent removals by the regrowth of these stands are tracked separately from commercially managed stands. This allows for improved differentiation of emissions and removals associated with direct forest management actions from non-anthropogenic emissions and removals occurring due to natural disturbances.

Tracking stands in which emissions and removals are dominated by natural disturbance dynamics is carried out by querying model results based on a decision-tree approach in which key decision points are based on stand origin, type of disturbance (partial or stand replacing) and an annual assessment of post-disturbance status, either commercial maturity threshold or pre-disturbance biomass (Figure A3.5–5).

After exclusion of the non-anthropogenic emissions and removals, the final reported values represent all forest stands in the managed forest land base that have attained commercial maturity or have had their growth

Figure A3.5–5 **Decision Tree for Differentiating Emissions and Removals from Anthropogenic and Natural Origin**



Notes: ND = Natural disturbance, MOA = Minimum operable age, FM = Forest management.

trajectory modified by a direct anthropogenic management action in the forest. The area temporarily excluded from reporting in any given year remains relatively constant, within a variation of +2.9/-3.6 million hectares (Mha), as stands undergoing natural disturbance in a given year are removed from reporting and lands that were disturbed historically re-enter reporting. The sum total of each of the stand categories included and excluded is equivalent to the sum of emissions and removals quantified using the methodological approach for reporting total emissions from the managed forest in previous inventory submissions.

A3.5.2.5. Forest Conversion

In order to account for long-term residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other land uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement/opinion. The basic methods have been tested in several pilot projects (Leckie, 2006a), and the methodology has been implemented across the country.

The core method involves remote sensing mapping of forest conversion based on samples from Landsat images dated circa 1975, 1990, 2000, 2007, 2011 and 2016. Change enhancements between two dates of imagery are produced to highlight areas of forest cover change and identify possible forest conversion events (i.e., “candidate events”). The imagery is then interpreted to determine whether the land cover of the candidate event was initially forest (at Time 1) and the actual land-use change at Time 2 (Leckie et al., 2002, 2010b). This forest conversion interpretation process is strongly supported by additional spatial data, including: digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage, and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al., 2006; Dyk et al., 2015). When readily available, detailed forest inventory information is also used.

Change imagery is interpreted and analyzed; each forest conversion event larger than 1 ha is manually delineated. The forest type, maturity and density prior to forest conversion is interpreted,[30] and the post-deforestation land use recorded (“post-class”). Confidence ratings on the land use at the initial time and a later time period are used in subsequent quality control and field validation procedures.

Monitoring of forest conversion activity covers all forest areas of Canada and is not limited to the managed forest. The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches

30 See Chapter 6 for the definitional parameters of “forest.”

range from complete mapping to systematic sampling over the entire analysis unit of interest to a representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec, in the Prairie fringe and in British Columbia a 12% sampling rate in earlier time periods was generally achieved, with 3.5 km by 3.5 km sample cells at the nodes of a 10 km by 10 km grid (Figure A3.5–7). A lower sampling rate is used in some of the forest activity zones characterized by low population density, where the main economic activities are forestry and other resource extraction. Special cases of known, localized and large forest conversion activities are also identified, such as hydroelectric reservoirs and oil sands development in Alberta. In such cases, the entire areas are handled as single events ("Hot Spot" in Figure A3.5–6), with spatially complete mapping.

In practice, resource constraints limit the size of the remote sensing sample. Wherever possible, a target sampling rate of 12% or 6% was achieved. It is also important to note that different sampling rates may be applied for each time period in an effort to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover a large portion of the Canadian land base, approximately 346 Mha. This total area was mapped over different time periods, of which over 17 Mha were mapped for 1975–1990, 41 Mha were mapped for 1990–2000, 22 Mha were mapped for 2000–2008, 23 Mha were mapped for 2008–2013 and 15 Mha were mapped for 2013–2018 (Figure A3.5–6). Mapping is updated on a roughly five-year time cycle for both the sampling and individual larger events and may be integrated progressively by project for the most recent time period.

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al., 2006). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are sometimes used to aid in the validation of estimates made through image interpretation. In particular, early mapping for British Columbia used records data to provide estimates of conversion activity for power lines and oil and gas activity. Remote sensing image interpretation is used to assess the areas of forest converted as a result of hydroelectric development.

Expert opinion is only called upon when remote sensing sampling is insufficient and records data are unavailable or of poor quality. Expert judgement is also used to reconcile differences between records and remote sensing information and to resolve large discrepancies in each sequential mapped time period (i.e., 1975–1990, 1990–2000, 2000–2008,and the most recent time periods are measured on a circa 5 year cycle) area estimate. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions are made (Leckie, 2006b; Leckie et al., 2010a; Dyk et al., 2015). For most estimates now—and certainly for those with large impact—estimates are derived directly from remote sensing samples.

Figure A3.5–6 **Forest Conversion Strata and Areas Sampled in 2013–2018**

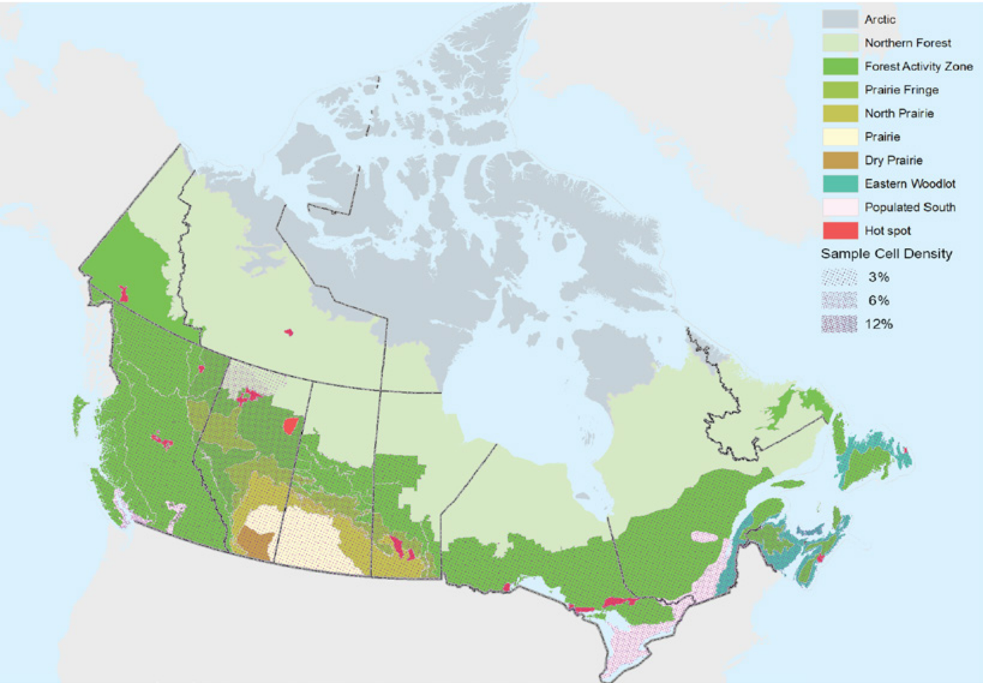


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Figure A3.5–7 **Three Sampling Rates over Satellite Imagery for Forest Conversion Mapping**

Note: Background imagery: Area near Fort Nelson, British Columbia (ESRI World Imagery). Denser grid cells at the center represent a 12% sampling density; lighter grid on the right is 6% intensity and sparse grid on the left is 3% intensity.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made to summarize events for detailed post-conversion classes for each RU. This compilation process also involves insertion of records data and expert judgement. In the course of these procedures, each event is compiled to yield a local forest conversion rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated a specific year, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned a time period, and the corresponding rate of forest conversion is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then would be assigned to the period 1975–1990. The total area interpreted in an analysis unit for that time period is then used to determine a relative rate of forest conversion ([ha/year]/km^2 interpreted) for all events of the same type. Relative rates are scaled up for each analysis unit. Data are finally grouped by end use (e.g., the change rate for agricultural crop or rural residential) and, in turn, are summarized by broader categories when recompiled by RU.

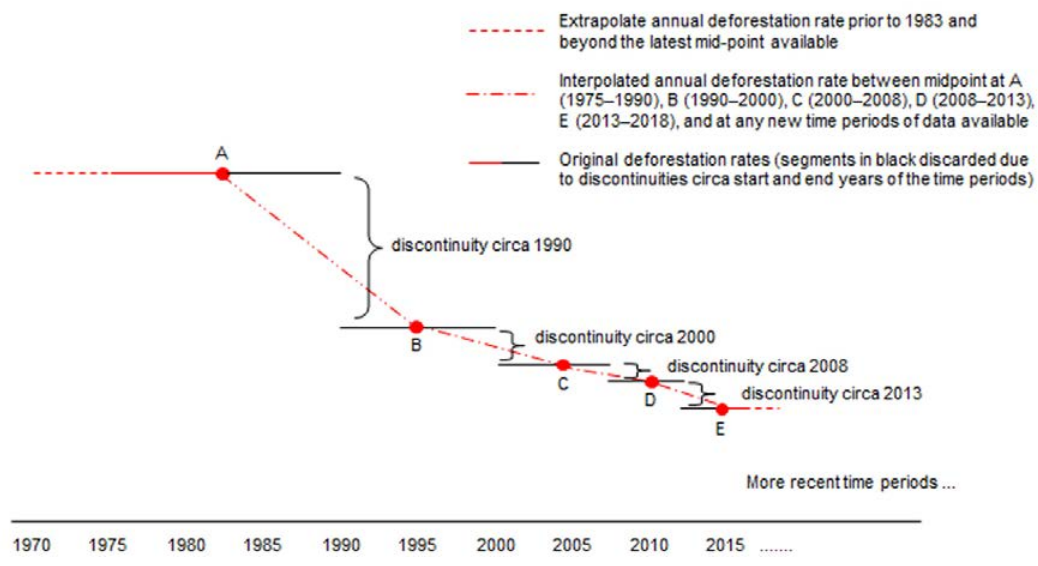
The remote sensing data are derived using medium-resolution imagery from circa 1975, 1990, 2000, 2007, 2011, 2016 and more recent years as new imagery has become available, whereas records data are annual or summarized over time periods. As explained, the remote sensing core method provides, to date, five distinct average rates of forest conversion for the mapped time periods, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970 to the current inventory year requires the simultaneous application of two procedures: (i) extrapolation of annual rates prior to 1983 and beyond the mid-point of the latest time period available, and (ii) linear interpolation between the mid-points in the mapped time periods and recent analyses that are completed at the time of submission (Figure A3.5–8). Added to the interpolated data are individual large events for which actual disturbance information is known either from records information or a detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Quality Assurance / Quality Control of Forest Conversion Data

Great care was taken in understanding the records data, their suitability and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed and, where available, numbers were checked against independent data sources, sampling of high-resolution imagery and the knowledge of experts.

The remote sensing interpretation follows defined procedures (Leckie et al., 2010b; Dyk et al., 2015), although it is conducted by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations and in-house government staff. The basic image analysis quality control (QC) process includes: internal checks within the mapping agency or company by a senior person; real-time quality assurance (QA) by Canadian Forest Service specialists during interpretation, with feedback provided within days of interpretation of an area; and a final QA and vetting of the interpretation by the Canadian Forest Service. Field validation is conducted on an ongoing basis as resources permit. Each QC point and revision is documented within the geographic information system (GIS) database of conversion events (Dyk et al., 2015).

Figure A3.5–8 **Procedure for Developing a Consistent Time Series of Rates of Forest Conversion**



Records of decision as to data used and expert judgement applied, as well as decisions on the resolution of contradictory data, are documented within the overall processing database (Leckie, 2006b) and updated for each new submission (Dyk et al., 2015). Data sources and limitations are recorded, and remote sensing data and interpretations archived.

Uncertainty of Forest Conversion Data

The development of an uncertainty estimate for forest conversion is a complex and difficult task because of its spatial and temporal variability. Compared to earlier estimates, current estimates benefit from several years of experience and knowledge gained through the development of previous estimates (Leckie, 2011; Dyk et al., 2015). Specific improvements include:

- expanded data sets with additional Earth observation (EO) data, Landsat, Sentinel 2, SPOT-5, aerial photography and high-resolution satellite imagery
- expansion of the sampled area for targeted and other areas
- analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads)
- extension of the temporal coverage to the most recent time period
- review of the 1970–2004 deforestation time series based on more current spatial analysis
- greater knowledge resulting from increased experience and expertise gained through QC review and validation activity

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of timing of conversion events.

Two approaches were considered to estimate uncertainties: an empirical approach and an analytical approach. The resulting estimate is based on consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. The additional sources of uncertainty related to the forest type being converted, post-conversion land category and event timing are not considered.

The empirical approach is an attempt to estimate an overall uncertainty in the forest conversion area estimate. This approach provides an estimate that considers all of its varied components and their potential interactions.

The empirical estimate was developed by making estimates of extreme low, low, high and extreme high forest conversion rates for each RU and end-use class. These estimates were based on expert knowledge of activity and practices at a regional scale. All of these estimates were then compiled on a national basis. Comparisons between extreme and non-extreme estimates provided some insight into the possible range for which conversion activity could occur. Based on this exercise, an estimate for overall uncertainty for forest conversion was determined to be in the range of ±20% to ±30%.

The analytical approach breaks down the uncertainty into subcomponents and then combines them through simple error propagation. The components considered are omission and commission, sampling and boundary delineation errors.

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Omission and commission errors are influenced by a number of factors, but in particular are dependent on the date and quality of pre- and post-imagery. Throughout the time series, there is a tendency for omitted events to be smaller in size, whereas commission errors are usually from a misinterpretation rather than an oversight, and thus are less size-dependent. Commission and omission errors tend to offset each other. For the post-2000 time periods, commission errors are likely to be greater than omission errors, particularly because of an insufficient post-disturbance time lapse to confirm that areas are in fact permanently deforested.

Uncertainty associated with boundary delineation errors considers the errors resulting from the displacement of the event boundary from the actual or true boundary of the event. Both underestimation and overestimation of area can result. This source of uncertainty is greatly influenced by the quality and resolution of imagery used in the delineation process; improvements made in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty take into account the uncertainty associated with the sampling process and the scaling of estimates to large regions (strata/RU). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design differed between all of the mapping periods. The sample error depends on the amount of activity in each region within each time period sampled. In addition, it is dependent on the conversion event size and spatial distribution (Leckie et al., 2015). Uncertainty due to sampling and scaling activity is therefore regionally variable and, because conversion activity causes may vary by region, the uncertainty is variable.

The results of this analytical approach are consistent with those made based on an empirical approach. Based on these efforts, a conservative estimate is taken, which sets the uncertainty at the higher range of ±30%. Further work will help improve the current understanding of the various sources of uncertainty, their interaction and approaches used to combine these components.

The ±30% range is an overall estimate considering all time periods, regions and forest conversion types. Caution should also be exercised in applying the 30% range to the cumulative area of forest land converted to another category over the last 20 years, or 10 years for reservoirs (land areas reported in the CRF tables).

A3.5.2.6. Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative (White and Kurz 2005). Conversion activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates from 2000 to 2008. Additional afforestation activity data were obtained through a data sharing agreement with Forests Ontario. A validation exercise on Forests Ontario plantation sites (5 456 spatially-explicit planting records covering 12 466 ha) resulted in 10 390 ha being classified as afforestation events from 2007 to 2016.

Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of C modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2016. For 1990–2016, the area planted was stratified by ecozone, province and tree species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each RU.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Growth curves for the Forests Ontario plantation sites were developed using the Forest Vegetation Simulator-Ontario (Woods and Robinson, 2007), which is a variant of the United States Forest Service's simulator adapted for use in Ontario. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteristics or the species most likely to have been present in that area. It was assumed that no woody biomass is present on the site prior to afforestation. Changes in soil C stocks are highly uncertain. It was assumed that the ecosystem would generally accumulate soil C at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty is minimal.

A3.5.2.7. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step and when an afforestation or forest conversion event is processed, the CBM-CFS3 first assigns the new land-use classification before the impacts of that event are recorded to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. The selection of forest stands affected by land-use change and non–land-use change disturbances is based on eligibility rules (Kurz et al., 2009).

Once the model has computed the immediate effect of disturbances on all forest stands, it simulates forest growth, litterfall and turnover, and decomposition as well as the associated C transfers (annual processes) for all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. The model output consists of C stock changes, fluxes and immediate emissions from burning from which the net GHG balance of managed forests can be calculated. Component fluxes include growth, immediate emissions due to disturbances (C stock changes, C losses to the atmosphere and to forest products), and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a "Land converted to" category for 20 years are converted into the "Land remaining" category, and the simulation of C dynamics—usually decay—continues in this new category.

The same data outputs are available on converted forest lands (except tree growth), but are reported in the new land category—e.g., the Forest Land Converted to Cropland (CRF Table 4.B subcategory 2.1), Land Converted to Wetlands (CRF Table 4.D subcategories 2.1 and 2.2.1) and Forest Land Converted to Settlements (CRF Table 4.E subcategory 2.1) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peat extraction fields, which are developed separately; methods are described in sections A3.5.4.3 and A3.5.6.1. Likewise, estimation methods for emissions (as opposed to C stock changes) from forest land converted to flooded lands are described in section A3.5.6.2 and for emissions from the use and disposal of forest products are described in section A3.5.3.

A3.5.2.8. Uncertainties

Good practice recommends the use of numerical methods for assessing uncertainties within complex modelling frameworks with multiple interactions between data and parameters. These methods are data intensive and computational requirements can quickly become a limiting factor. Not all model parameters or input data have equal influence on model outputs. Careful consideration must therefore be given to balance available computing capacity and the inclusion in the uncertainty assessment of input data, parameters and other functions with a large influence on model outputs.

The general approach to uncertainty assessment emphasizes model inputs and parameters as the main sources of uncertainty. The specific uncertainty sources are forest inventory data, influential model parameters and the initialization of soil and DOM C stocks prior to model runs. Additional randomization steps are also fed into the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of the output from 100 national-scale Monte Carlo runs (Metsaranta et al., 2017). Not all sources of uncertainty have been captured. Importantly, the analysis did not consider the impact of processes that are currently not simulated (Kurz et al., 2013); hence, the results should not be used to assess potential bias (or accuracy) of estimates. The following paragraphs provide details on the characterization of uncertainty sources.

The forest inventory data used in model simulations are developed for planning and operational purposes. Methods, standards, definitions and quality differ by jurisdiction, depending on their objectives. Although documentation on the different inventory techniques and procedures used across the country is usually available, it seldom contains any quantitative assessment of uncertainty. While it is currently impossible to quantify uncertainties about, for example, managed forest areas, the influence of this uncertainty source can be indirectly built into the uncertainty about the biomass increment simulated by the model. For the purpose of this assessment, a 50% uncertainty about biomass increment is assumed. In addition to managed forest areas, it incorporates uncertainties about the age-class distribution, yield curves and allometric equations that enter the estimation.

The areas of managed forests affected annually by both natural and anthropogenic disturbances have a large influence on forest C dynamics as a whole. Disturbances affect emissions and removals of C in the short term as well as in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed on the areas of managed forests subject annually to wildfires and insect infestations, respectively. The limited total forestry drainage area suggests that the impact of the uncertainty associated with this activity is minimal.

The uncertainties about the C removed in harvested material are regionally specific and incorporate error ranges in harvested volume (±1%) and standard deviations about roundwood-specific gravity and the bark adjustment factor (Table A3.5–4). No error was assumed for the C proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

Table A3.5–4 **Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory**

Province or Territory	Minimum Multiplier	Maximum Multiplier
Newfoundland	0.96	1.04
Prince Edward Island	0.88	1.12
Nova Scotia	0.88	1.12
New Brunswick	0.92	1.08
Quebec	0.86	1.14
Ontario	0.92	1.08
Manitoba	0.86	1.14
Saskatchewan	0.92	1.08
Alberta	0.90	1.10
British Columbia	0.92	1.08
Yukon	0.84	1.16
Northwest Territories	0.74	1.26

Note:

Source – Metsaranta et al. (2014)

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The assessment also provides uncertainties about emissions due to forest conversion that are subsequently used in Tier 1 uncertainty reporting for national estimates in conjunction with the 30% uncertainty for areas converted annually equally used in this analysis. The "Forest Conversion" section of this annex describes the derivation of this value (see A3.5.2.5).

Soil and DOM pools contain a considerable amount of C. Previous work has shown that the initial DOM C stocks, at the beginning of a complete run, are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by modifying the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. A sensitivity analysis of C emissions from the DOM and soil pools revealed that the most influential model parameters included decay rates for soil organic matter and the decay and release to the atmosphere of C from very-fast cycling pools, such as dead fine roots and litter (White et al., 2008).

For the purpose of this analysis, 28 model parameters are allowed to vary in the Monte Carlo runs:

- base decay rates for DOM pools (11 parameters)
- proportion of decayed material that is oxidized, versus that which is transferred to another DOM pool (5 parameters)
- turnover rates for biomass pools (12 parameters)

In the absence of evidence to support more complex functions, all input probability distribution functions for biomass increments, activity data on human and natural disturbances and decay parameters are triangular. A gamma probability distribution function is used for fire intervals (Metsaranta et al., 2014).

It is thought that significant uncertainty in the modelling framework may result from the random selection of forest stands subject to fire and deforestation disturbances (Kurz et al., 2008b), which interacts with the uncertainty about forest inventory data. The random effect of stand selection algorithms is included in the analysis by allowing different seed values to initiate the random selection algorithms.

It is important to note the interactions between input data and parameters. For example, the uncertainty about the age of a forest stand (or age-class structure of a forest landscape) may affect the simulated stand (or landscape) productivity, depending on the yield curves and the particular locations of a given age category along those curves. Emissions due to disturbances—including the conversion of forests to other land categories—are driven not only by the areas affected, but also by the pre-conversion standing C stocks, the parameters of the disturbance matrices that reallocate C among pools or "release" it to the atmosphere and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of "activity data" and "emission factor" uncertainties.

Uncertainty estimates are developed for both reported emissions and removals representing anthropogenic drivers and non-reported emissions and removals due to natural disturbances. In years where there are no substantial changes, no comprehensive uncertainty analysis using Monte Carlo simulation is performed. Instead, confidence intervals for each category for the current year of submission are statistically extrapolated for both forest and HWP estimates. These extrapolations use the results of the previous submission, where numerical estimates of uncertainty were derived using Monte Carlo simulations as explained above and further described in Metsaranta et al. (2017; 2020). Total uncertainty estimates are allocated to the reported and non-reported categories using the same categorization procedures used to estimate reported and excluded values (see section A3.5.2.4).

Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest C dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures, improved computer software implementations and access to more computing capacity.

A3.5.3. Harvested Wood Products

The LULUCF sector of the inventory includes an estimate of the CO_2 emissions associated with the use and disposal of HWP manufactured from wood resulting from forest harvest, forest conversion and firewood collection activities in Canada and consumed either in Canada or elsewhere in the world, in accordance with the general framework of the Simple Decay Approach, as described in the Annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006). The approach is similar to the Production Approach, but differs from it in that the HWP pool is treated as a C transfer related to wood harvest and hence does not assume instant oxidation of wood in the year of harvest. The approach tracks the fate of C in all woody biomass harvested domestically and taken off-site. Emissions of CO_2 from HWP use and disposal are estimated and reported by the LULUCF sector, while CH_4 and N_2O emissions from HWP combustion or domestic decomposition are estimated and reported by the Energy and Waste sectors.

General Approach and Methods

A country-specific model, called the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP), was developed to estimate and report on the fate of C harvested in Canada's forests.

Model Inputs and Data Sources

Input to the model includes the annual mass of C transferred to forest products that result from conventional forest harvesting and residential firewood harvesting in forest lands and from forest conversion activities since 1990. It is spatially distributed by RUs (see section A3.5.1), as calculated by the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, see section A3.5.2.1), thus ensuring there are no gains or losses as C flows from forests to products.

Data on the annual volume of residential firewood and industrial wood waste used for bioenergy are provided by the Energy sector. In the case of residential firewood, the consumption data were collected through a survey of residential wood use for the years 1997, 2003, 2007, 2015 and 2017 (Statistics Canada 1997, 2003, 2007, 2015, 2017). Pellet and manufactured log consumption data were collected for the years 1996, 2006, 2012, and 2017 (Canadian Facts 1997; TNS 2006, 2012; Statistics Canada, 2017). These data were collected only for the provinces (i.e. not for the territories) and grouped into eight major appliance-type categories: fireplaces, fireplace inserts, wood stoves, wood furnaces, pellet stoves, hydronic heater, water heater and other equipment. The 2017 survey also collected data on the type of wood used for firewood that was spatially aggregated by RU (Trégaro, 2020). As a result, species-dependant wood densities could be applied (Blondel and Tracey, 2018) which were maintained constant throughout the time series. The 2017 also collected pellet and manufactured log consumption data on a mass basis. These data were interpolated and extrapolated to other years using the number of heating degree days in each province in relation to the survey years (see section A3.1.4.1.4 for more details on these surveys). Data on firewood consumption for the territories come from fuelwood and firewood harvest statistics provided by the National Forestry Database[31] and data on industrial consumption of fuelwood (biomass and spent pulp liquors) come from the annual *Report on Energy Supply and Demand in Canada* (RESD).

For historical harvest, the C input comes from commodity production data from Statistics Canada at a national level of spatial resolution and covering the 1941–1989 period. For the 1900–1940 period, the C inputs are backcast based on historical production data by extrapolating information from the 1941–1989 period, while the consumed and exported magnitudes are calculated using average proportions from statistics in the five-year period from 1961 to 1965.

Model Flow and Parameters

The model uses a conceptual flow network describing the movement and transformation of harvested wood. (Figure A3.5–9). The model takes the C inputs and, in annual time steps, exports some of the harvested roundwood, converts all harvested wood into commodities (sawnwood and other-industrial roundwood, wood-based panels, pulp and paper, pellets and manufactured logs used for bioenergy, and residuals referred to as “milling residue”), exports some of the commodities produced, and keeps track of the additions to and retirements from HWP in-use and used for bioenergy. The complete model consists of 15 such networks—one for each province and territory (except Nunavut), plus one each for the United States and Japan, and one that combines all other importers of Canadian wood products. The on-site decay of harvest residues continues to be captured in C stock changes in the DOM pool of the Forest Land category.

Recent statistics available in the FAO databases of Forestry Production and Trade[32] and Forestry Trade Flows[33] were used to determine the proportion of Canadian roundwood and commodity production exported to three main destinations. For example, according to current statistics from the FAO, in any given year, around 98% of industrial roundwood from domestic harvest remains in Canada for further transformation, of which about 70% is converted to sawnwood, wood-based panels, other industrial roundwood or pulp and paper products. Likewise, over the entire time series, around 33% of sawnwood, between 19% and 65% of wood-based panels and less than 13% of pulp and paper are used domestically. The proportion of HWP transferred out of the in-use pool is determined through the application of Equation 12.1 from the IPCC 2006 Guidelines (IPCC, 2006). Upon being retired from the in-use pool, all C is assumed to be instantly oxidized. Emissions from residential firewood use and industrial processes flowing from milling residue (e.g., industrial bioenergy) have been represented separately to prevent any potential overlap with estimates reported by the Energy sector.

Manufacturing efficiencies determine the proportion of industrial roundwood biomass converted into commodities—the unused fraction being milling residue. These proportions are calculated using a mass-balance approach that reconciles domestic harvest with FAO data on commodity production and trade. Manufacturing efficiencies are calculated annually for each commodity type: for Canada, the United States and Japan separately; and jointly for all other export destinations. Default bark expansion factors and wood C content were used for all countries (Table A3.5–5). Default parameters were used to convert product volume to units of C for countries other than Canada and the United States and where country-specific parameters

31 National Forestry Database, available online at: http://nfdp.ccfm.org/en/data/harvest.php

32 FAOSTAT Forestry Production and Trade, available online at: http://www.fao.org/faostat/en/#data/FO

33 FAOSTAT Forestry Trade Flows, available online at: http://www.fao.org/faostat/en/#data/FT

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are not available for Canada or the United States (Table A3.5–6). Canada-specific wood density values were used for domestic roundwood, sawnwood, other industrial roundwood and panels, and default values were used for domestic pulp and paper market. Country-specific values were used for all domestic quantities for the United States. Default values were used for domestic and imported quantities for Japan and elsewhere. It is assumed that all wood fibre feedstock produced in a given year is processed by the forest products manufacturing sector in the same year.

All wood transferred from the forest to the HWP pool is included in the HWP model, but some of the products associated with portions of the wood, such as wood chips and pellets, are not explicitly identified in the data. Contrary to other HWP wood, chips and pellets are estimated from firewood consumption surveys. Wood used for bioenergy, such as pellets and chips, is assumed to be sourced from "milling residue" output category in the HWP model (see Figure A3.5–9). This C is quantified and allocated to bioenergy but is undifferentiated from other residual waste, all of which is assumed to be oxidized on disposal. The export of wood chips/pellets is currently not considered in the model.

The model starts the pool in 1900 and applies product in-use half-life parameters to wood product types based on geographic location. Half-life parameters are sourced directly from Table 3a.1.3 of IPCC (2003) or derived from that table using production-weighted averages to fit the wood product categories of the NFCMARS-HWP (Table A3.5–7).

Table A3.5–5 **Default Parameter Values Used in HWP Analysis**

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC, 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne [a]	0.5	IPCC, 2006 (Vol. 4, Table 12.4)

Note:

a. Tonnes carbon per oven dry tonne of wood material.

Table A3.5–6 **Wood Densities of Commodities**

Country/Countries	Description	Units	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m^3	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m^3	0.481	Derived
Canada	Species-weighted average density, Other industrial roundwood	od tonne/m^3	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m^3	0.643	Derived
Canada	Species-weighted average density, Bioenergy	od tonne/m^3	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m^3	0.455	FAO, 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m^3	0.527	FAO, 2010
U.S.	C+NC roundwood	od tonne/green m^3	0.465	FAO, 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m^3	0.28	Skog, 2008
U.S.	Softwood (SW) lumber	tonnes C/m^3	0.22	Skog, 2008
U.S.	HW lumber	tonnes C/m^3	0.26	Skog, 2008
U.S.	Particle board	tonnes C/m^3	0.29	Skog, 2008
U.S.	Hardboard	tonnes C/m^3	0.42	Skog, 2008
U.S.	Medium density fibreboard	tonnes C/m^3	0.32	Skog, 2008
U.S.	Fibreboard, compressed	tonnes C/m^3	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog, 2008
U.S.	Insulating board	tonnes C/m^3	0.45	Skog, 2008
All	Sawnwood – C	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Sawnwood – NC	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)
All	Wood pulp	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)

Notes:

od tonne = oven dry tonne of wood material

ad tonne = air dry tonne of product

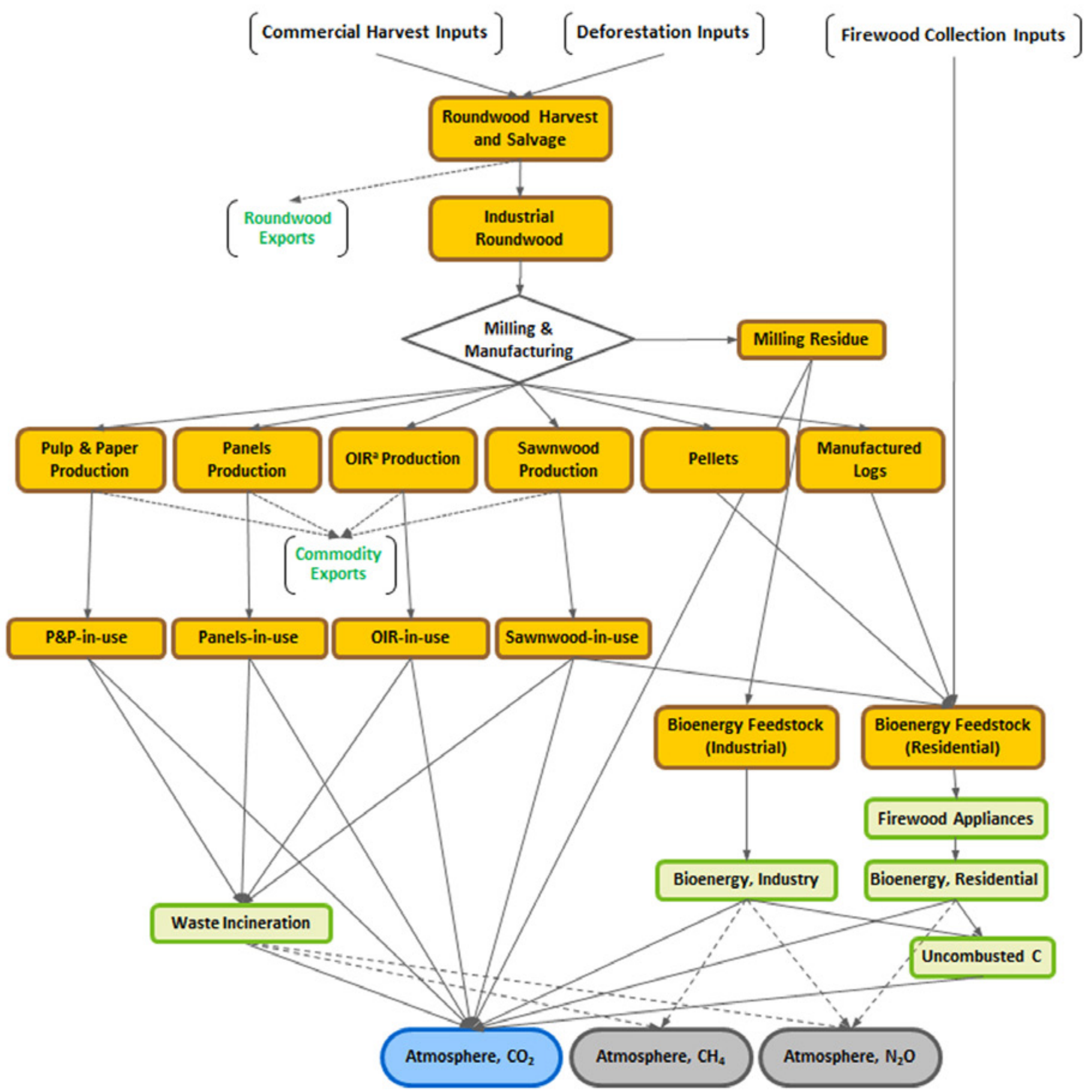
Table A3.5–7 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description [a]	Value	Source
Canada	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)

Note:

a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

Figure A3.5–9 **A Simplified Schematic of Carbon Flows in Harvested Wood Products**



Note:

a. OIR = Other Industrial Roundwood

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Biomass Combustion

Biomass emissions as reported in the Energy sector are grouped into three main sources: (i) residential firewood, (ii) industrial wood wastes (including spent pulp liquors), and (iii) fuel ethanol/biodiesel (assumed not to come from wood waste or pulp liquors).

Residential firewood combustion produces CO_2, CH_4, N_2O and some remaining unaccounted C likely found in VOCs, unburned hydrocarbons and charcoal assumed to be instantly oxidized, in amounts that are dependent on the combustion technology used. Emissions are derived by multiplying the amount of wood burned in each appliance type by the emission factor for that appliance type. The relevant emission factors are given in Table A6.6–1 expressed as grams of gas emitted per kilogram of fuel combusted, which for the purpose of the model have been converted to tonnes of C per kilogram of fuel.

Emissions from industrial use of wood-based energy (managed as "milling residue" in the model) are assumed to result from the combustion of wood wastes (i.e., hog fuel) and spent pulping liquors by the pulp and paper manufacturing sector. As with residential bioenergy use, emissions from industrial use of biomass energy are derived by multiplying the amount of fuel consumed by the emission factor for that fuel type. The emission factors for both industrial wood waste and spent pulp liquors are also given in Table A6.6–1. Note that the emission factors for industrial wood waste and spent pulp liquors are expressed as grams of gas emitted per kg of fuel consumed, assuming 0% moisture content of the fuel.

The processing of residential firewood data ensures consistency with the Energy sector and that the impacts of this type of harvest on the forest and other wooded ecosystems are represented in land emission modelling at the finest possible spatial resolution (Trégaro, 2020). All biomass C inputs to the firewood pool are based on the annual volumes provided by the Energy sector. Specifically, annual quantities of residential bioenergy consumption (in tonnes C) are calculated for each RU, for each of seven (7) allocation categories: (i) softwood collected from forest, (ii) hardwood collected from forest, (iii) mixedwood collected from forest, (iv) woody biomass collected from croplands, (v) firewood collected from urban trees in settlement lands, (vi) pellets, and (vii) manufactured logs, representing the targets of firewood collection to be implemented in the models (Trégaro, 2020, Trégaro et Blondel, 2019, Hafer et al., 2020). Targets for the first three categories in the list were implemented in the CBM-CFS3 simulations (see A3.5.2.3), while targets for the last four categories were implemented in the HWP model. Impacts of firewood harvest on Cropland and Settlements land-use categories were estimated (see sections A3.5.4.1 and A3.5.7.1 for more details).

Uncertainty

Uncertainty estimates associated with this category are mainly based on the uncertainty of the C inputs, namely (i) the C estimated as forest products from forest harvest and forest conversion in the CBM-CFS3 model, (ii) the volume of residential firewood provided by the Energy sector, and (iii) available statistics of pre-1990 commodity production.

The implementation of the uncertainty analysis updated for this inventory submission (Metsaranta et al., 2020) divides the uncertainty into three categories: (i) uncertainties in assumptions and approaches, e.g. the assumption that disposal of HWP follows the exponential decay pattern, (ii) uncertainties in factors or parameters that are not derived from activity data, e.g. half-lives of commodity-in-use pools and landfill pools, and (iii) uncertainties in input and allocation parameters that refer to C mass inputs (e.g. roundwood harvest) and partitioning parameters derived from activity data.

A sensitivity analysis was carried out to filter out parameters whose variation are unlikely to cause significant changes to the emission results prior to the Monte Carlo analysis. Uncertainty distributions and ranges were based on literature where possible and where no distributions were available were based on expert judgement.

Additional parameters were added to the Monte Carlo analysis for this submission including uncertain distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvest since 1990) and five allocation parameters related to bioenergy that were added to the HWP model structure. The historical inputs are directly allocated to commodity-in-use pools and are varied using a multiplier which is assigned a uniform distribution with a range between 0.75 and 1.25. Contemporary inputs are acquired from the outputs of the CBM-CFS3 model, which correspond to a range of C mass. These outputs are used as inputs for the uncertainty analysis for HWP. Three sets of pools with their corresponding events and parameters were also added to the analysis for this submission: pellets, manufactured logs and bioenergy (residential and industrial). The sample size (n) for the Monte-Carlo runs was 100.

As already noted in A3.5.2.8, in years where there are no substantial changes, no comprehensive uncertainty analysis is performed and, instead, confidence intervals for each category for the current year of submission are statistically extrapolated using the results of the previous submission.

A3.5.4. Cropland

The methodologies described in this section apply to C stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest Land and Grassland categories to the Cropland category, CO_2 emissions from the cultivation of histosols, changes in the biomass of woody perennial crops, and N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for C stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in section A3.5.2.7.

A3.5.4.1. Cropland Remaining Cropland

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

Change in Carbon Stocks in Mineral Soils

Changing Management Practices

The amount of organic C retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The development of the CO_2 estimate methodology is based on the premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed to be zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al., 1995, 1996a, 1996b; Janzen et al., 1998; McConkey et al., 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction in summerfallow (Campbell et al., 2000, 2005; McConkey et al., 2003) and greater use of perennial forage (Biederbeck et al., 1984; Bremer et al., 1994; Campbell et al., 1998). Intensification of cropping systems not only increases the amount of C entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the *Census of Agriculture*, provided the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of CO_2 from mineral soils are estimated for the following land management changes (LMCs):

1. Change in mixture of crop type
   a) Increase in perennial crops
   b) Increase in annual crops
2. Change in tillage practices
   a) IT to RT
   b) IT to NT
   c) RT to IT
   d) RT to NT
   e) NT to IT
   f) NT to RT
3. Change in area of summerfallow
   a) Increase in area of summerfallow
   b) Decrease in area of summerfallow

Where nutrients are strongly limiting, proper fertilization can increase SOC. In such conditions, however, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that the selected LMCs represent the most important and consistent influences on SOC in mineral soils.

Carbon Stock Change Factor

To estimate C emissions or removals, an SOC stock change factor specific to each combination of SLC polygon and management change is multiplied by the area of change. The factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3.5–1

$$\Delta C = F \times A$$

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, or C factor, Mg C/ha/year
A	=	LMC area, ha

Areas of LMC, such as changes in tillage, crop type and fallow, are obtained from the *Census of Agriculture*. Census data provide information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are

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available, two assumptions are made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the C changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is additive.

There is a relatively large set of Canadian observations of long-term changes in SOC for LMCs such as adoption of NT and reduced frequency of summerfallow (VandenBygaart et al., 2003; Campbell et al., 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, there are difficulties in comparing measurements among research sites, in determining the duration of an effect, in estimating full uncertainty from a range of initial soil conditions and in determining the variability of soil C stocks without management change.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al., 1987, 1988), is used to derive individual SOC factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The Century model has been widely used to simulate SOC change for Canadian conditions (Voroney and Angers, 1995; Liang et al., 1996; Monreal et al., 1997; Campbell et al., 2000, 2005; Pennock and Frick, 2001; Carter et al., 2003; Bolinder, 2004).

Smith et al. (1997, 2000, 2001) developed an approach using the Century model to estimate SOC change on agricultural land in Canada. To estimate C change, it was necessary to develop a generalized description of land use and management from 1910 onwards on cropland for a sample of soil types and climates across Canada. These scenarios were generated from a mixture of expert knowledge and agricultural statistics of land management, including crop types, fallow and fertilizer application (Smith et al., 1997, 2000). These have been used for the first comprehensive assessments of SOC change on agricultural land within a broader assessment of soil health (McCrae et al., 2000).

The starting points for developing C factors were the SOC values in the SLC polygon attribute database (CanSIS) (Figure A3.5–10 and Figure A3.5–11). These SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai, 1997) and were assumed to represent average SOC on cropland in 1985. Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon. Changes in SOC factors were estimated using the difference in SOC stocks over time between simulation of a generalized land use and management scenario with and without the LMC of interest (Smith et al., 2001).

A 10-year crop-and-tillage system (CTS) was developed for each analysis unit and census year, using data from the *Census of Agriculture*. The CTS focused on seven crops or crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops and summerfallow) and three tillage practices (IT, RT and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices are developed from expert-defined rule-sets, such as “summerfallow never follows summerfallow” and “corn typically follows soybeans.” The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input to the Century model.

The SOC change factor is determined as Factor = (C for CTS with LMC – C for base CTS) / [(fraction of CTS substituted with the LMC) × (duration considered)]. If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in SOC due to an LMC (ΔC_{LMC}) can be estimated as the difference in SOC stock between two land management systems divided by the proportion of the land area subject to an LMC.

Equation A3.5–2

$$\Delta C_{LMC}(t) = \frac{\Delta C}{P_{LMC}}$$

$\Delta C_{LMC}(t)$	=	the change in SOC between land management systems in year “t” (Mg SOC/ha)
ΔC	=	the change in SOC due to the LMC (Mg SOC)
P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC, ha

This proportion (P_{LMC}) can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after the LMC.

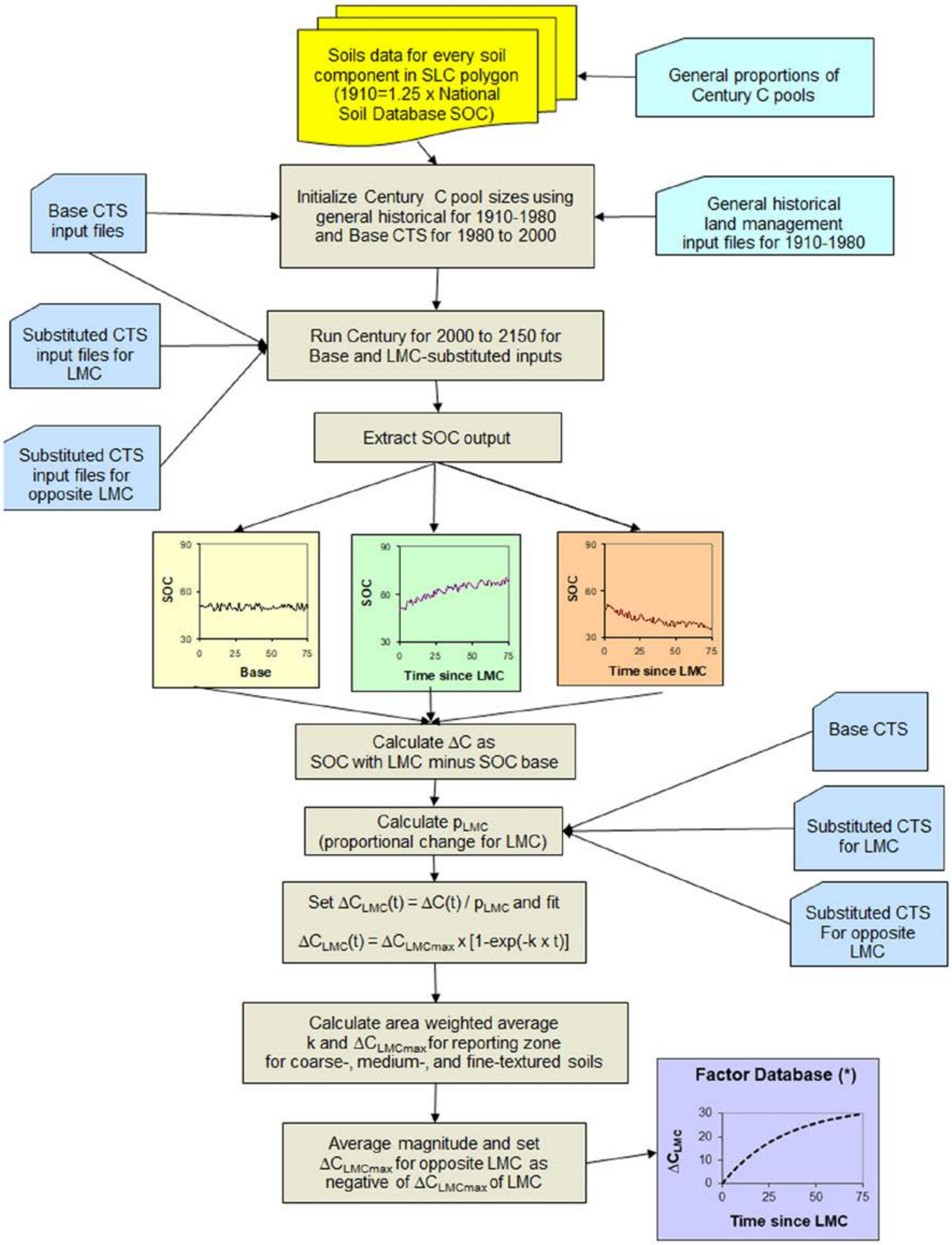
Equation A3.5–3

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC
P_{LMbase}	=	the fraction of land management of interest in the base land management system
P_{LMnew}	=	the fraction of land management of interest in the new land management system

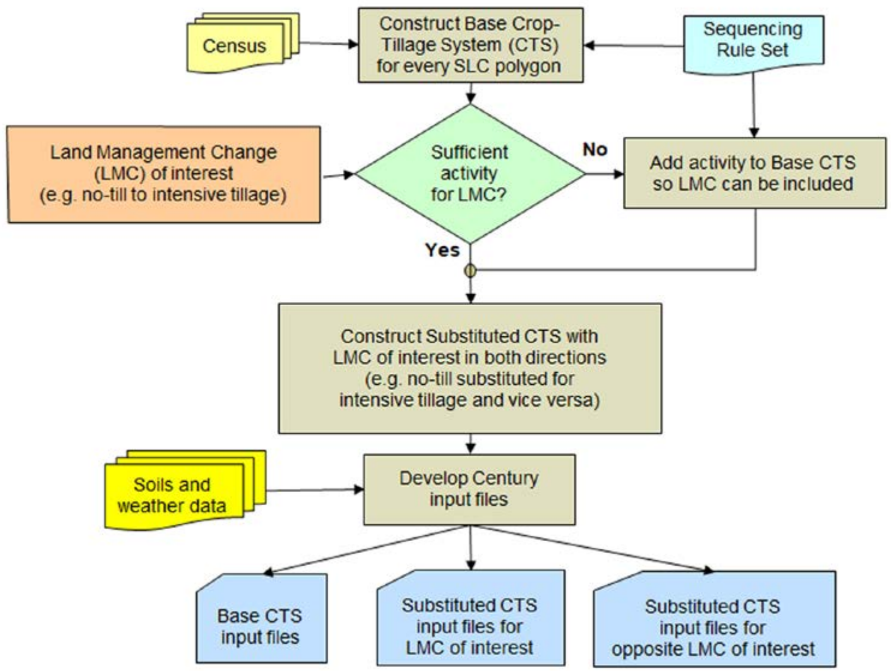
The following provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semiarid Prairies reporting zone. A base model run

Figure A3.5–10 **Method for Deriving Carbon Factors for a Land Management Change of Interest**



Note: (*) Factor is per ha of activity change (i.e. LMC)

Figure A3.5–11 **Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest**



was made using a 10-year base mix of crops based on the 1996 *Census of Agriculture* and weather data covering the years 1951–2000. Century simulations of SOC were made by substituting perennial crops for the 7 annual crops out of 10 in the base mixture. As a separate exercise, NT was substituted for IT 4 years out of 10 in the base mixture (Figure A3.5–12). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC of interest (Equation A3.5–2). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system divided by the P_{LMC}. In this particular case of the time series of ΔC_{LMC}, the respective values of P_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10 (Figure A3.5–13).

SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as:

Equation A3.5–4

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp^{(-k \times t)}]$$

$\Delta C_{LMC}(t)$	=	the change in SOC due to the LMC at a time, t (Mg C ha^{-1})
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg C ha^{-1})
k	=	the rate constant, year^{-1}
t	=	year after LMC

In practice, the exponential equations are fit statistically using methods of least squares. The slope of the natural log transformed exponential equation has units of Mg C/ha per year and is the instantaneous factor value. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e., from year t−1 to year t) is:

Equation A3.5–5

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [exp^{(-k \times [t-1])}) - exp^{(-k \times t)}]$$

$F_{LMC}(t)$	=	the instantaneous C factor value due to the LMC at a time t, Mg C ha^{-1} year^{-1}
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg C ha^{-1})
k	=	the rate constant, year^{-1}
t	=	year after LMC

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3.5–14).

Figure A3.5–12 **Soil Organic Carbon (SOC) for a Base Crop Mix, for Perennial (Alfalfa) Substituted for Annual Crops (Wheat) and for No-Till (NT) Substituted for Intensive Till (IT) Based on Century Runs for a Lethbridge Loam**

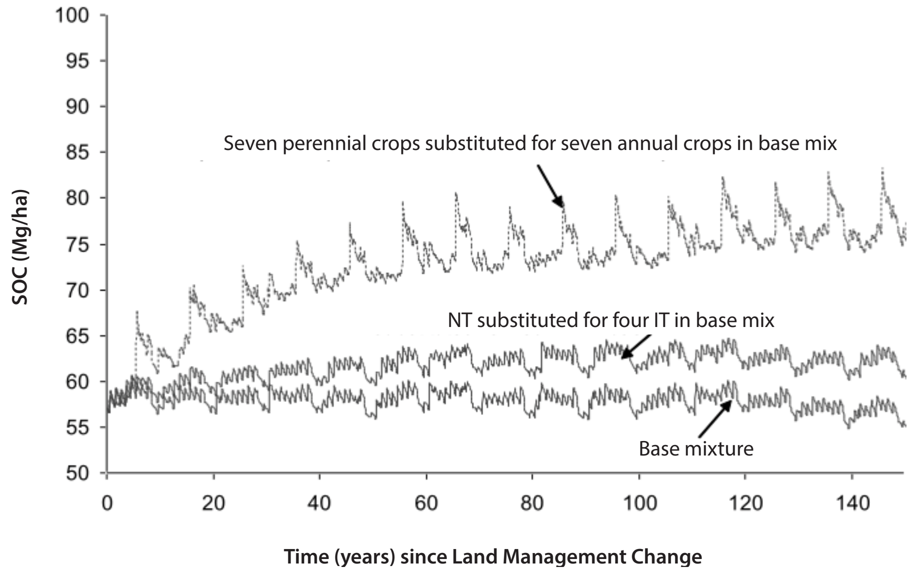
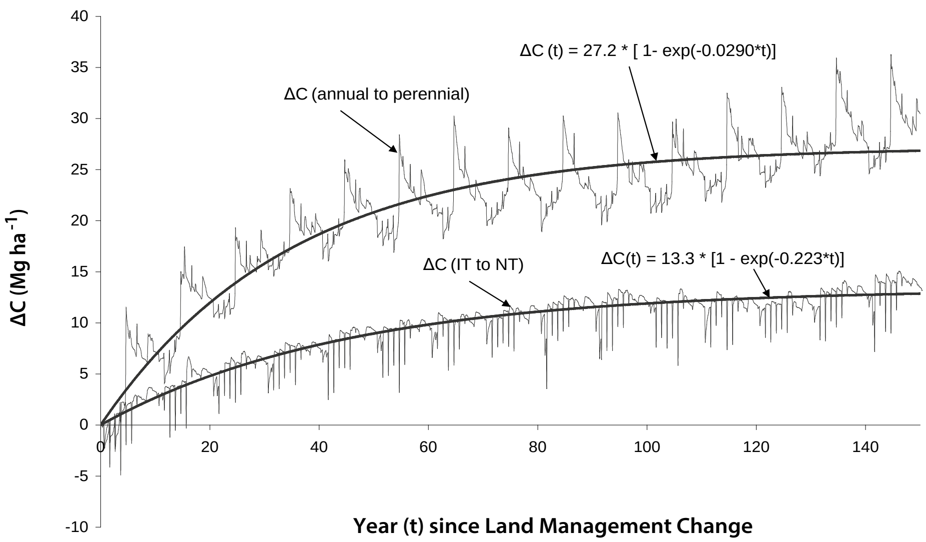


Figure A3.5–13 **Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix**



Estimating Mean k and ΔC_{LMCmax} for Practical Factor Calculations

The ΔC_{LMCmax} and k parameters were determined for all 11 602 soil components of the CanSIS database and three LMCs (changes in tillage practices, summerfallow and annual-perennial crop mix). These soil components represented a wide range of initial SOC states and combinations of base crop mixtures and amounts of substitutions. The parameter values were estimated for each reporting zone as the mean across these soil components, weighted by area of agriculture on each component (Table A3.5–8). The geometric mean was used for k, since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy and clayey) and applied to each soil component based on its textural class. Occasionally, k values less than 0 resulted from the fit to ΔC_{LMC}; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

The dynamics of SOC change in summerfallow have been well studied in Canada. Therefore, rather than using the value for ΔC_{LMCmax} from the Century simulations, the ΔC_{LMCmax} value was set so that F was 0.15 Mg C/ha per year (Campbell et al., 2005) at 20 years based on a P_{LMC} of 0.5 (for example a change from 50% fallow to no use of fallow). The k value was derived from the Century simulations as described above.

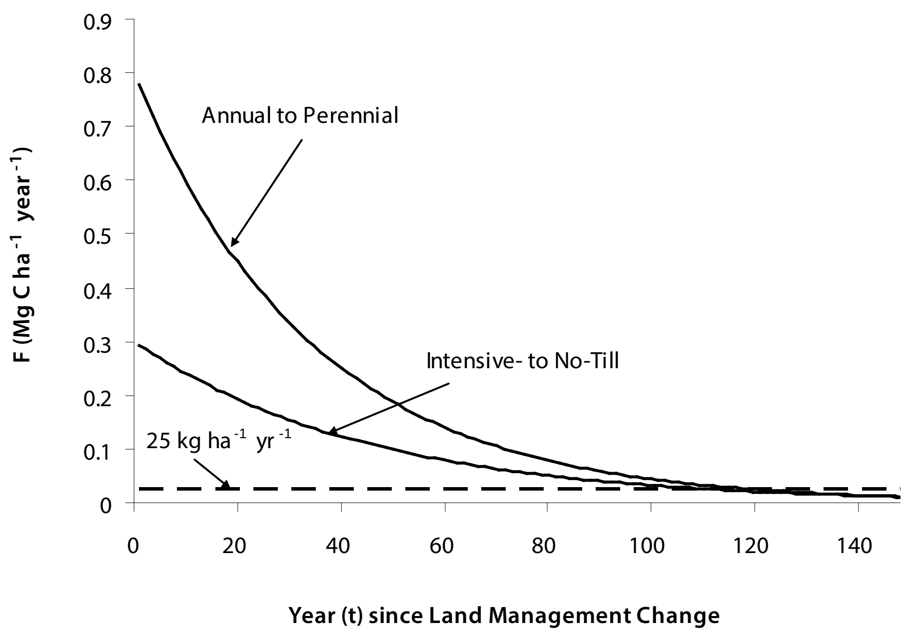
Generally, rates of SOC losses following an LMC are expected to be greater than rates of SOC gain following the reverse LMC. However, this effect is highly dependent on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible. Hence, for transparency and simplicity, the reversibility assumption was imposed, whereby the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

Soil Carbon Factor Validation

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor derived from experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-arid Prairies reporting zone. The mean Century model-derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, which compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in the Parkland, Semi-arid Prairies and West zones (Table A3.5–8). In Eastern Canada, only two empirical change factors were available in the East Central zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled).

Figure A3.5–14 **Carbon Factors as a Function of Time**



For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of 0.15 ± 0.06 Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory.

Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for all inventory years since 1990. Because the effect of LMCs declines over time, a time period when change was deemed to have occurred is maintained for each LMC. The C change factor was multiplied by the area of LMC and summed across soil components to produce an estimate of SOC change for the SLC polygon. This is the smallest georeferenced unit of SOC stocks and SOC stock changes calculated using an IPCC Tier 2 approach as follows:

Equation A3.5–6

$$\Delta C_{LMC} = \sum_{1951-n} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

ΔC_{LMC} = change in SOC stocks due to LMC for a specific year since 1951 until year n (latest inventory year)

$ALLSLC$ = all soil landscapes of Canada polygons that contain land management practices in cropland remaining cropland

ΔC_{TILL} = change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change

ΔC_{SF} = change in SOC stocks due to the change in summerfallow in each SLC

$\Delta C_{CROPPING}$ = change in soil C stocks due to the change in annual and perennial crops in each SLC

Figure A3.5–15 provides a schematic of the method for C estimation.

Table A3.5–8 **Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)**

Zone[a]	LMC[b, c]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC[d]	Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 Years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.025	5	65	0.06	0.1
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0233	29.4	142	0.2	0.55
Semi-arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.1
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0	0
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:

Effective Linear Coefficients of SOC were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.

a. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.

b. For LMCs in the opposite direction to that listed, the F_{LMCmax} will be the negative of the value listed.

c. IT = intensive tillage, RT = reduced tillage, NT = no-till

d. No further C changes once the absolute value of the rate of change is less than 25 kg C/ha per year.

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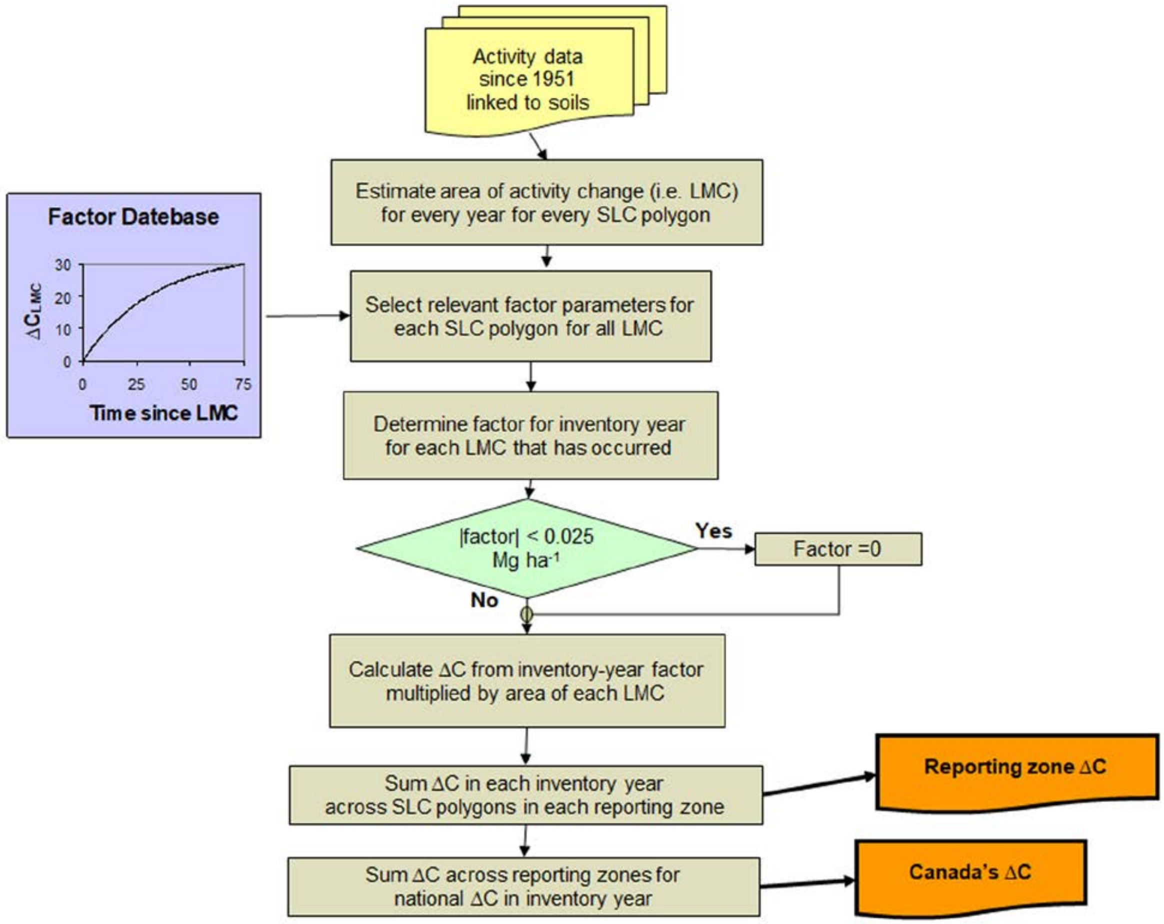
Figure A3.5–15 **Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas**



Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agriculture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of soil C stock change. The main data used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, crop yields, climatic data and activity data from other surveys and databases. The main data used for estimating annual soil C stock changes are data on land management practices from the *Census of Agriculture*.

Land Information and Activity

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million.[34] The SLC was chosen for the LULUCF inventory because of its national scope and standardized structure, which ensure that all areas of the country are treated in a consistent manner with regard to inventory assessment procedures. The current version of the SLC in the National Soil Database (NSDB) data holdings is version 3.2. The extent of the soil attribute information in this coverage is restricted primarily to the agricultural areas of Canada. In instances where agricultural land was mapped outside the coverage of SLC v3.2, then soil attribute information was extracted from SLC v2.2, an older but complete coverage of soils in Canada. All SLC polygons are “nested” within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

In all provinces within the agricultural region of Canada, detailed soil survey information with map scales greater than 1:1 million was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data, including soil C content, soil texture, pH, bulk density and soil hydraulic properties

34 Available online at http://sis.agr.gc.ca/cansis.

for modelling C factors with Century. The SLC polygon provides the spatial basis for allocating land management practices, such as tillage practices and cropping systems from the *Census of Agriculture* and Cropland converted from Forest Land and Grassland, to modelled C factors. The estimated areas of cropland and other land-use practices on an SLC polygon basis were derived from EO-based maps for 1990, 2000 and 2010.

Analysis Units

There are 3404 SLC polygons in which agricultural activities occur. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 13 771 unique combinations of soils, landforms and slope positions within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to the SLC based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make them more or less likely to be used for specific types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of high, moderate or low in terms of its likelihood of being under annual crop production. In this way, annual crop production is linked to those soils with a high rating. If there was insufficient area with high likelihood of being under annual cropland to be assigned to annual crop production, the remaining annual crop production will be assigned to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After the annual crop production area was linked, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production and stocks of the principal field crops grown in Canada. Several publications are released at strategic points in the crop year. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, whereas the November estimate is released after the harvest. The data are released at the census agricultural region level, providing crop yields for approximately 70 spatial units in the country. Census agricultural region boundaries were overlaid on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. These yields were used to calibrate the Century crop growth submodel.

Climatic Data

There are 958 weather stations in the database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (ºC) and precipitation (mm) from 1951 to 2000 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by Environment and Climate Change Canada's Meteorological Service of Canada.

Earth Observation and the *Census of Agriculture*

Activity data for C estimation in the Cropland Remaining Cropland category rely mainly on a combination of data from the *Census of Agriculture* and area estimates based on EO analyses. The *Census of Agriculture* is conducted every five years to develop a statistical portrait of Canada's farms and agricultural operators. For confidentiality reasons, the smallest area for which Statistics Canada externally releases data from the *Census of Agriculture* is the dissemination/enumeration area level (of which there are approximately 52 000 in Canada). To provide a biophysical basis on which to model, data at this level were attributed to the SLC polygons (McConkey et al., 2007a).

Mapping data based on EO were used to provide area estimates of all land-use practices within each of the agricultural SLCs in Canada. Land-use maps based on EO information were generated for 1990, 2000 and 2010 (Huffman et al., 2015a). Using SLC polygons as the level of spatial stratification, data were compiled into seven primary land cover categories: cropland, grassland, forest land, settlements, wetlands, water, and other land. From 1990 to the latest inventory year, annual estimates of land-use areas were generated by interpolating between EO years and extrapolating beyond 2010. Agricultural land-use estimates prior to 1990 were generated using the *Census of Agriculture* and the relative change in cropland and grassland areas between census periods. Land-use estimates for 1981 were generated by calculating the relative change in agricultural land use with the use of data from the 1991 and 1981 censuses and applying this change to the 1990 EO data. Then, moving progressively back through periods between census years, the relative changes were used to generate agricultural land-use estimates back to 1951. To minimize spatial variability associated with known issues related to reporting land-use areas based on farm headquarters, the relative change in land-use estimates was calculated at the spatial scale of the ecodistrict and applied to all SLC polygons nested within.

The EO-based cropland attributes were estimated using ratios of cropland area attributes to total cropland area from the *Census of Agriculture*. To reduce differences between EO and census estimates of provincial crop areas, EO cropland categories (i.e., cropland, pasture,

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orchards and vineyards) were reconciled using provincial scaling factors. Reconciliations were constrained by the total area of agricultural land within SLC polygons, as interpreted through EO analysis. Data on tillage management practices were taken from the *Census of Agriculture* according to the following categories: IT– tillage that incorporates most of the crop residue into the soil, RT– tillage that retains most of the crop residue on the surface, and NT– no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: NT– the area on which chemicals only were used for weed control, IT– the area on which tillage only was used, and RT– the area on which a combination of tillage and chemicals was used. More technical details on the methodological approach used to create the EO-based agricultural activity data are provided in Cerkowniak (2019).

Uncertainty

The derivation of uncertainties about estimates of CO_2 emissions or removals requires estimates of uncertainties for LMC areas and the C factors associated with changes in fallow, tillage and annual/perennial crops (McConkey et al., 2007b). The uncertainty described in this report is based on the 2014 submission methodology and has not yet been updated for the new EO methodology.

The uncertainty of area of change was determined for ecodistricts. The average area of agricultural land within an ecodistrict is about 140 kha, i.e., sufficiently large that the areas of different management practice were considered independent of those in others, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of those in other ecodistricts. Further, the ecodistrict area is sufficiently large that a null report of an activity can be assumed to mean that the activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliable when considered in relative terms for an ecodistrict than for an SLC polygon.

The uncertainty of the area in a management practice at any time for an average ecodistrict was based on the relative proportion of the area of that management practice in that ecodistrict. The relative uncertainty of the area of management practice expressed as standard deviation of an assumed normal population decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased.[35]

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were assumed to arise from two main influences: 1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of the management practice were to be defined perfectly, and 2) situational uncertainty in C change due to variation in the situation of the management practice.

35 Huffman T. 2006. Personal communication (from Huffman T, Agriculture and Agri-Food Canada to McConkey BG, Agriculture and Agri-Food Canada).

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions from uncertain model parameters and from inaccurate and/or incomplete representation of all relevant processes by the model. Where empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements and/or components of C change not measured. To estimate the process error, the variation from measured C change for controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty derives from the inability to accurately describe each situation. This includes the effect of interactions with past or concurrent changes to land use or land management, variability in the weather or soil properties, variability in crop management and/or continuity of LMCs. The situational uncertainty scaling coefficients for fallow change, tillage change and annual-perennial crop change were estimated from the observed variability of Century-simulated C change for all soil component-management-climate combinations within the reconciliation unit. There were many combinations of management within which C change was calculated. There was also a range of historical ecodistrict weather that was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of reversibility of C change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al., 2007b).

Although process and situational uncertainty are expected to interact, it is infeasible to describe their relationship given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due to situation uncertainty. Hence, it was assumed that the total deviation in total C change was the sum of the deviation from process and situational uncertainty. Details of uncertainty estimate development are provided in McConkey et al. (2007b). Results of this analysis are provided in Chapter 6.

CO_2 Emissions and Removals from Woody Biomass

Estimates of emissions and removals from woody biomass on croplands include those originating from trees and shrubs in agricultural land as well as vineyards, fruit orchards and Christmas trees. A remote sensing-based sampling approach was used to determine areas of trees and shrubs over the reporting period, whereas the *Census of Agriculture* was used to acquire area estimates of vineyards, fruit orchards and Christmas trees.

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground C dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam, 2002). Because of intensive pruning, linear rates of above-ground and below-ground biomass accumulation in trunks and roots were set at 0.4 and 0.3 Mg/ha per year, respectively (Nendel and Kersebaum, 2004). These were converted to C values using a 50% C content in biomass. Upon a decrease in vineyard areas, an instantaneous loss of 4.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al., 2007a).

Because of different standard planting densities, the range of standing biomass per area for apple and peach trees varied narrowly between 36 and 40 Mg/ha (McConkey et al., 2007a). This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of C sequestration was calculated over a 10-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root to shoot ratio of 0.4 (Bartelink, 1998), was used to estimate C sequestration in below-ground biomass. Instantaneous C loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Christmas trees are marketed at about 10 years of age (McConkey et al., 2007a). With a root to shoot ratio of 0.3 (Bartelink, 1998; Litton et al., 2003; Xiao and Ceulemans, 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

Trees and shrubs in agricultural land include perennial woody cover types in farmyards, shelterbelts and hedgerows. Carbon storage on the landscape in woody biomass changes over time as trees and shrubs grow and die, or areas of lands with woody biomass change due to planting or colonization of cropland areas or the clearing of trees.

The EO-based sampling approach used to quantify changes in woody biomass on Canadian croplands was developed by Huffman et al. (2015b). Briefly, the national ecological framework (Marshall et al., 1999) was used to develop a spatially stratified random sampling approach. A target of 30 sample sites per ecozone was identified. High-resolution historical aerial photos from the National Air Photo Library of Natural Resources Canada and from provincial databases were selected to digitize trees and shrubs land cover within a 2 km by 2 km plot for circa 1990, circa 2000 and circa 2010 at 1:10000 scale. The “trees” land cover class was defined as having less than 25% crown closure and being less than 1 ha in size. The “shrubs” land cover class represents non-agricultural woody plants that would not be expected to meet the forest or “trees” definition when mature. Wood volume yield estimates for each ecozone were derived based on published literature and consultations with provincial forestry and agriculture specialists, conservation associations and academia. Overall, estimates of above-ground wood volume varied between 99.3 and 181.7 m^3/ha across ecozones, and mean annual increments varied between 1.2 and 3.8 m^3 ha^{-1} year-1. With the addition of a new dataset in 2020, the growth, loss and gain in the biomass of trees and shrubs (in tonnes of C) were calculated for two time periods: 1990-2000 and 2000-2010 in croplands. The analysis, coefficients and parameters used to estimate C stock changes were based on the methodology described by Huffman et al. (2015b) for both time periods.

Analysis of firewood production suggested that agricultural lands serve as an important source for residential bioenergy production in Canada (Doyon et al., 2019). Based on this analysis, a portion of the tree biomass loss from cropland was transferred to the HWP pool as firewood input to meet regional residential bioenergy requirements (refer section A3.5.3) at the RU level. Further in regions where there was a shortage of supply in the forest biomass in a given RU, fractions of lost tree biomass from cropland were assumed to be sourced from the neighbouring RU. To avoid double counting of emissions between the Cropland and Harvested Wood Products categories, the amount of C transferred to the HWP pool was not reported as C loss under Cropland, normally being reported as instant oxidation. As a result an apparent increase in the sink or reduced emissions from woody biomass is reported, though once considering the transfer to HWP, no net change in total C emissions or removals occurs.

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Uncertainty

Poorly growing orchards and vineyards are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

For loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on uncertainty for vineyards, orchards and Christmas trees. Therefore, the default uncertainty of ±75% for woody biomass on cropland from the 2006 IPCC Guidelines was used for these land cover types. An error propagation approach described in Huffman et al. (2015b) was applied for trees and shrubs. If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial-to-annual crop conversion with associated C change uncertainty that contributes to C change uncertainty for a reporting zone.

Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage and fertilization. All these practices increase decomposition of SOC and, thus, release of CO_2 to the atmosphere.

Methodology

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

Equation A3.5–7

$$C = \sum(A_i \times EF)$$

C = carbon emissions from cultivation of organic soils (Mg C year^{-1})

A_i = area of organic soils that is cultivated for annual crop production in province i, ha

EF = C emission factor, Mg C loss/ha per year. The default EF of 5.0 Mg C/ha per year was used (IPCC, 2006).

Data Sources

Areas of cultivated histosols at a provincial level are not included in the *Census of Agriculture*. In the absence of these data, consultations with numerous soil and crop specialists across Canada were undertaken. Based on these consultations, the total area of cultivated organic soils in Canada was estimated at 16 kha (Liang et al., 2004).

Uncertainty

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and of the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50%. The 95% confidence limits of the emission factor provided in the 2006 IPCC Guidelines (IPCC, 2006) is ±90%.

A3.5.4.2. Grassland Converted to Cropland

Conversion of native grassland to cropland results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of CO_2 and N_2O to the atmosphere. According to a recent study on the burning of managed grassland in Canada by Bailey and Liang (2013), C changes from above-ground or below-ground biomass or DOM upon conversion are generally insignificant. The authors reported that the average above-ground biomass was 1100 kg ha^{-1} in the Brown Chernozem and 1700 kg ha^{-1} in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its yield under crop production (Liang et al., 2005).

A number of studies on changes of SOC and SON in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies, and their results are summarized by McConkey et al. (2007a).

Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al., 2007a). Many of the studies involved comparisons within 30 years of breaking of the native grassland, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after the land was broken.

The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3.5–16) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to C added from roots, simulated SOC dynamics can be described by the following equation:

Equation A3.5–8

$$\Delta C(t) = \Delta C_{Bmax} \times [1 - exp^{(-k[t - t_{lag}])}]$$

$\Delta C(t)$ = change in SOC for the tth year after conversion, Mg C/ha

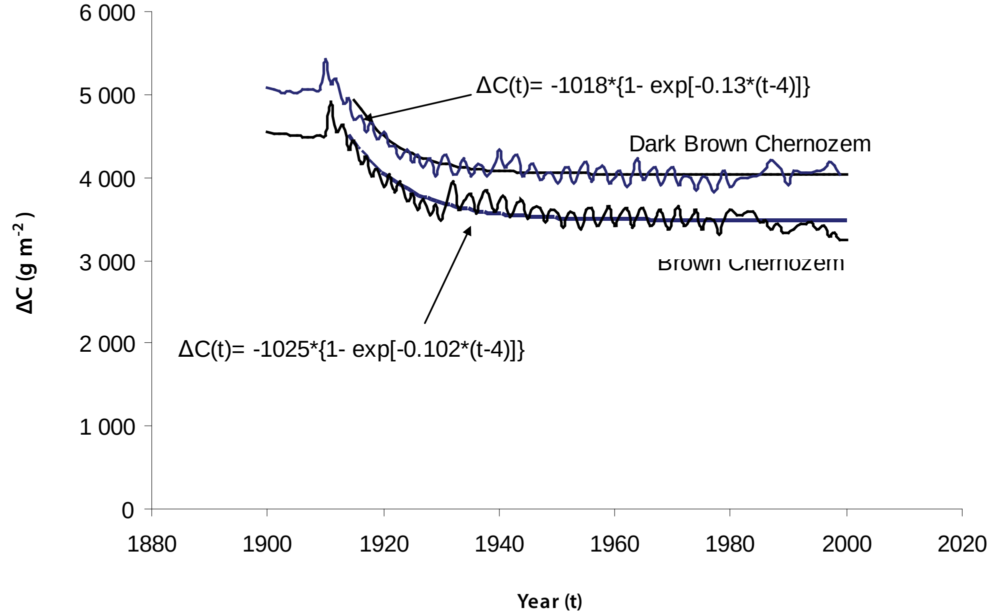
ΔC_{Bmax} = ultimate change in SOC from grassland to cropland, Mg C/ha

k = rate constant for describing the decomposition, year^{-1}

t = time since breaking of grassland, years

t_{lag} = time lag before ΔC becomes negative, years

Figure A3.5–16 **Century-Simulated SOC Dynamics after Breaking of Grassland to Cropland for Brown and Dark Brown Chernozemic Soils**



Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔC_{Bmax} is 0.22/(1−0.22) = 28% of the stabilized SOC under agriculture. Given the uncertainty of actual dynamics, it was assumed that there was no time lag in SOC loss from breaking grassland, so that SOC starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes:

Equation A3.5–9

$$\Delta C(t) = 0.28 \times SOC_{agric} \times [1 - exp^{(-0.12 \times t)}]$$

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C/ha
t	=	time since breaking, years
SOC_{agric}	=	0- to 30-cm SOC from the National Soil Database within CanSIS under an agricultural land use (Cropland category), Mg C/ha

Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5–10

$$\Delta C_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

ΔC_{GLCL}	=	losses of SOC in the inventory year n due to conversion of grassland to cropland since 1951 until year n, Mg C
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha

Losses of Soil Organic N and N_2O Emissions

Change in SON is estimated as a fixed proportion of C losses. Where changes in both SON and SOC were determined, the average change in SON was 0.06 kg N lost/kg C lost (McConkey et al., 2007a). Thus, the emissions of N_2O in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5–11

$$N_2O_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

N_2O_{GLCL}	=	emissions of N_2O in the year n due to the conversion of grassland to cropland since 1951 until year n, kt
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the t[th] year after grassland conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_{BASE}	=	N_2O emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (see section A3.4.6)
0.06	=	ratio of ON to OC losses
$44/28$	=	coefficient converting N_2O-N to N_2O

Data Sources

The area of grassland reported in the category Grassland Remaining Grassland was estimated using a combination of data from the *Census of Agriculture* and EO data. Area estimates reported in the category Grassland Converted to Cropland were based on reconciling changes in land area between Grassland Remaining Grassland and land in cropland management. To avoid issues associated with farm headquarters reporting, data were aggregated to the ecodistrict level prior to the land reconciliation process. Ecodistrict estimates of area of grassland converted to cropland were then apportioned back to SLC polygons.

Within an SLC, areas under Grassland Remaining Grassland were allocated to soil components identified as “low” for “likelihood of being cropped.” Soil C data from the National Soil Database were used to calculate an average SOC content for soils within the SLC polygon.

Uncertainty

The conversion of agricultural grassland to cropland occurs, but the reverse does not. The uncertainty of the area of this conversion in a given ecodistrict cannot be larger than the uncertainty of the final area of cropland or the initial area of grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of land in the Cropland or Grassland category. The factor scaling coefficient was assumed to be the same as for annual-perennial crop conversions (McConkey et al., 2007b).

A3.5.4.3. Forest Converted to Cropland

Emissions of CO_2 and N_2O from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with the resulting soil disturbance. The method for estimating emissions from biomass upon conversion is presented in sections A3.5.2.1 and A3.5.2.5. For SOC change, it is necessary to differentiate between Eastern and Western Canada.

Eastern Canada

There are many observations that compare SOC for land under forest with SOC for adjacent land under agriculture in Eastern Canada. The mean loss of C was 20.3% for a depth of approximately 30 cm (McConkey et al., 2007a). This value is comparable to that found in the soil database in CanSIS (Table A3.5–9), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than that of soil under forest.

Although the SOC for forested land accounts for C in the litter layer above mineral soil, in practice there is always uncertainty in quantifying the litter layer C and organic C within soil debris (Paul et al., 2002). Soil erosion, which is generally assumed to increase under agriculture, also reduces measured SOC on agricultural land.

The Century model (version 4.0) was used to estimate the SOC dynamics from forest conversion (Figure A3.5–17). In the first years after conversion, there is an increase in soil organic matter, as litter and above-ground and below-ground DOM become part of SOC. After a few years, SOC falls below the amount that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Figure A3.5–15, neglecting the initial SOC increase:

Equation A3.5–12

$$\Delta C(t) = \Delta C_{Dmax} \times [1 - exp^{(-k \times [t - t\_lag])}]$$

$\Delta C(t)$	=	change in SOC for the t[th] year after conversion, Mg C/ha
ΔC_{Dmax}	=	maximum change in SOC from forest conversion to agriculture, Mg C/ha
k	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since conversion of forest land, years
t_{lag}	=	time lag before ΔC becomes negative, years

In the case of simulated SOC after conversion of deciduous forest to cropland (Figure A3.5–17), 25% of C losses occur within 20 years of forest conversion and 90% within 100 years. Given the uncertainty of actual dynamics, it was assumed that there is no time lag in SOC loss from forest conversion, so that SOC starts to decline immediately upon forest conversion, i.e., the fitted SOC loss (Figure A3.5–14) is used to estimate SOC loss with time lag set to 0 after fitting.

The mean loss of 20.5% of SOC resulting from forest conversion to cropland for Eastern Canada, based on CanSIS information, was assumed to correspond to approximately 100 years after forest conversion. The ΔCDmax is therefore corrected by a factor of 1/0.927, where it is assumed that only 92.7% of the C has been lost after 100 years, based on the integration of Equation A3.5–13, resulting in a ΔC_{Dmax} value of 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long-term cropland than on SOC under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e., loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for forest conversion to cropland in Eastern Canada is:

Equation A3.5–13

$$\Delta C(t) = 0.284 \times SOC_{agric} \times [1 - exp^{(-0.0262 \times t)}]$$

$\Delta C(t)$	=	change in SOC for the t[th] year after conversion, Mg C/ha
SOC_{agric}	=	0- to 30-cm SOC from CanSIS for a cropland soil, Mg C/ha
-0.0262	=	rate constant for describing the decomposition, year^{-1}
t	=	time since conversion, years

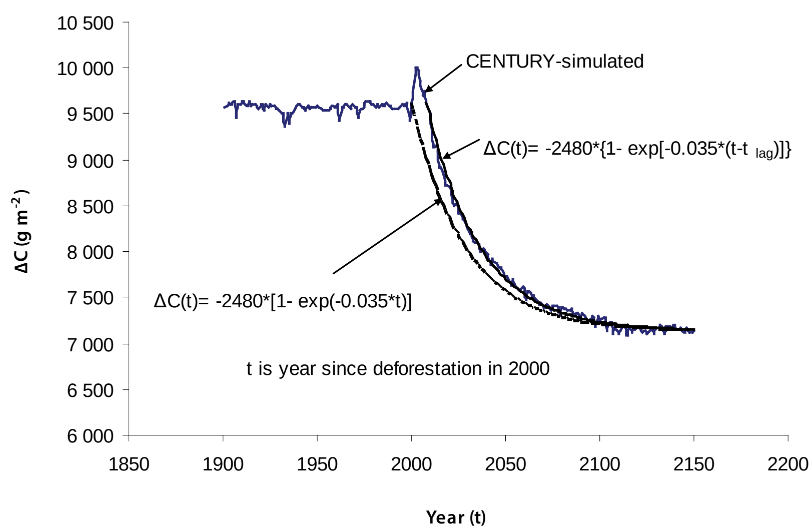
Table A3.5–9 **Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)**

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[a]	Cropland[a]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:

a. Standard deviation in parentheses.

Figure A3.5–17 **Century-Simulated Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland**



Thus, the total amount of SOC lost from forest land converted to cropland is estimated using the following equation:

Equation A3.5–14

$$\Delta C_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

ΔC_{FLCL}	=	total SOC loss in year n from the conversion of forest land to cropland since 1970 until year n, Mg C/ha
t	=	time after the conversion, year
$ALLSLC$	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha (see Equation A3.5–13)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3.5–14 is in addition to C stock changes in tree biomass and woody DOM that existed in the forest at the time of forest conversion.

Based on the field observations, average N change in Eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al., 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha, and C loss was 50 times N loss. For simplicity, it was assumed that N loss was a constant 2% of C loss. Thus, N_2O emissions from the conversion of forest land to cropland are estimated using the following equation:

Equation A3.5–15

$$N_2O_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28} \times 1 \times e^{-3}$$

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970 until year n (latest inventory year), kt
$ALL\ SLC$	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha per year
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha
0.02	=	conversion of C to N
EF_{BASE}	=	base emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (see section A3.4.5)
t	=	time after the conversion, year
$44/28$	=	coefficient converting N_2O-N to N_2O
e^{-3}	=	Converting from Mg to kt

Western Canada

Much of the current agricultural soil in Western Canada was grassland prior to cultivation. Hence, forest conversion has involved primarily forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less important in Western Canada than in Eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature. Ellert and Bettany (1995) reported that there was no difference in SOC between native aspen forest and long-term pasture that remained uncultivated since clearing for an Orthic Gray Luvisol near Star City, Saskatchewan.

The CanSIS data provide numerous comparisons of SOC under forest with that under cropland (Table A3.5–9). On average, these data indicate that there is no loss of SOC from forest conversion. This suggests that, in the long term, the balance between C input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most forest conversion is now occurring, is marginal for annual crops, and pasture and forage crops are the primary agricultural uses after clearing. In general, C loss from forest conversion to agriculture is lowest where agricultural land contains forages and pastures.

For Western Canada, no loss of SOC over the long term was assumed from forest conversion to pasture and forage crops. Therefore, the C loss from land conversion in Western Canada would be from losses of C in above-ground and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic N change in Western Canada for sites at least 50 years from breaking was +52% (McConkey et al., 2007a), reflecting substantial added N in agricultural systems compared with forests. However, recognizing the uncertainty about actual soil C–N dynamics upon conversion, forest land converted to cropland was assumed not to be a source of N_2O from the soil pool. N_2O emissions are reported wherever biomass burning occurs during conversion (see section A3.5.2.1).

Data Sources

The approach used to estimate the area converted from forest to cropland is described in section A3.5.2.3. The annual forest conversion by RU was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the RU.

Uncertainty

The uncertainty of C change in each reporting zone was estimated differently for Eastern and Western Canada because of differences in C change estimation methods (McConkey et al., 2007b). For Western Canada, an uncertainty of C change was estimated, although the mean value of SOC change factor was 0. The assumption was that the uncertainty of SOC change after forest land to cropland conversion in Western Canada would follow a similar pattern as that for Eastern Canada.

A3.5.5. Grassland

Land in the agricultural Grassland category is defined as unimproved pasture used for grazing domestic livestock, but only in geographical areas where grassland would not naturally grow into forest if abandoned, i.e., southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals, such as bison, and periodic burning. Essentially, the agricultural Grassland category consists of extensively managed native range in Canada.

The primary direct human activities on agricultural grassland in Canada are fire suppression; seeding new plant species into the grassland; and adjusting the amount, duration and timing of grazing by domestic livestock. Methodologies for estimating emissions or removals of CO_2 as a result of direct human activities and for estimating CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada are presented in the following section.

A3.5.5.1. Grassland Remaining Grassland

The development of the CO_2 estimate method is based on the premise that on long-existing managed grassland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to or C losses from the soil.

Equation A3.5–16

$$SOC = SOC_{REF} \times F_{MG} \times F_I$$

SOC	=	soil organic carbon stock at any particular time since management and input change, Mg C ha^{-1}
SOC_{REF}	=	the reference soil organic carbon stock, Mg C ha^{-1}
F_{MG}	=	carbon stock change factor for management regime, dimensionless
F_I	=	carbon stock change factor for input of organic matter, dimensionless

The total area of managed grassland is calculated as follows:

Equation A3.5–17

$$A_n = GLGL_{1990} - \sum_{1990}^{n} GLCL$$

A_n	=	the total area of grassland remaining grassland in the inventory year n, ha
$GLGL_{1990}$	=	the area of grassland remaining grassland in 1990, ha
$GLCL$	=	the area of grassland converted to cropland since 1990, ha

Therefore, the net change in SOC because of management and input changes from Grassland remaining Grassland can be estimated using the IPCC tier-1 method as follows:

Equation A3.5–18

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0\text{-}T}) \times A] / t$$

$\Delta C_{GGMineral}$	=	the net change in SOC due to management and input from grassland remaining grassland, Mg C ha^{-1}yr^{-1}
SOC_0	=	soil organic carbon stock in the inventory year, Mg C ha^{-1}
SOC_{0-T}	=	soil organic carbon stock T years prior to the inventory year, Mg C ha^{-1}
A	=	area of change in management and input from grassland remaining grassland, ha
t	=	inventory time period, years (default 20 years)

If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and the change in C stocks is therefore deemed to be zero.

There are a number of studies on the effects of grazing versus no grazing on SOC. Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske, 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community as well as effects on C input to soil from both above-ground and below-ground plant growth (Schuman et al., 2002; Liebig et al., 2005). An additional influence of grazing regime is the increased return of C in fecal matter as stocking rate increases (Baron et al., 2002). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

The addition of organic amendments and inorganic fertilizer will increase the productivity of native grassland (Smoliak, 1965), suggesting that these practices could increase SOC through greater C inputs. However, such practices are basically of academic interest, as the only economically practical management options for semi-arid grasslands are altering grazing regime, burning, and introducing new plant species (Liebig et al., 2005).

Grasslands managed for grazing in Western Canada in the Brown and Dark Brown soil zones of Alberta, Saskatchewan and British Columbia are occasionally burned by wildfire and by prescribed burning for purposes such as brush management, habitat management, the removal of decadent vegetation, and military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O.

Equation A3.5–19

$$EMISSION_{BURN} = \sum(AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) / 1000$$

$EMISSION_{BURN}$	=	emissions of CH_4 or N_2O from prescribed and non-prescribed burning of managed agricultural grassland, kt CH_4 or N_2O
$AREA_i$	=	area of the ith managed agricultural grassland subject to burning, ha
$FUELLOAD_i$	=	average fuel load for the ith managed agricultural grassland subject to burning, Mg DM ha^{-1}
$C_{F,i}$	=	combustion efficiency for the ith managed agricultural grassland subject to burning, fraction, unitless
G_{EF}	=	emission factor of CH_4 (2.7 g CH_4 kg^{-1} dry matter burnt) or N_2O (0.07 g N_2O kg^{-1} dry matter burnt) (IPCC, 2006)
1000	=	conversion of Mg to kt

Data Sources

As discussed in the section Grassland Converted to Cropland, the area reported for the subcategory Grassland Remaining Grassland was estimated using a combination of data from the *Census of Agriculture* and EO, as described in section A3.5.4.1. There are no detailed comprehensive activity data over time on management change for Canadian agricultural grassland, except for wild and prescribed fires. Activity data on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). Activity data from 2013 to 2015 were updated in 2017 and were kept constant after the sampling period.

A3.5.6. Wetlands

A3.5.6.1. Peat Extraction

General Approach and Methods

Peat extraction in Canada is for the production of horticultural peat products and related applications, and not for use as fuel. Since the 1970s, the vacuum harvesting technique has been the dominant method of peat extraction. This technique requires an extensive network of drainage ditches to dry the peat for harvesting by heavy vacuum harvesters. Prior to the implementation of vacuum harvesting, manual block-cutting was used to extract peat blocks with shovels, resulting in topography of high baulks and low trenches. Although these manual methods are no longer used, numerous abandoned block-cut sites remain in the landscape.

Emissions of CO_2, CH_4 and N_2O were estimated for the conversion and management of peatlands for peat extraction using an IPCC Tier 2 method in accordance with guidance from a combination of the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement (IPCC, 2014). The approach is based on domestic science and land management practices specific to peat extraction activity in Canada. Emission estimates include on-site CO_2, CH_4 and N_2O emissions, off-site CO_2 emissions from extracted peat, and waterborne C losses of dissolved organic carbon (DOC) from drained and rewetted sites.

Domestic GHG flux studies at peat extraction sites in Canada were reviewed and measurements compiled to develop country-specific emission factors and parameters (Table A3.5–10). As the majority of flux measurements were reported for the growing season, annual CO_2 emission factors were developed by adding measured winter values from Strack and Zuback (2013), consistent with drained peatlands having higher winter CO_2 emissions than natural peatlands. Annual CH_4 emission factors were developed assuming that non-growing season fluxes are 15% of annual totals based on natural peatland sites (Saarnio et al., 2007).

Owing to the extraction technology and desired properties of sphagnum peat, preference with respect to site selection is given to open bog (nutrient poor – ombrotrophic) peatlands, which are classified as Other Land under Canada's land categorization framework for the LULUCF sector. Therefore, only approximately 5% of pre-conversion area meets the definition of the Forest Land category. Emission estimates are separated into the subcategories Land Converted to Peat Extraction and Peat Extraction Remaining Peat Extraction. In calculating emissions from land conversion, a land-use change period of one year is used to represent the land conversion practices of draining and clearing the surface vegetation layer (acrotelm) in preparation for peat extraction. Subsequently, emissions from the ongoing management of peat extraction sites, as well as their decommissioning through abandonment, rehabilitation, or rewetting and restoration, are all reported under Peat Extraction Remaining Peat Extraction. The following sections describe the sources of GHG emissions and removals through the peat extraction land management phases.

Biomass Clearing and Drainage

At extraction sites, vegetation removal and drainage result in a loss of CO_2 uptake, enhanced peat decomposition, and DOC export resulting in increased CO_2 emissions. Emissions of CH_4 decrease substantially from drained fields, but drainage ditches, which occupy 5% of the drained area, become CH_4 hot spots (Waddington and Day, 2007). Enhanced peat decomposition also increases N_2O emissions. CO_2 and CH_4 emission factors for drained areas were derived from domestic studies (Table A3.5–10), but due to a lack of domestic N_2O measurements, the default emission factor for peat extraction sites from the 2013 IPCC Wetlands Supplement (IPCC, 2014) was used.

Sites that are no longer economical for extraction are decommissioned or abandoned. The altered hydrology and peat properties of these sites hinder natural regeneration, resulting in persistent CO_2 emissions (Waddington et al., 2002). However, revegetation occurs more frequently at abandoned block-cut sites, although total vegetation coverage is low and moss regeneration is limited to wetter trench depressions (Poulin et al., 2005). The CO_2 emission factor for abandoned block-cut areas is lower than for areas drained for vacuum harvesting, while the CH_4 emission factor is higher, likely due to greater revegetation and wetter conditions at block-cut sites.

At some abandoned sites, rehabilitation measures are undertaken to establish another type of environment. Given the lack of flux measurements for these sites, the emission factors for drained areas are generally used for rehabilitated areas. However, the uptake of CO_2 by trees in tree plantations is calculated on the basis of measurements at a tree plantation study (Garcia Bravo, 2015). Tree plantations may increase CO_2 sequestration in tree biomass, but this does not offset the large CO_2 emissions from drained peat.

Peat Stockpiling and Product Production

Harvested peat is left in stockpiles before being processed into various peat products. Emissions from peat stockpiles are calculated as an exponential decay for half a year (Cleary et al., 2005). Once it is packaged into products, Canadian peat is transported off-site, largely to the United States, for non-energy uses such as horticulture, where it is assumed to decay in an aerobic environment. Due to the lack of information on decay rates by end use, it is assumed that all peat is emitted in the extraction year. Emissions of CO_2 are calculated based on an estimate of total organic C in the peat using a country-specific C fraction parameter (Table A3.5–10) derived from laboratory analysis of pure peat products with moisture contents ranging from 27% to 64% (Hayne et al., 2014).

Rewetting and Restoration

An increasing number of decommissioned sites are rewetted and restored. Rewetting practices increase anaerobic conditions, which reduce peat decay and DOC export, thereby decreasing CO_2 emissions while increasing CH_4 emissions (Strack and Zuback, 2013). Since the 1990s, the moss layer transfer technique has been used in Canada for the restoration of peatlands dominated by *Sphagnum* mosses with the aim of restoring sites to peat-accumulating ecosystems. This technique consists of rewetting and sowing fields with fresh moss spores and spreading a layer of straw mulch to support moss regeneration (Rochefort et al., 2003). Long-term monitoring of restoration sites indicates that rewetting and restoration success varies due to management (e.g., effectiveness of blocking secondary drainage network, timing of restoration procedures and quality of plant material spread) and weather conditions post-restoration (González and Rochefort, 2014). Domestic GHG research at sites restored for 10 years or less has shown that there is high variability among sites ranging from sources to sinks. Given the range of success among sites and the variability in flux measurements, average emission values are used to best represent the net flux of rewetted and restored sites.

Data Sources

An EO mapping approach based on manual delineation and interpretation of aerial photography, satellite imagery and ancillary data was developed to map the extent of peatland areas disturbed by peat extraction for circa 1990, 2007 and 2013 time periods. Through image interpretation, the total disturbed area was allocated into the following four land management subcategories: active extraction areas, abandoned areas, rehabilitated areas, and restored areas. Geospatial data developed by the Peatland Ecology Research Group and information provided by industry experts were utilized to aid subcategory allocation. In addition, for a subset of sites, the pre-disturbance land cover class (forest, shrubby or open bog peatland) was determined in order to identify the land category types converted (Forest Land or Other Land).

Annual area estimates were developed using interpolation between mapped time periods and extrapolation after 2013. Annual area estimates for various land management categories were then refined based on secondary data sources. The two main secondary data sources were industry statistics on peatland areas managed for peat extraction in 2015 compiled by the Canadian Sphagnum Peat Moss Association (CSPMA) and a survey of abandoned peat extraction sites in the provinces of Quebec and New Brunswick (Poulin et al,. 2005). Secondary data sources were used to provide a comparative check of total areas converted to peat extraction historically and current production areas, and to complement limitations in the ability of the mapping approach to identify land management subcategories. National peat production statistics were used to represent the annual amount of extracted peat transported off site (NRCan, 2019).

Uncertainty

Given the increased availability and quality of EO imagery and ancillary information over time, it is assumed that there is a decrease in uncertainty in the mapped areas for the later mapping periods. The use of high-resolution satellite imagery for the 2013 time period reduced uncertainty in the overall estimate of the total areas converted for peat extraction. However, there is considerable uncertainty associated with identifying land management subcategories. Uncertainty in the 2015 CSPMA industry statistics is associated with different interpretations of land management category definitions (e.g., restoration) and incomplete coverage of lands not managed by industry association members.

There is a lack of domestic GHG measurements for the various categories of decommissioned sites. Therefore, emission factors may not represent the full range and success rates of applied rehabilitation and restoration techniques. The large variation in moisture content among peat products may contribute substantially to the uncertainty of off-site CO_2 emission estimates from extracted peat.

A3.5.6.2. Flooded Lands

General Approach and Methods

Following the 2006 IPCC Guidelines, emissions from Land Converted to Wetlands (creation of flooded lands, namely reservoirs) are estimated for all known reservoirs flooded for 10 years or less. Only CO_2 emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO_2 emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2014). It is believed that the default approach, assuming that all biomass C would be emitted

Table A3.5–10 **Parameters and Emission Factors for Estimating Emissions from Peat Extraction**

Emission Factor/Parameter	Unit	Value	Sources
Biomass Clearing			
Forest land biomass cleared	t C ha^{-1}	19.2	Hayne and Verbicki, 2011
Other land biomass cleared	t C ha^{-1}	2.8	Hayne and Verbicki, 2011
Drainage			
CO_2 from drained areas	t CO_2 ha^{-1} yr^{-1}	11.4	Moore et al., 2002, as cited in Cleary, 2003; Glatzel et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2 -DOC from drained areas	t CO_2 ha^{-1} yr^{-1}	0.60	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from drained fields	t CH_4 ha^{-1} yr^{-1}	0.008	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from drainage ditches	t CH_4 ha^{-1} yr^{-1}	0.15	Waddington and Day, 2007
N_2O from drained areas	t N_2O ha^{-1} yr^{-1}	0.00047	IPCC, 2014 (Table 2.5, Default value for Boreal & Temperate climate zone)
CO_2 from abandoned block-cut areas	t CO_2 ha^{-1} yr^{-1}	8.6	Waddington and Price, 2000; Waddington and Warner, 2001; Waddington et al., 2002; McNeil and Waddington, 2003
CH_4 from abandoned block-cut areas	t CH_4 ha^{-1} yr^{-1}	0.012	Waddington and Price, 2000
CO_2 tree plantation biomass uptake	t CO_2 ha^{-1} yr^{-1}	-0.32	Garcia Bravo, 2015
Peat Stockpiling and Product Production			
Amount of stockpiled peat	t C ha^{-1}	50	Cleary, 2003
Exponential decay constant, stockpiled peat		0.05	Cleary, 2003
Carbon fraction of peat products	t C t air-dry peat^{-1}	0.26	Hayne et al., 2014
Rewetting and Restoration			
CO_2 from restored areas	t CO_2 ha^{-1} yr^{-1}	7.60	Moore et al., 2002 as cited in Cleary, 2003; Petrone et al., 2001; Petrone et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2-DOC from restored areas	t CO_2 ha^{-1} yr^{-1}	0.13	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from restored fields	t CH_4 ha^{-1} yr^{-1}	0.03	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from restored ditches	t CH_4 ha^{-1} yr^{-1}	0.28	Waddington and Day, 2007; Strack and Zuback, 2013
N_2O from restored areas	t N_2O ha^{-1} yr^{-1}	N/A	IPCC, 2014, Default assumption of no N2O emissions from rewetted/ restored areas

Note: All units where the greenhouse gas (GHG) is specified use units of the relevant GHG (CO_2, CH_4 or N_2O) instead of C and N.

upon flooding, would overestimate immediate forest conversion emissions from reservoir creation, because the majority of submerged forest biomass does not decay for an extended period of time.

Two complementary estimation methodologies are used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all forest C pools are estimated with the CBM-CFS3 (see section A3.5.2.1). Emissions from forest clearing for infrastructure development are reported under the subcategory Forest Land Converted to Settlements. Emissions resulting from the use and disposal of wood products that are harvested before flooding are reported under the category Harvested Wood Products (see section A3.5.3).

In the absence of evidence of forest clearing, it was assumed that all vegetation was simply flooded, leading to the emission—as CO_2—of a fraction of the submerged C from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either the Forest Land Converted to Wetlands category or the Other Land Converted to Wetlands category.

Since 1993, measurements of CO_2 fluxes have been made above some 57 hydroelectric reservoirs in four provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin, 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of CO_2, CH_4 or N_2O (in order of frequency) were measured. Studies on ebullition, degassing emissions and winter emissions are rare and insufficient to support the development of domestic emission factors. Measurements of diffusive fluxes above the surface of reservoirs were compiled for the entire country. Out of these measured reservoirs, a subset of 25 was selected to develop a national emission curve for the 50-year period following impoundment. These measurements were selected based on the availability of documentation of measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 34 measurements (Figure A3.5–18). It is important to note that each of these measurements (data points in Figure A3.5–18) represents, on average, the integration of between 8 and 28 flux samples per reservoir.

Non-linear regression analysis was used to parameterize the emission curve of the form.

Equation A3.5–20

$$CO_{2\ rate\ L\_reservoir} = b_0 + b_1 \times In(t)$$

$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg m^{-2} per day
b_0, b_1	=	curve parameters, unit less
t	=	time since flooding, years

Total CO_2 emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Equation A3.5–21

$$CO_{2\ L\_reservoirs} = \sum(CO_{2\ rate\ L\_reservoir} \times A_{reservoir} \times Days_{ice\ free} \times 10^{-8})$$

$CO_{2\ L\_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2 yr^{-1}
$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions for each reservoir, mg m^{-2} per day
$A_{reservoir}$	=	reservoir area, ha
$Days_{ice\ free}$	=	number of days without ice, days
10^{-8}	=	conversion factor from mg to Gg

Reservoir area was used as the best available estimate of the area converted to managed wetlands (reservoirs) although, in reality, reservoirs may contain islands, i.e., emergent land areas. “Ice-free period” was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al., 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the *Lakes – Ice-Free Period* isoline map of Canada (NRCan, 1974).

Emissions were calculated starting on the year of flooding completion. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed. As CO_2 emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding events since 1980 were used.

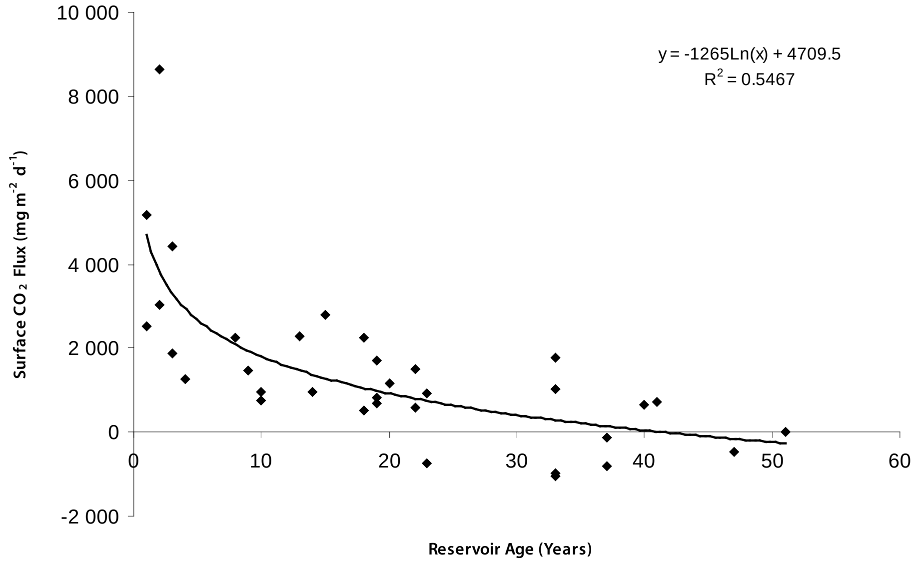
Data Sources

The three main data sources used to develop area estimates were information on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see section A3.5.2.3, Forest Conversion), the Canadian Reservoir Database (Duchemin, 2002), and official industry numbers derived from industry correspondence (Eichel, 2006; Tremblay[36]).

The Canadian Reservoir Database contains records of 282 hydro reservoirs. Information from provincial and private hydroelectric utilities was accessed to update the database and cross-check the date of reservoir construction and the total reservoir area for all these reservoirs. In some instances, the database reported as new facilities some small, refurbished hydroelectric generation sites in the province of Quebec that entered into production under new ownership. As a result, a separate category was added to the database to document both the original construction and commissioning of a dam and the date when a hydroelectric facility was refurbished without any changes to the reservoir area.

36 Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment Canada.

Figure A3.5–18 **Logarithmic Curve Fit for National Reservoir Emission Factors**



It is important to note that fluctuations in the area of land converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently converted (less than 10 years ago) to reservoirs and older reservoirs (more than 10 years old), whose areas are thus transferred out of the accounting. The reporting system does not encompass all reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

Uncertainty

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, important sources of uncertainty still remain:

- **Seasonal variability**—Some reservoirs display marked seasonal variability in CO_2 fluxes, which are not taken into account in estimate development; anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.
- **Reservoir area**—There are variations in reservoir area due to water level fluctuations during the year.
- **Emission pathways**—The omission of potentially important CO_2 emission pathways (e.g., degassing).

A3.5.7. Settlements

This category comprises estimates of removals of CO_2 from land classified as Settlements Remaining Settlements (C sinks in urban trees) and emissions from Land Converted to Settlements (conversion of forest land and of unmanaged grassland to Settlements). The following sections describe the approaches developed to estimate C sequestration by urban trees, emissions from the conversion of non-forest land (unmanaged grassland or tundra) to settlements in the Canadian Arctic and sub-Arctic and estimation of areas of conversion from cropland to settlements. Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in sections A3.5.2.1 and A3.5.2.3.

A3.5.7.1. Settlements Remaining Settlements

General Approach and Methods

In Canada, the management and monitoring of urban trees is done at the level of individual municipalities, and there is no centralized authority or organization with responsibility for compiling national-scale urban tree information. Taking into consideration the lack of specific species class information and the considerable resources it would require to develop such information, an approach based on urban tree crown (UTC) cover area was developed to estimate CO_2 sequestration by urban trees in Canada. The approach involves the sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas. The growth of urban trees in Canada was estimated using an IPCC Tier 2A approach (IPCC, 2006):

Equation A3.5–22

$$\Delta C_G = \sum AT \times CRW$$

ΔC_G = annual carbon accumulation attributed to biomass increment of urban trees in settlements remaining settlements, tonnes C yr^{-1}

AT = total crown cover area of urban trees, ha

CRW = crown cover area-based growth rate for urban trees, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

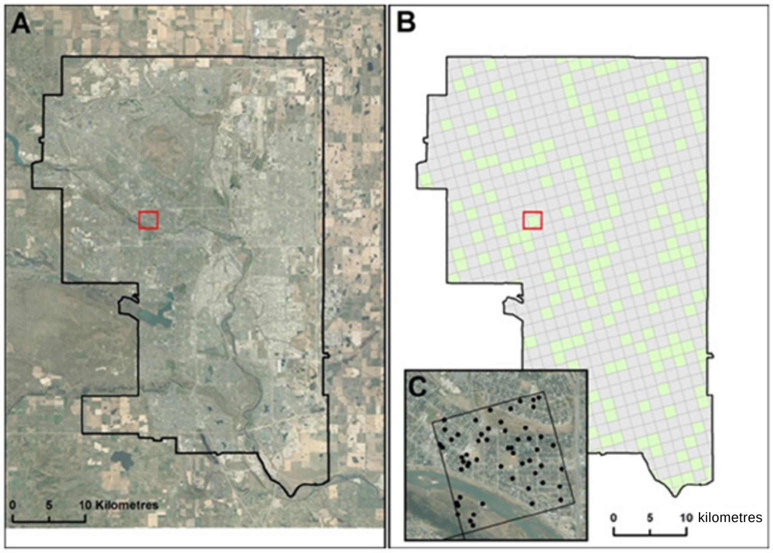
The total urban area of Canada in 2012 was estimated using the boundaries of Statistics Canada's 2011 populated place digital boundary layer,[37] as it was the most nationally consistent delineation of urban areas available. The urban boundaries of 1990 were based on Statistics Canada 1990 polygon layer, but manually edited through visual interpretation of aerial photos and the 1990 GeoCover (MDA-Federal, 2004) ortho-rectified image data set, to reduce known over-bounding errors (Statistics Canada, 2010). The resulting 1990 urban layer represented a smaller total area (1.53 Mha) than the total urban area identified for 2012. Of the 947 population centres (2.42 Mha) in Canada, 69 (1.53 Mha) were extracted from the Statistics Canada data set that had populations greater than 30 000 individuals. This subset captures all major Canadian cities and represented 62% and 67% of the total urban area in 1990 and 2012, respectively. Furthermore, this subset holds the urban centres that represented approximately 79% and 76% of Canada's population in 1990 and 2012, respectively (Statistics Canada, 2011; McGovern and Pasher, 2016). While the population centres selected did not completely represent all populated places in Canada, many of the smaller communities that were filtered out are parts of an overall matrix of forest or agricultural land that may be captured under other land categories.

The 69 population centres were spatially allocated to 18 of the 60 reconciliation units (RUs) (see section A3.5.1). The 18 RUs encompassed 97% and 99% of the total area and population, respectively, of the total of 947 population centres. Estimates of the proportion of UTC cover were developed for each RU using a point-based sampling approach (Pasher et al., 2014). A grid cell approach was used to ensure good spatial distribution of sampling cells (Figure A3.5–19). Random points at a density of 55 points/km^2 on digital air photos or high-resolution satellite imagery were interpreted manually and classed into broad categories of tree crown or non-tree crown.

The same sampling point locations were used for both the 1990 and 2012 UTC assessments, although sampling cells and points which fell outside the 1990 urban boundary were not included in order to ensure that sampling was

37 Statistics Canada Populated Place spatial data and information available online at: http://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2011-eng.cfm.

Figure A3.5–19 **Sampling Grids and Point Sampling over Georeferenced Air Photo**



Note: Background imagery: (A) Calgary, Alberta urban area boundary, (B) 1 km × 1 km grid cells representing a 25% sampling rate with randomly selected grid cells shown in green, and (C) close-up of a single grid cell (20 pts/km^2 sampling). Orthophoto courtesy of City of Calgary.

restricted so as to represent urban areas for that time period. A quality control process was implemented which involved random checks by alternative interpreters or reinterpretation. The percent UTC for each RU was calculated as the proportion of all points identified as tree canopy out of the total points that were assessed within the RU. The national-scale UTC estimate was 28.5% in 1990 and 27% in 2012.

The total crown cover area of urban trees for each RU was estimated by multiplying the % UTC by the total urban area estimates for the associated RU in 1990 and 2012. Although the urban area boundary has increased by 6% from 1990 to 2012, the national-scale estimate of crown cover changed little, with regional variation in trends. Gains in crown cover area (e.g., tree growth and planting) tended to balance with losses (e.g., tree removal, mortality and urban land-use change).

The crown cover area-based growth rate (CRW) values for the 18 RUs (see Table A3.5–11) are derived from assessments carried out in 16 Canadian cities using the same methodology used to develop CRW values for the United States. In RUs where cities were not assessed using that approach, values from proxy cities were used based on an ecologically similar Canadian RU, with the exception of RU 41, Pacific Maritime, for which the assessment for the U.S. city of Seattle was used (Steenberg et al., 2021). These assessments take into consideration the tree species, age and environmental conditions for each RU to determine gross sequestration rates. Net C sequestration was estimated as 74% of gross sequestration, accounting for urban tree growth characteristics and tree mortality and decomposition (Nowak et al., 2013). These growth and sequestration rates are applied to the 18 RUs and, as a result, estimates of UTC cover area and the sequestration rate are the main drivers of overall removal estimates. Interpolation and extrapolation were used to develop a consistent time series for the period 1990 to the latest inventory year.

Analysis of the fate of urban tree mortality (Tree Canada 2019) suggested that approximately 13% of mortality in urban centres is used for firewood. As a result, the volume of firewood collected from urban trees was estimated by multiplying the C stocks for individual population centres by a 2.4% mortality rate of urban trees taken from (Tree Canada, 2018) and 13% of C from dead trees was assumed to be used as firewood (Tree Canada 2019). The firewood supply was aggregated by RU and supplied a portion of the firewood demand estimated from consumption surveys described in section A3.5.3. To avoid double counting of emissions between the Settlements and Harvested Wood Products categories, the amount of C transferred to the HWP pool was attributed to the difference between the gross and net annual sequestration rates estimated by the i-tree model. As a consequence the apparent sink in C under Settlements is increased due to the combustion of this C as residential firewood being reported under Harvested Wood Products.

Table A3.5–11 **Carbon Storage and Sequestration Densities in Urban Trees for Canadian RUs**

Reconcilliation Unit (RU)	Carbon Storage (t C ha^{-1} yr^{-1})	Carbon Sequestration (t C ha^{-1} yr^{-1})
1 NF – Boreal Shield East	40	3.0
5 NS – Atlantic Maritime	62	3.4
6 PE – Atlantic Maritime	62	3.4
7 NB – Atlantic Maritime	62	3.4
11 QC – Atlantic Maritime	62	3.4
12 QC – Mixedwood Plains	58	2.4
15 QC – Boreal Shield East	40	3.0
16 ON – Boreal Shield West	40	3.0
17 ON – Mixedwood Plains	58	2.4
19 ON – Boreal Shield East	40	3.0
24 MB – Subhumid Prairies	55	2.9
28 SK – Boreal Plains	40	3.0
30 SK – Semiarid Prairies	55	2.9
34 AB – Boreal Plains	40	3.0
35 AB – Subhumid Prairies	55	2.9
37 AB – Semiarid Prairies	55	2.9
41 BC – Pacific Maritime	97	6.9
42 BC – Montane Cordillera	23	1.4

Note:
Source – Steenberg et al., 2021

Uncertainty

The uncertainties associated with the estimates of urban area, UTC and C sequestration rate all contribute to the overall uncertainty of the estimates of CO_2 removals by urban trees. The result of these combined uncertainties using a Tier 2 Monte Carlo analysis approach provides an estimated total uncertainty of 39% for 1990 and 2012.

The uncertainties associated with 1990 and 2012 urban areas were not quantified by Statistics Canada. An error estimate of 10% was used for the 2012 urban area following the approach used in the United States' 2012 national GHG inventory report (U.S. EPA, 2013). The error associated with the 1990 urban area estimate was assumed to be slightly higher at 15% than for 2012, based on expert judgement. This approach is similar to the uncertainty estimate for boundary delineation (15%) used for developing forest conversion estimates (Leckie, 2011).

The uncertainty associated with UTC estimates was based on the standard error of the sampling approach calculated for each sampling period (1990/2012). Standard errors for the UTC estimates were low (0.2% for the national UTC estimate) given the very high number of sampling points used.

The uncertainty estimate for the national gross C sequestration rate (27%) was developed from a Monte Carlo analysis associated with each RU for the urban tree field data collected in Canada and for the city of Seattle. This uncertainty estimate does not include the estimation error related to the use of biomass equations or conversion factors or to measurement error (Nowak et al., 2013).

A3.5.7.2. Cropland Converted to Settlements

Data Sources

Urban and industrial expansion has been one of the main drivers of cropland conversion in Canada. Areas of cropland conversion to settlements were estimated based on the land-use maps for 1990, 2000 and 2010 developed in Huffman et al. (2015a). Areas of conversion for the 1990–2000 and 2000–2010 periods were calculated through spatial analysis for each reporting unit and divided by the number of years in order to develop constant annual conversion rates. Areas of conversion were extrapolated after 2010. The total area of cropland converted to settlements for the 1990–2000 and 2000–2010 time periods was 184 kha and 115 kha, respectively, with the majority of change due to urban expansion in reporting zones 7 and 11. This is largely due to urban expansion in the main populated centres, such as Toronto, Hamilton, Oshawa, Montreal and Edmonton.

Uncertainty

Given that the highest conversion rates are caused by urban expansion, an independent assessment was conducted on the areas of conversion by comparing the land cover in each map against visual interpretation of ortho-rectified Landsat imagery over urban centres. The sampling strategy for this assessment was to perform the analysis on five main census metropolitan areas (CMA[38]), which contribute to 45% of the total area change from Cropland to Settlements. Polygons from the 2011 census were used to define the boundary of each CMA, and over 400 stratified random points were used to verify the land cover class in areas in which there were examples of either change or no-change from Cropland to Settlements, separated by a minimum distance of 1 km, to avoid statistical bias. The minimum mapping unit for the accuracy analysis was defined as a circle with radius of 100 m to prevent errors due to the presence of noise in each classified map. The class in each location was assigned based on the class of the majority of the pixels, to account for changes in land use. An overall accuracy of 80% and 84% was obtained for the areas of change computed from these maps, which concurs with the accuracy assessment carried out in Huffman et al. (2015a).

A3.5.7.3. Grassland Converted to Settlements

General Approach and Methods

Nearly half of Canada's land mass is in the Arctic and sub-Arctic regions and includes all land categories (IPCC, 2006), excluding Cropland. An approach was developed specifically for capturing the associated emissions by finding the land-use change and the amount of biomass stocks in this vast and remote landscape and included the following components: (i) manual digitizing of land-use polygons in Canada's Arctic/sub-Arctic for 1990, 2000 and 2010 based on ortho-rectified Landsat imagery and assessment of land-use change over about 359 million hectares, including areas in reporting zones 1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18, north of 60°N latitude; and (ii) estimation of above-ground biomass based on field samples taken in Canada's Arctic/sub-Arctic regions between 2004 and 2010, covering the northern part of the Boreal Cordillera, Taiga Plains, Taiga Shield East, Taiga Shield West, Southern Arctic, Northern Arctic, and Arctic Cordillera.

A comprehensive, wall-to-wall analysis of land-use circa 1990, 2000 and 2010 was carried out based on image interpretation followed by manual digitization of the sites undergoing change (McGovern et al., 2016). A wide range of human disturbances such as airstrips, roads, power lines, seismic lines, urban areas, mines, reservoirs and even smaller features like well sites and some roadside clearings were identified using snow- and ice-free imagery. Analysis of existing GIS data sets denoting the occurrence of anthropogenic development were used to guide the search for areas with high probability of land-use change. Mapping was then expanded outwards from these regions based on the observation of additional disturbances. The resulting spatial data set provided the most comprehensive and complete mapping product for human disturbances in Canada's Northern region, and builds on previous boreal disturbance mapping activities conducted by Environment and Climate Change Canada (ECCC). An interpretation guide similar to that of the Canadian Forest Service (Dyk et al., 2015) was used to guarantee consistency in the detection, digitization and categorization of disturbances. A total of 1135 scenes were used for the interpretation process (395 for 1990, 348 for 2000 and 392 for 2010).

Land-use change was derived from the difference in polygon areas for each date, providing an area of change between the time periods (i.e.,1990–2000, 2000–2010), which was divided by the total years in the time period to produce a constant annual rate of change. The same annual rate of land-use change was applied for the years prior to 1990 and following 2010. The pre-conversion land-use type for each of the land-use change polygons was based on available land cover maps (Wulder et al., 2008; Hermosilla et al., 2016), visual interpretation and vegetation indices of concurrent imagery to avoid including areas in other land-use categories (e.g., Forest Land, Cropland, Wetlands and Other Land). Furthermore, deforestation events above 60 degrees latitude were also used to confirm that areas determined to be forest conversion to settlements were excluded, to avoid double-counting.

The biomass lost was derived from statistical analysis of field samples surveyed between 2004 and 2011 over the Canadian north (Figure A3.5–20). Over 116 samples were collected in different land cover types (e.g., shrubs, grass tundra, wetland, forest and barren land) in eight reporting

38 This term has been defined by Statistics Canada as the area consisting of one or more neighbouring municipalities with a population of 100 000 inhabitants or more.

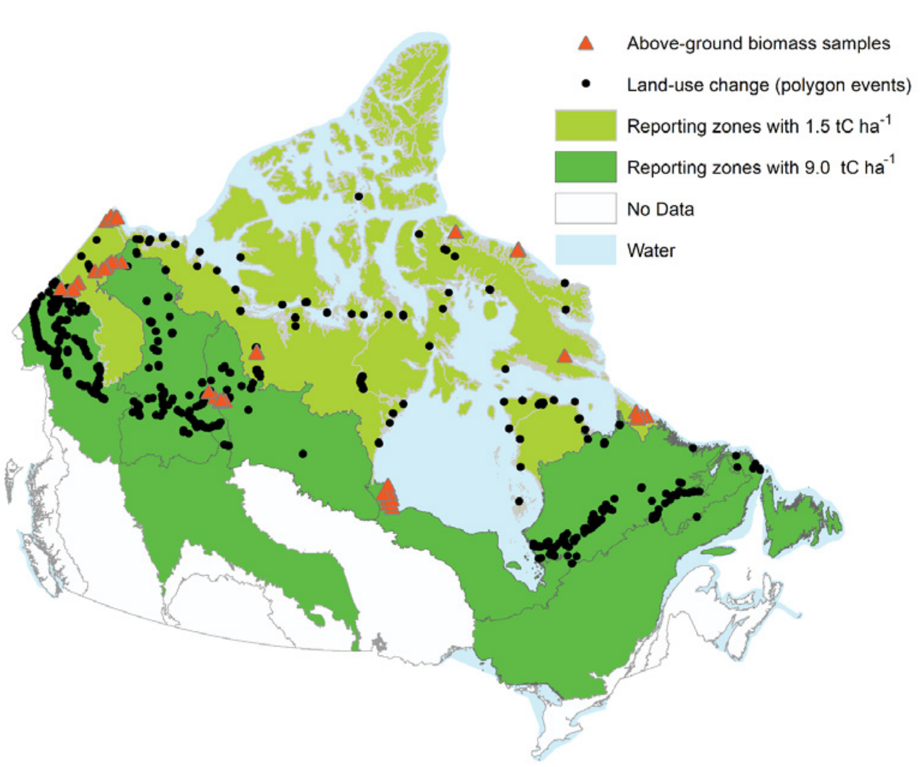
zones. The vegetation in this region consists of forest patches in the Boreal Cordillera and Taiga Plains, but predominantly low vegetation composed of sparse shrubs, mixed grass-dwarf shrub, lichen, moss tussock sedge, bare soil and Arctic willow tundra for the remaining reporting zones. Due to diversity of vegetation types and landscapes over the extent of this region, field samples on forest were excluded and the remaining samples were grouped into two classes: high and low vegetation. This grouping was based on the fact that, after statistical examination of the above-ground biomass values, there was significant variability in the sampled vegetation types between reporting zones. As an initial implementation, the mean of the samples for reporting zones 1 (Arctic Cordillera), 2 (Northern Arctic), 3 (Southern Arctic) and 17 (Taiga Cordillera) was used to obtain a single value of above-ground biomass (1.5t C/ha) that was applied to all of them—areas with "low" vegetation types. Similarly, a single average value (9 tC/ha) from all samples in the remaining reporting zones (Taiga Plain, Taiga Shield West, Boreal Cordillera and Hudson Plains) was used and applied for the remaining areas—areas with "high" vegetation. Reporting zones with land-use change data but without field samples (i.e., Taiga Shield East, Boreal Shield East and Boreal Plains) were assigned to either of the two groups of low or high vegetation based on an analysis of vegetation indices. Emissions from land-use change were estimated by multiplying the annual area of land-use change by their respective biomass lost factor to obtain C stock changes. Annual area rates and emissions for years after 2010 were extrapolated from the 2000–2010 period, assuming a constant yearly rate.

The biomass factor obtained for each of the two vegetation groups was assessed based on the vegetation characteristics of each ecozone (Marshall et al., 1999) and values in the literature (Shaver and Chapin, 1991; Hudson and Henry, 2009; Gould et al., 2003) and was also compared against values reported by the IPCC for the boreal and cool temperate regions. All land-use change activities involved conversion of Arctic tundra vegetation to settlements, and all pre-conversion biomass C was deemed emitted upon clearing.

Uncertainty

The error propagation approach was used to estimate uncertainty using a 95% confidence interval. The percentage of uncertainty for the above-ground biomass volume was 70% for ecozones with low vegetation and 80% for all the other ecozones, based on the coefficient of variation. The uncertainty of the total land-use change area was estimated to be 30%, based on random sampling and image interpretation. A 20% uncertainty was used for the C content, estimated to be 50% of the dry biomass weight, based on the IPCC guidelines. Using these values, an overall uncertainty of 87% was estimated for this category.

Figure A3.5–20 **Location of Land-Use Events and Field Samples of Above-Ground Biomass in Canada's North**



Note: More southerly reporting zones are attributed to the 9 tC ha^{-1} biomass class, as some sites border on the northernmost boundary of these reporting zones.

A3.6. Methodology for Waste Sector

The Waste sector consists of four categories: Solid Waste Disposal (Landfills), Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for these categories with a focus on the following categories and gases:

- CH_4 emissions from solid waste disposal (municipal solid waste and industrial wood waste landfills)
- CH_4 and N_2O emissions from biological treatment of solid waste (composting and anaerobic digestion)
- CO_2, CH_4, and N_2O emissions from waste incineration (municipal solid waste, hazardous, clinical and sewage sludge waste)
- CH_4 and N_2O emissions from wastewater treatment (municipal and industrial)

A3.6.1. Emissions from Solid Waste Disposal (Landfills)

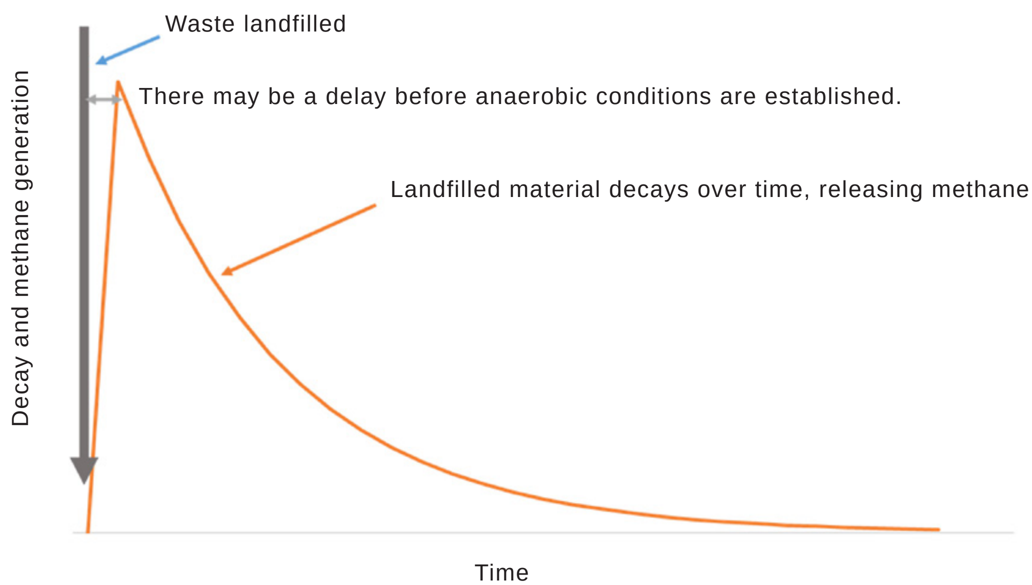
A3.6.1.1. General Approach and Methods

In Canada, the Solid Waste Disposal (Landfills) category comprises two types of landfills: municipal solid waste (MSW) landfills and industrial wood waste (WW) landfills. The treatment and disposal of solid waste produces significant amounts of CH_4, in addition to smaller amounts of CO_2. However, as the CO_2 is primarily from biogenic sources, it is not included in total waste emissions. Emissions of N_2O from landfills are not estimated as they are not significant, and no quantification methodology is provided by the IPCC (IPCC 2006; IPCC 2019).

Emissions for MSW and WW landfills are calculated separately at the provincial and territorial level. Emissions from MSW landfills are reported to the UNFCCC under category 5.A.1, Managed Waste Disposal Sites, while emissions from WW landfills are reported under category 5.A.2, Unmanaged Waste Disposal Sites.

Methane generated from landfills is calculated using a first-order decay (FOD) model, in accordance with Volume 5, Chapter 3, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, hereafter referred to as the 2006 IPCC Guidelines (IPCC 2006). The FOD model considers that waste deposited in any given year decays over several decades at an initially high-rate, which decreases over time (Figure A3.6–1).

Figure A3.6–1 **Representation of First Order Decay Emissions from One-Time Waste Deposition in Landfill**



A 3

Landfill gas capture, flaring, and utilization practices are increasingly common in Canadian landfills. The amount of methane in landfill gas captured by facilities is subtracted from the total amount generated within the landfill to determine the amount that is actually released annually from the decomposing waste. A small amount of methane is released from flaring and utilization of landfill gas (combustion for heat or energy). The amount of CH_4 ultimately emitted by a landfill is further reduced by the oxidation of some of the CH_4 into CO_2 by methanotrophic bacteria in landfill cover material.

The calculation of CH_4 emissions from waste landfilled can be summarized with Equation A3.6–1. The stepwise calculations that make up the FOD model are represented by Equation A3.6–2 to Equation A3.6–5. Methane generation is calculated by material.

Equation A3.6–1 **(modified from the 2006 IPCC Guidelines Eq. 3.1)**

$$CH_4\ emitted_T = [CH_4\ generated_T - R_T] \times (1 - OX) + (CH_4\ flared_T \times (1 - Efcy_{flr}))$$

$CH_4\ emitted_T$	=	CH_4 emitted from landfills in year T (tonne)
T	=	inventory year
$CH_4\ generated_T$	=	CH_4 generated by landfilled waste in year T (tonne)
R_T	=	CH_4 recovered through landfill gas capture in year T (tonne)
OX	=	oxidation factor (fraction)
$CH_4\ Flared_T$	=	amount of CH_4 flared in year T (tonne)
$Efcy_{flr}$	=	flaring efficiency (fraction)

Note:

Methane emitted from utilization of landfill gas for energy are calculated and reported as part of the Energy section.

Equation A3.6–2 **(modified from 2006 IPCC Guidelines Eq. 3.2)**

$$DDOC_{m,T} = Waste\ deposited_{m,T} \times DOC_m \times DOC_{fm}$$

$DDOC_{m,T}$	=	mass of decomposable degradable organic carbon from material m that is deposited in year T (tonne)
m	=	type of waste material type deposited (e.g., food, paper)
T	=	year
$Waste\ deposited_{m,T}$	=	mass of waste material m deposited in year T (tonne)
DOC_m	=	fraction of degradable organic carbon in waste type m
$DOC_{f,m}$	=	fraction of DOC that can/does decompose, for waste type m

Equation A3.6–3 **(modified from the 2006 IPCC Guidelines Eq. 3.4)**

$$DDOCma_T = DDOCmd_y + (DDOCma_{y-1} \times e^{-k})$$

T	=	inventory year
$DDOCma_T$	=	DDOCm (decomposable degradable organic carbon, from waste material m) accumulated in the landfill at the end of year (tonne)
$DDOCma_{T-1}$	=	DDOCm accumulated in the landfill at the end of year (*T*-1) (tonne)
$DDOCmd_T$	=	DDOCm deposited into the landfill in year *T* (tonne)
k	=	decay rate constant (year^{-1})

Equation A3.6–4 **(modified from the 2006 IPCC Guidelines Eq. 3.5)**

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

$DDOCm\ decomp_{T,}$	=	DDOCm (decomposable degradable organic carbon, from waste material m) that decomposed in the landfill in year *T* (tonne)
T	=	inventory year
$DDOCma_{T-1}$	=	DDOCm accumulated in the landfill at the end of year (*T*-1) (tonne)
k	=	decay rate constant (year^{-1})

Equation A3.6–5 **(2006 IPCC Guidelines Eq. 3.6)**

$$CH_4\ generated = DDOCm\ decomp_{m,T} \times FracCH_4 \times 16/12 \times MCF$$

$CH_4\ generated$	=	amount of CH_4 generated from decomposable material
$DDOCm\ decomp_{m,T}$	=	DDOCm (decomposable degradable organic carbon, from waste material m) that decomposed in year T (tonne)
$FracCH_4$	=	fraction of CH_4, by volume, in landfill gas
$16/12$	=	molecular weight ratio CH_4/C
MCF	=	methane correction factor

The parameters used, including material-specific DOC and DOC_f values and decay rate constants, are presented in section A3.6.1.1 for municipal solid waste landfills and in section A3.6.1.3 for industrial wood waste landfills. For more details on the parameters themselves, such as how they are developed and guidance on selecting appropriate values, see Volume 5, Chapter 3, of the 2006 IPCC Guidelines (IPCC 2006).

A3.6.1.2. **Municipal Solid Waste (MSW) Landfills**

A3.6.1.2.1. Model Parameters for MSW Landfills

Degradable Organic Carbon

The degradable organic carbon (DOC) represents the portion of the organic carbon in the waste that is available for decomposition. It is a characteristic of the materials deposited. DOC is generally measured as a fraction of wet weight of the waste material, with the exception of sewage sludge, which is measured in dry weight. The total DOC is determined by the composition of the waste entering into the landfill. The material-specific DOC values used are shown in Table A3.6–1.

Fraction of Degradable Organic Carbon Which Decomposes

The decomposable degradable organic carbon (DOC_f) is an estimate of the amount of DOC in waste that actually decomposes in the landfill. The material-specific DOC_f values are taken primarily from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019). The values are shown in Table A3.6–1.

Waste classifications varied over time with each characterization study. In other words, a given waste type might only be used in one characterization, but not used in others characterizations. Some examples are “Rubber and Leather” which were grouped together in the characterization study by SMi (SMi 2016), or the category “Other Inert,” which is the remainder of non-organic waste from the SMi study, which only characterized waste that had organic components.

Methane Correction Factor

The methane correction factor (MCF) accounts for the decomposition of waste under different management practices. It is used to account for the fact that unmanaged landfills produce less CH_4 from a given amount of waste than anaerobic managed landfills (IPCC 2006). All municipal solid waste landfills in Canada are assumed to be anaerobic managed landfills (MCF = 1.0).

Decay Rate Constant (k)

The decay rate constant, k, represents the rate at which CH_4 is generated in the FOD reaction after waste has been landfilled. The value of k can be affected by moisture content, nutrient availability, temperature and pH, among other factors. The 2006 IPCC Guidelines decay rate constants, k, for the boreal-temperate wet and dry climate zones are used (IPCC 2006). The “wet” and “dry” climates are defined by the ratio of mean annual precipitation to potential evapotranspiration: wet climates have a mean annual precipitation that is greater than the potential evapotranspiration, while dry climates have a

Table A3.6–1 **Waste Material Degradable Organic Carbon (DOC) Content and Fraction of Degradable Organic Carbon That Does Decay (DOC_f)**

Material	DOC	DOC Source	DOC_f	DOC_f Source
Food	0.15	IPCC 2006	0.7	IPCC 2019 Refinement
Paper	0.4	IPCC 2006	0.5	
Textiles	0.24	IPCC 2006	0.5	
Wood	0.43	IPCC 2006	0.1	
Yard and Garden	0.2	IPCC 2006	0.7	
Other Organics	0.5	IPCC 2006 Bulk	0.7	
Leather	0.39	IPCC 2006	0.1	
Rubber	0.39	IPCC 2006	0	IPCC 2006 Guidelines Footnote Table 2.4 (Natural rubber doesn’t decompose in landfill)
Diapers	0.24	IPCC 2006	0.5	IPCC 2019 Refinement “moderately decomposable”
Pet Waste	0.24	ECCC estimate	0.5	
Construction Debris	0.22	ECCC estimate	0.5	IPCC 2006/2019 Default (bulk waste)
Other – Unknown	0.5	IPCC 2006 Bulk	0.5	
Plastics	0	IPCC 2006	0	
Oils Paints and Solvents	0	ECCC estimate	0	ECCC estimate
Unknown (Presumed Inert)	0	ECCC estimate	0	
Glass	0	IPCC 2006	0	
Metals	0	IPCC 2006	0	
Hazardous	0	ECCC estimate	0	
Concrete	0	IPCC 2006	0	
Asphalt	0	ECCC estimate	0	
Other Inert	0	ECCC estimate	0	
Electronics	0	ECCC estimate	0	
Soil and Dirt	0.5	IPCC 2006 Bulk	0.1	
Sewage Sludge	0.3	IPCC 2019 Refinement	0.5	IPCC 2006/2019 Default (bulk waste)

mean annual precipitation that is less than the potential evapotranspiration. The material-specific decay rate constants, by climate, are shown in Table A3.6–2. The estimates of waste landfilled by climate zone, for each province, is discussed in section A3.6.1.2.2.

Applying decay rate constants by material, rather than as bulk averages for all waste, better captures both the differences between materials and the variations in waste composition over time. For example, food waste has a decay rate constant of 0.185 or a half life 3.7 years in wet climates, whereas paper has a decay rate constant of 0.06 or a half life 11.6 years in the same climate. Each material will produce emissions at different rates after initial deposition in landfills. Again, taking the example of food and paper, food will exhibit rapid decay and release of emissions early on, dropping off more quickly. In contrast, paper will initially produce less emissions, but those emissions will not decrease as quickly, resulting in relatively higher rates at later periods.

Fraction of Landfill Gas that is CH_4

The FracCH_4 value in Equation A3.6–5 represents the methane fraction of landfill gas generated by anaerobic decomposition within the landfill, by volume. The 2006 IPCC Guidelines (IPCC 2006) recommended default of 0.5 is used for all time periods and regions.

Methane Recovery

Methane emissions are reduced by the recovery of landfill gas, which is commonly practiced in Canada. A study commissioned by ECCC found that approximately 90% of medium- and large-sized landfills surveyed currently employ landfill gas capture technologies (GHD 2017). Methane in landfill gas is destroyed (oxidized to CO_2) by flaring or when combusted for energy purposes. Methane escaping flaring due to combustion inefficiencies are included in the emission totals. Methane escaping combustion for energy purposes due to inefficiencies are estimated and reported as part of the Energy sector and are not included in the Waste totals.

Emissions from Flaring and Utilization

Combustion by flaring is considered to be 99.7% efficient. CH_4 released from flaring is added to the CH_4 released from landfills to obtain the total CH_4 emitted. CH_4 released from combustion (utilization) of landfill gas is reported in the Energy sector.

Oxidation through Landfill Cover

Methane emissions from landfills are reduced further by the oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill cover material. A broad range of provincial regulations mandate that Canadian landfills be capped with a daily cover of material such as soil, compost, woody material or fill. When a landfill is no longer operational, it is capped with a final, more robust cover.

The 2006 IPCC Guidelines' (IPCC 2006) default factor of 0.1 for managed landfills covered with CH_4 oxidizing material is used for all regions and time periods.

Table A3.6–2 **Decay Rate Constants and Half-Lives of Waste Materials, by Climate**

Material	Decay Rate, k (yr^{-1})		Half-Life (yr)		Source
	Dry	Wet	Dry	Wet	
Food	0.06	0.185	11.6	3.7	IPCC 2006 Guidelines
Paper	0.04	0.06	17.3	11.6	IPCC 2006 Guidelines
Textiles	0.04	0.06	17.3	11.6	IPCC 2006 Guidelines
Wood	0.02	0.03	34.7	23.1	IPCC 2006 Guidelines
Yard and Garden	0.05	0.1	13.9	6.9	IPCC 2006 Guidelines
Other Organics	0.05	0.1	13.9	6.9	IPCC 2006 Guidelines, Moderately Degrading Waste
Leather	0.01	0.01	69.3	69.3	ECCC estimate
Rubber	0.01	0.01	69.3	69.3	ECCC estimate
Diapers	0.06	0.185	11.6	3.7	IPCC 2006 Guidelines, Sewage Sludge
Pet Waste	0.06	0.185	11.6	3.7	
Sewage Sludge (dry wt)	0.06	0.185	11.6	3.7	
Construction Debris	0.02	0.03	34.7	23.1	IPCC 2006 Guidelines, Wood
Soil and Dirt	0.05	0.09	13.9	7.7	IPCC 2006 Guidelines, Default Bulk Waste
Plastics	0.05	0.09	13.9	7.7	
Other – Unknown	0.05	0.09	13.9	7.7	
Oils Paints and Solvents	0.05	0.09	13.9	7.7	
Glass	0.05	0.09	13.9	7.7	
Metals	0.05	0.09	13.9	7.7	
Hazardous	0.05	0.09	13.9	7.7	
Concrete	0.05	0.09	13.9	7.7	
Asphalt	0.05	0.09	13.9	7.7	
Electronics	0.05	0.09	13.9	7.7	

A3.6.1.2.2. Data Sources Municipal Solid Waste (MSW) Landfills

Waste deposited in municipal landfills in Canada is an aggregate of waste from industrial, commercial and institutional (ICI), construction and demolition (C&D) and residential sources, but also includes sewage sludge, which is a by-product of wastewater treatment (section A3.6.4).

There is no consistent and comprehensive data set of waste landfilled in Canada. There are, however, data available on the total amount of municipal solid waste (MSW) disposed, which is the solid waste from residential, ICI and C&D sources that is landfilled, incinerated and exported. Note that waste disposed does not include sewage sludge (which must be quantified separately), or waste diverted at source for recycling or compost.

The total waste landfilled can be determined from the amount disposed after accounting for amounts incinerated and amounts exported, and adding the amount of sewage sludge landfilled.

Equation A3.6–6 **Waste Landfilled in Municipal Landfills**

$$\textit{Total Waste Landfilled} = [MSW_{Disposed} - MSW_{Incinerated} - MSW_{Exported}] + \textit{Sewage Sludge}_{Landfilled}$$

Total Waste Landfilled	=	mass of waste landfilled, tonnes
MSWDisposed	=	mass of municipal solid waste (MSW) disposed in Canada, which includes solid waste landfilled, incinerated and exported, tonnes
MSWIncinerated	=	mass of MSW incinerated in Canada, tonnes
MSWExported	=	net mass of MSW exported (imported) to (from) the United States, tonnes
$\textit{Sewage Sludge}_{Landfilled}$	=	mass of sewage sludge landfilled, tonne

Quantity of Waste Disposed

Municipal solid waste (MSW) disposed includes waste from institutional, commercial and industrial (ICI), construction and demolition (C&D) and residential sources. MSW disposal data are required from 1941 onward. Two primary data sources and calculation approaches are used: per-capita disposal rates from 1941 to 1993, and reported disposal quantities from 1994 onward.

Waste disposal data from 1994 onward are obtained through Statistics Canada's biennial Waste Management Industry Survey (Statistics Canada, no date [a]) *which* compiles waste disposal data for every even year. Disposal quantities are linearly interpolated for intermediary years (e.g., 1995, 1997, etc.). When survey data have not yet been released for the latest inventory year, the most recent survey results are held constant.

Waste disposal quantities for PEI and the territories are suppressed for the years 1994 to 2016 in Statistics Canada tables, for confidentiality reasons, but available from 2018. Waste disposal data for PEI has been obtained from the province for the years 1995 to 2000 and 2004 to 2018. Data gaps were bridged through linear interpolation. Waste disposal for the territories from 1994 onward is estimated using the 2018 per-capita waste disposal rate of 0.73 tonnes/capita/year for the three territories.

Waste disposal amounts for 1941 to 1980 for all provinces and territories are calculated using national per-capita disposal rates obtained from Levelton (Levelton 1991) and population from Statistics Canada (Statistics Canada, no date (d), Statistics Canada, no date [e]). Levelton presented per-capita disposal rates at 5- to 20-year increments. Disposal rates were linearly interpolated for intermediary years. Disposal rates for 1985 and 1990 were published in the report, but these were an extrapolation at the time and are not used. Disposal rates for the provinces and territories from 1981 to 1993 are linearly interpolated between the per-capita disposal rate in 1980 from Levelton (1991) and the per-capita disposal rate in 1994 (1995 in PEI) from Statistics Canada.

Waste Incinerated

Data on the amount of waste incinerated are discussed in section A3.6.3.

Waste Exported

Waste exports are not directly tracked by Canada. An ECCC internal database of waste exports to the United States since 1989 has been compiled from U.S. state databases and congressional reports and by contacting state officials. Where data are not available for the most recent reporting years, the last data point is held constant.

Waste Landfilled

The total amount of waste landfilled is calculated from the municipal solid waste disposed, accounting for exports and incineration and quantities of sludge landfilled. The final amount of waste landfilled, as determined from waste disposed, incinerated and exported, is shown in Table A3.6–3.

Sewage Sludge Landfilled

Sewage sludge produced is estimated as part of the wastewater treatment organics flow calculations. The amount of sewage sludge landfilled can be estimated in a manner similar to that used for MSW, accounting for incineration and export, but also anaerobic digestion, compost and land application. Accounting to determine sewage sludge landfilled is shown in section A3.6.4 and Equation A3.6–28 Sludge Volatile Suspended Solids Fraction After Anaerobic Digestion.

Table A3.6–3 **Waste Landfilled in Municipal Solid Waste Landfills 1990–2019 (tonnes)**

Year	Food	Other Organics	Paper	Diapers and Pet Waste	Textiles	Rubber and Leather	Sludge (Dry Wt)	Yard and Garden	Wood	Construction Debris	Other	Inert	Total
1990	2.77	0.00	6.16	0.00	0.22	0.25	0.17	2.74	0.86	0.96	1.79	3.80	19.72
1991	2.82	0.00	6.23	0.00	0.22	0.26	0.17	2.79	0.87	0.97	1.82	3.85	20.00
1992	2.73	0.00	5.94	0.00	0.22	0.26	0.17	2.70	0.83	0.94	1.77	3.69	19.25
1993	2.89	0.00	6.31	0.00	0.23	0.27	0.17	2.85	0.89	0.99	1.88	3.91	20.39
1994	3.05	0.00	6.71	0.00	0.24	0.28	0.16	3.02	0.94	1.05	1.98	4.15	21.58
1995	2.98	0.00	6.60	0.00	0.24	0.27	0.16	2.95	0.93	1.02	1.93	4.08	21.16
1996	2.83	0.00	6.25	0.00	0.23	0.26	0.16	2.79	0.87	0.97	1.81	3.87	20.04
1997	2.84	0.00	6.29	0.00	0.22	0.26	0.15	2.80	0.88	0.97	1.82	3.89	20.12
1998	2.84	0.00	6.29	0.00	0.22	0.26	0.15	2.80	0.88	0.97	1.82	3.89	20.12
1999	3.01	0.00	6.73	0.00	0.23	0.26	0.15	2.97	0.95	1.02	1.93	4.15	21.40
2000	3.09	0.00	6.93	0.00	0.23	0.27	0.15	3.05	0.98	1.05	1.98	4.27	22.00
2001	3.06	0.00	6.84	0.00	0.23	0.27	0.14	3.02	0.97	1.04	1.96	4.22	21.75
2002	4.11	0.00	5.77	0.43	0.58	0.17	0.13	1.20	2.45	0.00	0.71	6.60	22.15
2003	4.09	0.00	5.63	0.43	0.58	0.17	0.12	1.22	2.41	0.00	0.69	6.45	21.79
2004	3.99	0.00	5.26	0.44	0.58	0.17	0.12	1.24	2.63	0.00	0.65	6.66	21.74
2005	4.05	0.00	5.31	0.45	0.60	0.18	0.12	1.31	2.69	0.00	0.65	6.73	22.09
2006	4.24	0.00	5.49	0.50	0.62	0.18	0.11	1.45	2.69	0.00	0.67	6.83	22.78
2007	4.23	0.00	5.54	0.50	0.62	0.18	0.11	1.45	2.69	0.00	0.69	6.85	22.86
2008	4.21	0.00	5.59	0.49	0.62	0.18	0.10	1.50	2.63	0.00	0.71	6.68	22.71
2009	4.19	0.00	5.61	0.49	0.61	0.18	0.10	1.48	2.63	0.00	0.71	6.70	22.70
2010	4.19	0.00	5.48	0.50	0.62	0.18	0.10	1.48	2.48	0.00	0.69	6.52	22.24
2011	4.24	0.00	5.61	0.50	0.63	0.18	0.09	1.48	2.52	0.00	0.71	6.66	22.62
2012	4.26	0.00	5.63	0.51	0.63	0.19	0.08	1.47	2.44	0.00	0.71	6.62	22.54
2013	4.08	0.00	5.24	0.50	0.61	0.18	0.08	1.45	2.33	0.00	0.66	6.23	21.36
2014	4.03	0.00	5.17	0.50	0.62	0.18	0.07	1.45	2.40	0.00	0.65	6.29	21.36
2015	5.01	1.41	2.42	1.22	0.30	0.27	0.07	0.97	2.18	1.99	1.70	4.18	21.72
2016	4.93	1.38	2.37	1.22	0.29	0.27	0.07	0.99	2.06	1.90	1.65	4.07	21.20
2017	4.85	1.36	2.33	1.20	0.29	0.27	0.07	0.98	2.03	1.88	1.62	4.01	20.89
2018	5.02	1.41	2.41	1.25	0.30	0.28	0.07	1.00	2.10	1.94	1.69	4.17	21.64
2019	5.18	1.45	2.49	1.30	0.31	0.28	0.07	1.03	2.17	1.98	1.74	4.30	22.30

Notes:

a. Inert includes Glass, Metals, Ash, Concrete, Asphalt, Plastics, Other Inert, Electronics

b. Full data set, by Province, Territory and climate region available on request

Municipal Solid Waste Characterization

Waste characterization is the quantification of the material composition of the waste. Municipal solid waste is characterized after accounting for exports and incineration. Sewage sludge is added to the totals landfilled afterwards and is not included in or impacted by the characterization.

Waste characterization studies with sufficient scope to describe waste composition across all regions of Canada are challenging and costly. As a result, they tend to be infrequent. Ideally, waste is characterized separately for every region (province and territory) and for all waste streams or sources. Waste sources, which are available from the Statistics Canada Waste Management Industry Survey and which are used for some characterizations, consist of industrial, institutional and commercial (ICI), construction and demolition (C&D) and residential waste streams.

The level of detail and material classifications vary between characterization studies. Some studies provide regional characterizations, or even characterization by region and waste source. Each characterization study uses slightly different classifications for waste material. For example, some group rubber and leather, others do not; only the most recent characterization study (ECCC 2020[a]) includes pet waste.

The characterization study by NRCan (2006) included details for both waste disposed and recycling. Municipal recycling in Canada only started in earnest in the 1990s. To reflect the waste composition before recycling, the recycling characterization and waste characterization from NRCan (2006) were combined for the 1976 to 1989 period. The characterization by Bond and Straub (1973) is for the United States and was used on the assumption that the Canadian waste profile at the time was reasonably similar. The SMi characterization did not quantify material classes deemed to have low or negligible organic content (SMi 2016).

A full characterization of waste landfilled by waste source, including sewage sludge, is shown in Chapter 7, figure 7.1. Sources used and applicable timeframes for each source are summarized by general waste type in Table A3.6–4.

Waste Deposited by Climate Region

The 2006 IPCC Guidelines (IPCC 2006) define a wet climate as having a mean annual precipitation greater than the mean annual potential evapotranspiration and a dry climate as having a mean annual precipitation less than the mean annual potential evapotranspiration. To determine the proportion of waste landfilled in either wet or dry climate zones (by province), the known quantities of waste disposed of at the largest (approximately 300) landfills were mapped against long-term mean annual precipitation and mean annual potential evapotranspiration (1941 to 2018; Climate Research Unit, University of East Anglia, 0.5 degree spatial resolution; CRU Version 4.03; Figure A3.6–2). The resulting proportions of wet and dry climate for each province and territory are found in Table A3.6–5.

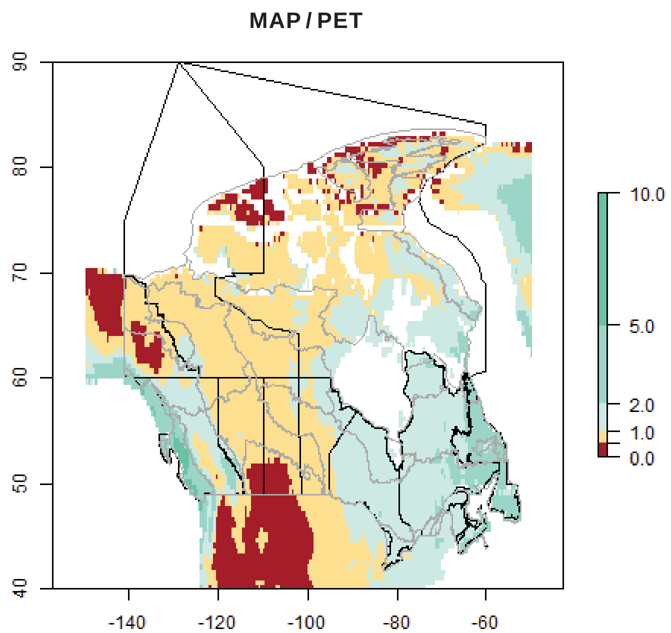
Methane Recovery

Landfill gas capture at large municipal solid waste facilities is common across Canada. Given its relatively high concentration of CH_4, captured landfill gas can be used for heat and/or electricity production. Facilities may also choose to simply flare the captured gas. Note that any emissions resulting from the production of heat or electricity using landfill gas are reported under the Energy sector. See Chapter 7, figure 7-1, and Table A3.6–6 for methane recovery totals.

Table A3.6–4 **Waste Characterization Sources Used in the Inventory—Characterizations Describe the Composition of Waste Disposed Over Given Time-Periods (They Sometimes Describe Composition by Region or Waste Source)**

Characterization	From	To	Characterized By	Notes
Bond and Straub 1973	1941	1975		Composition is not specific to Canada
NRCan 2006 (with recycling re-categorized as disposed)	1976	1989	Region	Recycling added to waste disposed (as recycling only truly began in earnest in Canada in the 1990s).
NRCan 2006	1990	2001	Region	
SMi 2016	2002	2014	Region and Waste Source (Residential, C&D, ICI)	This study only characterized waste with organic content. All other waste was lumped together as "other inert."
ECCC 2020	2015		Region and Waste Source (Residential, C&D, ICI)	

Figure A3.6–2 **Long-Term Climate Regions in Canada, Defined as Wet (Mean Annual Precipitation Greater Than Potential Evapotranspiration) or Dry (Mean Annual Precipitation Less Than Potential Evapotranspiration)**



Data from CRU 4.03, for 1941–2018

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Table A3.6–5 **Proportion of Waste Landfilled in Wet or Dry Climate Regions of each Province or Territory**

Region	Dry	Wet
AB	1	0
BC	0.29	0.71
MB	1	0
NB	0	1
NL	0	1
NS	0	1
NT	1	0
NU	0.5	0.5
ON	0.07	0.93
PE	0	1
QC	0	1
SK	1	0
YT	1	0

Data on landfill gas capture are collected through biennial, voluntary surveys conducted by Environment and Climate Change Canada (ECCC 2019). Gaps in the time series for reporting facilities are filled using linear interpolation. If data gaps exist before the earliest record for a facility, the landfill gas recovery is extrapolated back in time to the year when operation of flaring or methane utilization first began at that facility (and not extrapolated if these dates are unknown). If survey results for the latest years are not yet available, the most recent data are held constant.

The amount of methane recovered for each province is calculated from the volume of gas captured by all facilities in that province. National totals are shown in Table A3.6–6.

While flaring of captured landfill gas greatly reduces CH_4 emissions when utilization is not viable, it is not a 100% efficient process. A flaring efficiency of 99.7% is used to calculate the total CH_4 generated from landfills (U.S. EPA 1995). Methane emissions from utilization are reported in the Energy section.

A3.6.1.2.3. Emissions Estimates for MSW Landfills

Methane emissions are the net result of methane generated (estimated using the first-order decay model) minus methane recovery and oxidization and emissions from flaring and utilization. Emissions from methane utilization for energy are reported in the Energy section, and not included in Waste sector totals. Estimates are presented in Table A3.6–6.

Table A3.6–6 **Methane Generated, Recovered and Emitted from Municipal Solid Waste Landfills in Canada**

Year	CH_4 Generated in Landfills (kt)	CH_4 Flared (kt)	CH_4 Emitted from Flaring (kt)	CH_4 Utilized[a] (kt)	CH_4 Oxidized by Landfill Cover (kt)	Total CH_4 Recovery (Flaring + Utilization) (kt)	Total CH_4 Emitted (kt)
1990	985.5	53.1	0.2	0.0	93.2	52.9	839.4
1991	1 033.5	53.9	0.2	0.0	98.0	53.7	881.8
1992	1 078.7	79.3	0.2	0.0	99.9	79.1	899.7
1993	1 115.2	79.5	0.2	0.1	103.6	79.4	932.3
1994	1 155.8	76.2	0.2	0.7	107.9	76.6	971.2
1995	1 200.2	57.7	0.2	21.7	112.1	79.2	1 008.9
1996	1 238.2	43.0	0.1	58.9	113.6	101.7	1 022.8
1997	1 265.6	69.7	0.2	178.8	101.7	248.3	915.7
1998	1 291.7	57.6	0.2	204.4	103.0	261.8	926.9
1999	1 315.9	64.7	0.2	182.0	106.9	246.5	962.4
2000	1 346.3	70.2	0.2	179.1	109.7	249.1	987.5
2001	1 378.2	109.7	0.3	176.0	109.3	285.3	983.7
2002	1 406.1	108.3	0.3	174.0	112.4	282.0	1 011.8
2003	1 410.8	121.6	0.4	167.1	112.2	288.3	1 010.3
2004	1 412.6	124.9	0.4	161.9	112.6	286.4	1 013.5
2005	1 408.9	142.3	0.4	152.1	111.4	294.0	1 003.4
2006	1 405.9	134.3	0.4	177.5	109.4	311.4	985.1
2007	1 407.5	151.4	0.5	184.9	107.1	335.8	964.5
2008	1 408.4	154.4	0.5	192.6	106.1	346.6	955.7
2009	1 408.9	206.7	0.6	190.8	101.1	396.8	911.0
2010	1 409.3	219.9	0.7	201.6	98.8	420.8	889.7
2011	1 408.2	225.8	0.7	205.3	97.7	430.4	880.1
2012	1 408.9	239.9	0.7	203.5	96.6	442.7	869.7
2013	1 410.0	224.0	0.7	214.4	97.2	437.7	875.1
2014	1 404.6	209.2	0.6	233.1	96.2	441.7	866.7
2015	1 398.2	185.6	0.6	243.1	96.9	428.2	873.1
2016	1 425.3	202.1	0.6	250.9	97.2	452.3	875.7
2017	1 446.5	204.6	0.6	255.3	98.7	459.2	888.6
2018	1 463.1	200.4	0.6	261.7	100.1	461.5	901.5
2019	1 483.1	200.4	0.6	261.7	102.1	461.5	919.6

Note:

a. CH_4 emitted from combustion for utilization as heat and power is captured in Energy.

A3.6.1.3. **Industrial Wood Waste Landfills**

A3.6.1.3.1. Data Sources

Wood waste estimates are based on the amount of wood waste residuals estimated to be disposed of in private landfills. This category captures wood waste that does not enter waste management streams in Canada and thus is not accounted for in the MSW component of the Solid Waste Disposal (Landfills) category.

Wood waste disposed of in Canada is assumed to come from two sources; the solid wood industry and the pulp and paper industry. Quantities of wood waste residuals from 2005 onwards are derived from a literature review, from consultations with industry experts, and from survey data prepared by the National Council for Air and Stream Improvement (ECCC 2020(b), NCASI 2020). Given that the repurposing of wood waste is increasingly preferred over landfilling, it is assumed that the amount of wood waste disposed of is decreasing rapidly. Specific to Canadian sawmills, the combination of increasingly lower surplus residues, combined with their use as a resource (energy or otherwise) and the necessity in maintaining profit margins, there is little incentive for facilities to landfill any waste residues. As a result, it is believed that sawmills have landfilled little to no waste residuals since 2010. However, landfilling of residuals in the pulp and paper sector in Canada is ongoing; the quantity of residuals landfilled for this sector is based on NCASI survey data. As this data was only available at the national level, provincial level ratios were developed using waste emissions reported by facilities to the Greenhouse Gas Facility Reporting Program that were then applied to the national values.

Quantities of wood waste disposed of between 1990 and 2004 for the pulp and paper sector and between 1990 and 2010 for the solid wood industry are based on three studies published by Natural Resources Canada (NRCan, 1997, 1999, 2005). For this time period, it is estimated that 80% of wood waste is disposed of by the solid wood industry, while the remaining 20% is disposed of by the pulp and paper industry (MWA Consultant Paprican 1998). Of the total volume of waste disposed, the amount sent to private landfills is assumed to be 15% for the solid wood industry and 86% for the pulp and paper industry (NRCan 1997). The estimated amount of wood waste disposed of is then converted from “bone dry” units to “hydrated” units using a wood waste moisture content of 20% (Tchobanoglous et al. 1993). Given the lack of historical data, quantities used for the time period 1970–1990 are assumed to be the same as 1990 levels. The national values for wood waste disposed of and landfilled are shown in Table A3.6–7. The final estimated amount of wood waste landfilled by province is shown in Table A3.6–8.

Table A3.6–7 **Quantity of Industrial Wood Waste Landfilled in Canada (1990–2019)**

Year[a]	Landfilled		
	Pulp and Paper[b] (BDt)	Solid Wood (BDt)	Total[b] (Hydrated Tonnes)
1970–1990	1 557 513	1 086 637	3 305 188
1991	1 478 924	1 030 904	3 137 286
1992	1 400 335	976 718	2 971 316
1993	1 321 746	922 531	2 805 346
1994	1 243 157	868 344	2 639 376
1995	1 164 567	814 157	2 473 406
1996	1 085 978	759 970	2 307 436
1997	1 007 389	705 784	2 141 466
1998	928 800	648 000	1 971 000
1999	852 484	597 410	1 812 367
2000	776 167	543 223	1 649 238
2001	699 851	489 037	1 486 110
2002	623 535	434 850	1 322 981
2003	547 219	380 663	1 159 852
2004	470 902	328 537	999 299
2005	164 768	272 289	546 322
2006	126 333	218 103	430 545
2007	87 898	163 916	314 767
2008	80 848	109 729	238 221
2009	73 798	55 542	161 676
2010	66 748	1 355	85 130
2011	59 699	0	74 623
2012	52 649	0	65 811
2013	45 599	0	56 999
2014	38 549	0	48 186
2015	37 228	0	46 535
2016	35 907	0	44 884
2017	49 848	0	62 310
2018	63 789	0	79 737
2019	63 789	0	79 737

Notes:

BDt = Bone dry tonnes

a. Where no data was available, linear interpolation was used between data points. For the year 2019, the 2018 value was used.

b. Converted from bone-dry tonnes (BDt) to hydrated tonnes using a moisture content of 20%.

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Table A3.6–8 **Wood Waste Landfilled by Province (Hydrated Tonnes)**

Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1970–1990 [a]	49 702	674	50 587	32 527	418 671	285 928	21 592	89 629	472 427	1 883 451
1991	47 178	639	48 017	30 874	397 403	271 402	20 495	85 076	448 428	1 787 772
1992	44 682	606	45 477	29 241	376 380	257 045	19 411	80 575	424 705	1 693 195
1993	42 186	572	42 936	27 608	355 356	242 687	18 326	76 075	400 982	1 598 617
1994	39 690	538	40 396	25 974	334 332	228 329	17 242	71 574	377 259	1 504 040
1995	37 194	504	37 856	24 341	313 309	213 971	16 158	67 073	353 537	1 409 462
1996	34 699	470	35 316	22 708	292 285	199 613	15 074	62 572	329 814	1 314 885
1997	32 203	436	32 776	21 074	271 262	185 255	13 990	58 072	306 091	1 220 308
1998	7 884	0	21 681	65 043	601 155	165 564	7 884	17 739	329 157	754 893
1999	7 249	0	19 936	59 808	552 772	152 239	7 249	16 311	302 665	694 137
2000	6 597	0	18 142	54 425	503 018	138 536	6 597	14 843	275 423	631 658
2001	5 944	0	16 347	49 042	453 263	124 833	5 944	13 375	248 180	569 180
2002	5 292	0	14 553	43 658	403 509	111 130	5 292	11 907	220 938	506 702
2003	4 639	0	12 758	38 275	353 755	97 428	4 639	10 439	193 695	444 223
2004	9 993	0	9 993	-	39 972	39 972	9 993	59 958	179 874	649 544
2005	3 404	0	3 404	7 453	39 305	28 971	8 062	23 667	104 810	327 247
2006	2 726	0	2 726	5 714	30 603	22 680	6 298	18 846	82 460	258 491
2007	2 049	0	2 049	3 976	21 901	16 388	4 534	14 025	60 111	189 735
2008	1 372	0	1 372	3 657	18 092	13 022	3 657	9 822	46 056	141 172
2009	694	0	694	3 338	14 284	9 655	2 781	5 619	32 000	92 610
2010	17	0	17	3 019	10 475	6 289	1 904	1 416	17 945	44 047
2011	0	0	0	2 700	9 308	5 564	1 688	1 176	15 777	38 410
2012	0	0	0	2 381	8 209	4 907	1 488	1 037	13 914	33 874
2013	0	0	0	2 063	7 110	4 250	1 289	898	12 051	29 338
2014	0	0	0	1 685	8 354	2 289	1 067	280	10 428	24 084
2015	0	0	0	1 580	5 989	1 810	906	871	12 429	22 950
2016	0	0	0	1 488	5 544	1 731	1 154	331	12 474	22 161
2017	0	0	0	2 012	10 864	1 658	893	438	14 875	31 569
2018	0	0	0	3 227	14 651	2 797	1 408	449	19 431	37 774
2019	0	0	0	3 227	14 651	2 797	1 408	449	19 431	37 774

Note:

a. Values for 1990 are used for 1970–1990.

A3.6.1.3.2. Model Parameters

Degradable Organic Carbon

It is assumed that all waste sent to private wood waste lots is composed entirely of wood. Therefore, the recommended 2006 IPCC Guidelines (IPCC 2006) default degradable organic carbon (DOC) value for wood, i.e., 0.43, is used for all regions and time periods.

Fraction of Degradable Organic Carbon Which Decomposes

The 2006 IPCC Guidelines (IPCC 2006) recommended default value of 0.5 for degradable organic carbon which decomposes (DOC_f) is used for all regions and time periods.

Methane Correction Factor

The 2006 IPCC Guidelines (IPCC 2006) recommended default methane correction factor (MFC) value of 0.8 for unmanaged deep landfill sites was selected, as it best represents industry practices.

Reaction Constant

The default decay rate constant (k) value of 0.03/year recommended by the National Council for Air and Stream Improvement Inc. for estimating the wood products industry's landfill CH_4 emissions was used for all regions and time frames (NCASI 2003).

Fraction of Landfill Gas that is CH_4

The default fraction (F) of 0.5 recommended by the 2006 IPCC Guidelines (IPCC 2006) is used for all time periods and regions.

Oxidation Factor

The 2006 IPCC Guidelines (IPCC 2006) recommended default oxidation factor (OX) of 0.1 is used for all time periods and regions.

Table A3.6–9 **Methane Generated, Oxidized and Emitted from Wood Waste Landfills in Canada (1990–2019)**

Year	CH_4 Generated (kt)	CH_4 Oxidized by Landfill Cover (kt)	CH_4 Emitted (kt)
1990	170 998	17 100	153 898
1991	177 145	17 715	159 431
1992	182 542	18 254	164 288
1993	187 216	18 722	168 495
1994	191 190	19 119	172 071
1995	194 485	19 448	175 036
1996	197 119	19 712	177 407
1997	199 113	19 911	179 201
1998	200 485	20 049	180 437
1999	201 240	20 124	181 116
2000	201 434	20 143	181 291
2001	201 070	20 107	180 963
2002	200 164	20 016	180 147
2003	198 731	19 873	178 858
2004	196 789	19 679	177 110
2005	194 359	19 436	174 923
2006	190 466	19 047	171 420
2007	186 296	18 630	167 667
2008	181 857	18 186	163 671
2009	177 290	17 729	159 561
2010	172 598	17 260	155 338
2011	167 785	16 779	151 007
2012	163 080	16 308	146 772
2013	158 483	15 848	142 635
2014	153 992	15 399	138 593
2015	149 604	14 960	134 644
2016	145 341	14 534	130 806
2017	141 197	14 120	127 077
2018	137 235	13 724	123 512
2019	133 450	13 345	120 105

Methane Recovery

It is assumed that no landfill gas capture technologies are used at private wood lots. Use of these sites is rapidly decreasing, and it is unlikely that facilities would invest in such infrastructure given the more popular practice of repurposing wood waste.

Methane Emitted

Table A3.6–9 outlines the final estimated CH_4 emissions from wood waste landfills in Canada.

A3.6.2. Biological Treatment of Solid Waste (5.B)

The Biological Treatment of Solid Waste category consists of the following two emission sources: composting and anaerobic digestion.

A3.6.2.1. Composting (5.B.1)

The greenhouse gas emissions estimated from composting in Canada include CH_4 and N_2O. Since CO_2 emissions released by composting result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.1.1. Methodology

A Tier 3 method is used to estimate emissions from composting. Feedstock-specific emission factors developed through an in-house literature review are applied to quantities of treated compost, as shown in Equation A3.6–7 and Equation A3.6–8. Emissions are calculated at a facility level and combined to create emissions estimates at provincial and national levels..

Equation A3.6–7 **CH_4 Emissions from Composting**

$$CH_4 Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

CH_4 *Emissions*	=	total CH_4 emissions in inventory year, Gg CH_4
M_i	=	mass of organic wet waste treated by type *i*, Gg
EF	=	emission factor for treatment *i*, g CH_4/kg waste treated by waste type
i	=	composting feedstock at facility *i*

Emission factors for various feedstocks include those for yard waste (1.72 g/kg), municipal solid waste (1.51 g/kg), biosolids/manure (3.54 g/kg) and a mixture of the aforementioned wastes co-composted (1.09 g/kg) based on wet weight (ECCC, 2020[c]).

Equation A3.6–8 **N_2O Emissions from Composting**

$$N_2O\ Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

N_2O *Emissions*	=	total N_2O emissions in inventory year, Gg N_2O
M_i	=	mass of organic wet waste treated by type *i*, Gg
EF	=	emission factor for treatment *i*, g N_2O/kg waste treated by waste type
i	=	composting feedstock at facility *i*

Emission factors for various feedstocks include those for yard waste (0.25 g/kg), municipal solid waste (0.18 g/kg), biosolids/manure (0.18 g/kg) and a mixture of the aforementioned wastes co-composted (0.11 g/kg) based on wet weight (ECCC, 2020[c]).

A3.6.2.1.2. Data Sources

The activity data used to estimate CH_4 and N_2O emissions from composting are based on commercial/municipal facility-level information collected from industry surveys (from 1992 forward), technical reports, and facility websites. Home composting is not included in the Canadian inventory at this time due to lack of available data. To address the missing data years at the facility level, the last data point was carried forward to the next available data point, with the exception of the 1992 survey results being carried backward to develop a complete time series from 1990.

A3.6.2.2. Anaerobic Digestion at Biogas Facilities (5.B.2)

The greenhouse gas emissions estimated from anaerobic digestion of solid waste in Canada include CH_4. N_2O is considered to be negligible according to the 2006 IPCC Guidelines and is therefore not estimated for this sector. Since CO_2 emissions released by anaerobic digestion result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.2.1. Methodology

Greenhouse gas emissions from anaerobic digestion of solid waste at biogas facilities are estimated for Canada using a Tier 3 method. The Tier 3 method includes determination of the methane component of the biogas at the facility-level, a portion of which is lost through on-site leakages in the system.. The loss from on-site leakages in the system is calculated at 2.1% of the methane in the biogas produced. This value was developed from compiling losses found in primary literature and survey data from municipal, industrial and wastewater digesters (ECCC, 2020[d]). Losses from biogas upgrading and incomplete combustion are not included in on-site leakage loss. Losses from venting are not reported as they are considered sporadic in nature and are avoided as much as possible in Canada; it is believed these emissions are negligible. Emissions are calculated according to Equation A3.6–9.

Equation A3.6–9 **CH_4 Emissions from Anaerobic Digestion**

$$CH_4\ Emissions = \sum_i (M_i \cdot D) \cdot (EF) \cdot 10^{-3}$$

CH_4 *Emissions*	=	total CH_4 emissions in inventory year, Gg
M_i	=	biogas production by *i*, m^3
D	=	density of biogas at normal temperature and pressure
EF	=	emission factor for treatment *i*, as percentage of total biogas produced that is lost through onsite leakages
i	=	facility *i*

A3.6.2.2.2. Data Sources

The activity data is based on facility level biogas production reported through in-house and industry based surveys. In the absence of facility reported data for biogas production, a conversion factor by feedstock type is used to generate biogas production from initial feedstock input. Only municipal and industrial anaerobic digestion facilities are reported under 5.B.2, whereas wastewater anaerobic digesters are reported under CRF category 5.D. On-farm anaerobic digesters are currently not included in our Canadian inventory, but will be considered in future inventories.

A3.6.3. Incineration and Open Burning of Waste (5.C)

Waste incineration is defined in the 2006 IPCC Guidelines as the combustion of solid and liquid waste in controlled incineration facilities. Incineration emissions in Canada come from municipal solid waste (MSW) incineration, hazardous waste incineration, clinical waste incineration and sewage sludge incineration. Open burning of waste occurs mainly in rural areas and includes burning garbage in backyard barrels and/or open pits. This section of Annex 3 details the accounting methodologies that are used to describe the GHG emission estimates for these categories.

In keeping with the 2006 IPCC Guidelines (IPCC 2006), only CO_2 emissions resulting from oxidation of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and are included in the national CO_2 emissions estimate. CO_2 emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and are not included in national total emission estimates.

Some facilities generate energy in the form of electricity and/or heat from waste incineration. These facilities are referred to as energy-from-waste (EFW) facilities. Other facilities simply incinerate waste for disposal purposes and are referred to as non-energy-from-waste (non-EFW) facilities. In accordance with the 2006 IPCC Guidelines, emissions from waste incineration with energy recovery are reported in the Energy sector, while emissions from waste incineration without energy recovery are reported in the Waste sector. The following section describes the methodology used for all incinerators, though final emissions are reported under the appropriate sector (Figure A3.6–3).

The Greenhouse Gas Reporting Program (GHGRP) has significant coverage of the incineration sector in more recent years. Over time, incineration practices have changed from many small facilities treating waste on site, to large specialized central facilities treating waste shipped in from across the provinces. Where GHGRP does not have coverage, facility-specific emission estimates were developed using the best available information. This bottom-up, facility-specific approach to developing emissions estimates was implemented for the MSW sector for Canada's 2019 National Inventory Report submission. New for this submission is that the other incineration sectors are calculated using the same approach, such that all incineration types are reported in a consistent manner.

Some facilities in Canada burn waste from multiple waste sources. For example, clinical waste is often burned alongside MSW waste. Emissions from facilities that treat more than one type of waste have been calculated according to the specific waste type but are reported under the facilities' primary waste sector. Therefore, if a facility treats small quantities of clinical waste alongside MSW, it is considered an MSW facility and the clinical waste emissions will be reported under MSW.

A3.6.3.1. Data Sources

Tonnage of Waste Incinerated

The total amount of waste incinerated is only directly used for facilities that do not report to the GHGRP. It is important to note that these data are also used to isolate the amount of waste landfilled in Canada from the amount of waste disposed of, as discussed in section A3.6.1.2.2. Therefore, even where a facility reports GHG emission totals to GHGRP, annual tonnage incinerated is still collected. The amount of waste incinerated at facilities across Canada is obtained through voluntary biennial surveys of incineration facilities conducted by ECCC. The survey has collected data every two years since 2008, with the most recent data collection occurring in the summer of 2020.

Supplemental data sources are used for facilities not included in the survey either due to non-response or because the facility closed before the first survey cycle in 2008. Tonnage is estimated using old reports (Sawell et al. 1996; Environment Canada 1999, 2003[b]). Other sources include progress reports prepared by the Canadian Council of Ministers of the Environment on issues related to dioxins, furans and mercury emissions, as clinical waste incineration was formerly a major source of these pollutants (CCME 2006, 2007 and 2010). A report on solid waste incineration in Canada prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b) was also used. Quantities of material incineration in Canada are found in Table A3.6–10.

Figure A3.6–3 **Decision Tree for Collecting, Estimating and Reporting GHG Emissions from Incineration Facilities**

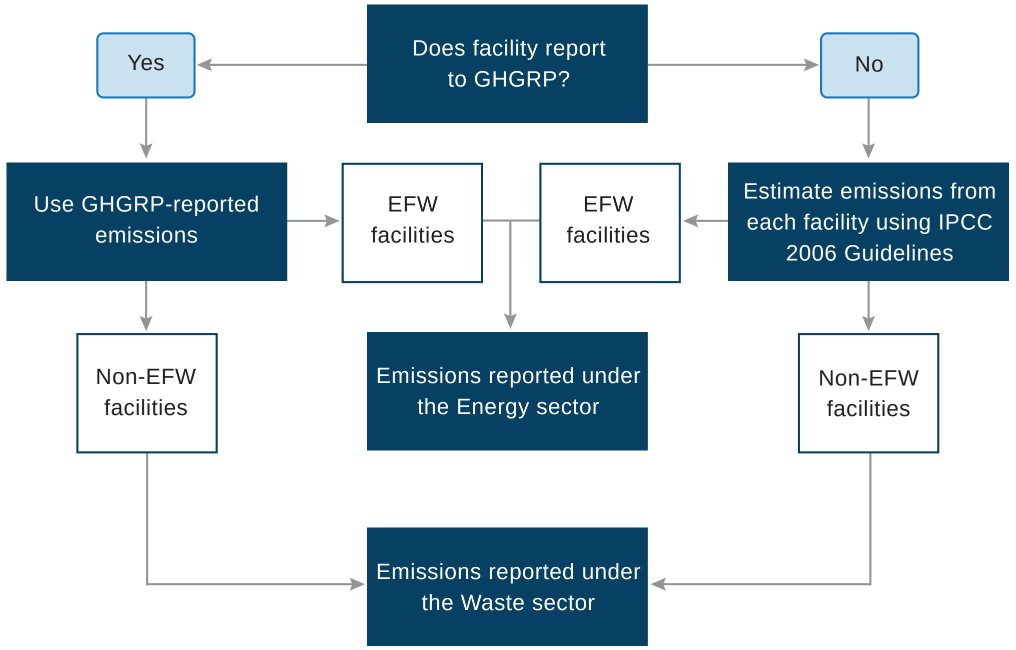

Table A3.6–10 **Estimated Tonnes of Waste Incinerated by Waste Source 1990–2019**

Year	Non-EFW Facilities				EFW Facilities
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	MSW
1990	1 197 622	1 279	100 762	128 402	1 071 051
1991	1 194 730	1 291	109 111	137 375	1 068 478
1992	1 355 028	1 300	117 879	144 575	1 226 525
1993	1 224 413	2 868	125 109	152 557	1 098 529
1994	1 029 607	2 879	142 050	168 795	901 510
1995	1 020 171	2 929	164 727	169 091	907 344
1996	1 042 754	2 937	146 125	187 196	926 637
1997	1 014 789	2 944	132 348	180 380	899 973
1998	1 013 078	2 943	155 511	179 186	909 667
1999	1 027 135	2 947	140 820	189 185	919 051
2000	1 015 348	3 039	168 379	187 889	907 473
2001	1 003 547	3 828	179 525	192 546	896 178
2002	1 030 485	3 957	184 845	206 450	923 902
2003	900 056	3 914	144 036	196 049	793 462
2004	908 199	4 519	161 891	195 525	814 834
2005	887 064	5 001	157 788	192 699	806 924
2006	840 855	5 452	147 775	196 287	760 637
2007	830 635	3 986	134 878	195 058	752 372
2008	835 676	5 606	147 528	190 919	764 102
2009	798 612	5 784	133 356	192 681	751 868
2010	734 087	5 020	137 830	193 360	699 119
2011	811 542	5 400	130 319	207 415	788 144
2012	809 464	5 032	84 785	202 062	782 115
2013	803 351	5 240	90 090	201 486	780 712
2014	781 360	5 208	107 810	209 675	760 124
2015	824 859	5 046	122 911	217 696	805 496
2016	876 088	3 635	124 695	205 774	863 445
2017	904 134	3 416	124 747	206 135	860 963
2018	892 867	3 423	121 105	209 105	869 729
2019	891 112	3 431	118 757	218 722	868 244

Where the time series of tonnage incinerated is incomplete for the operational lifetime of a facility, the nearest data are carried forward or backward. Facilities in the clinical waste incineration sector are treated slightly differently as it used to be common practice to have small batch incinerators located at hospitals. Over time, provinces underwent mass closures of their small batch hospital incinerators and switched to shipping waste to central specialized facilities. Missing data points for these small hospital incinerators are estimated based on interpolation using provincial population numbers.

Contents of MSW waste incinerated include paper, glass, metal, plastic, food waste, yard waste, textiles, rubber, wood and other materials. The types of clinical waste incinerated in Canada include cytotoxic waste, human or animal anatomical waste and pharmaceutical waste (Stericycle 2014). Hazardous waste incineration includes contaminated substrates such as soils, wood, metal and other material. The hazardous waste quantities may also include inorganic wastes such as aqueous solutions containing heavy metals, or wastes such as water-based urethanes, as opposed to solvent-based urethane wastes that have high fossil fuel carbon content. Sewage sludge incineration is the incineration of biosolids resulting from the processing of municipal sewage.

A3.6.3.1.1. Methodology

Emission estimates are compiled at a facility level, and a distinction is made between EFW facilities and non-EFW facilities. Where GHGRP emissions are available, they are used. Where GHGRP emissions are not available, facility-specific emissions are estimated using methodologies prescribed in the 2006 IPCC Guidelines (IPCC 2006).

Facilities Reporting to the GHGRP

GHGRP facility data are available annually from 2004 onwards, though most MSW incinerators started reporting in 2009. Where facilities were operating before 2009, the emissions time series was completed by assuming that tonnage incinerated is directly correlated with emissions. The “Surrogate Data” method prescribed in Volume 1, Chapter 5.3.3.2, of the 2006 IPCC Guidelines (IPCC 2006) is used to complete the time series of emissions using annual tonnage incinerated by the facility, obtained through surveys and/or reports, as well as GHGRP data for all years for which such data are available.

Note that GHGRP reporting guidelines require that facility-reported CO_2 emissions are derived only from wastes of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents and waste oil). CO_2 from the biogenic portion of waste (e.g., food, wood, garden waste) are excluded from emissions totals.

Non-reporting Facilities

There are a large number of incinerators that either closed before the GHGRP was launched or operated below the reporting threshold. Many of these facilities that are classified under MSW were small incinerators across Newfoundland and Labrador, but also include some larger facilities in Ontario, Quebec, British Columbia and Alberta. Estimates for these facilities were developed using the 2006 IPCC Guidelines and the best available parameters for each facility.

CO_2 Emissions

Emissions of CO_2 from MSW incineration are estimated using the mass-balance approach prescribed by Equation A3.6–10 (modified from 2006 IPCC Guidelines Equation 5.2), equivalent to Equation 5.2 in the 2006 IPCC Guidelines.

Where available, facility-specific waste characterization data was used to determine the different materials of waste in the waste incinerated (factor "WFj" in Equation A3.6–10). Where facility-specific characterization data were not available, provincial characterization data were taken from Environment Canada (1996). This report contains waste characterization data for EFW and non-EFW streams of waste incineration. Table A3.6–11 contains the default factors from the 2006 IPCC Guidelines that were used to determine the CO_2 emissions from each waste type incinerated. The default values of 60% for total carbon (% of dry weight) and 40% for fossil carbon as a percentage of total carbon was used for clinical waste, and a carbon content of 50% and fossil carbon of 90% as a percentage of total carbon were used for hazardous waste. These values come from the 2006 IPCC Guidelines (IPCC 2006).

A default factor of 1 is used as the oxidation factor (OF) for all waste types and facilities.

Table A3.6–11 **Default Factors Used in Equation A3.6–12 to Determine CO_2 from Incineration**

Waste Type	Dry Matter Content (% Wet Weight)	Total Carbon (% Dry Weight)	Fossil Carbon (% Total Carbon)
Paper	0.90	0.46	0.01
Textiles	0.82	0.59	0.20
Food	0.40	0.38	0.00
Wood	0.85	0.50	0.00
Yard	0.40	0.70	0.10
Organics[a]	0.40	0.44	0.00
Nappies	0.40	0.70	0.10
Rubber	0.82	0.59	0.20
Plastic	1.00	0.75	1.00
Metal	1.00	0.00	0.00
Glass	1.00	0.00	0.00
MSW Other[b]	1.00	0.34	0.35
Clinical	0.65	0.60	0.40
Hazardous Waste	1.00	0.50	0.90
Sewage Sludge	1.00	0.45	0.00
Inorganics	1.00	0.03	1.00
Fossil Liquid Waste	1.00	0.80	1.00
Solvents	1.00	0.80	0.80
Industrial Wood	0.85	0.41	0.01
Other Industrial Waste	1.00	0.50	0.90

Notes:

a. In cases where facility waste characterization includes organics in general, the organics parameters are used. If the facility distinguishes between food and garden waste, those specific factors are used.

b. Many facilities report "other" waste, without identifying what it includes. Therefore, an average of textiles, food, garden, rubber and inert waste are used in these cases. Note that paper and plastic are always characterized separately and so are not incorporated into the "other" parameter.

Equation A3.6–10 **(modified from 2006 IPCC Guidelines Equation 5.2)**

$$CO_2\ Emissions = Waste \times \sum(WF_j \times dm_j \times CF_j \times FCF_j \times OF) \times 44/12$$

CO_2 *Emissions*	=	CO_2 emissions in inventory year
Waste	=	total amount of waste incinerated
J	=	component of MSW incinerated, such as paper/cardboard, textiles, food waste, wood, plastic, garden waste, plastics, metal, glass, etc.
WF_j	=	fraction of waste type/material *j* in total MSW waste incinerated
dm_j	=	dry matter content of component *j* in total MSW waste incinerated
CF_j	=	fraction of carbon in the dry matter (i.e., carbon content) of component *j*
FCF_j	=	fraction of fossil carbon in the total carbon of component *j*
OF	=	oxidation factor
44/12	=	conversion factor from C to CO_2

CH_4 Emissions

CH_4 emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–11). Emission factors vary depending on how the incinerator is fed (continuous, semi-continuous, or batch-type incineration) and on the incinerator type (stoker vs fluidized bed). The most appropriate emission factor was chosen for each facility. In the absence of IPCC default emission factor values for hazardous waste, CH_4, emission factors were derived using data from one hazardous waste incineration facility that had provided total emissions based on direct measurements taken in 2007. The site emitted 0.03 tonnes of N_2O and burned 177 tonnes of hazardous waste. Therefore, the emission factor 169 g CH_4/ tonnes of hazardous waste was determined. CH_4 emissions from sewage sludge are derived using the emission factor of 9.7 kg/kt of total dried solids for fluidized bed sewage incinerators obtained from the U.S. Environmental Protection Agency

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(U.S. EPA 1995). CH_4 emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor.

Equation A3.6–11 **(modified from 2006 IPCC Guidelines Equation 5.4)**

$$CH_4\ Emissions = \sum(W_f \times EF_f)$$

$CH_4\ Emissions$	=	CH_4 emissions from waste incineration in inventory year
W_f	=	total amount of waste incinerated at facility *f*
EF_f	=	emission factor most appropriate for facility *f*

N_2O Emissions

As with CH_4 emissions, N_2O emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–12). Emission factors vary depending on the feed type of the incinerator (continuous, semi-continuous, and batch-type incineration) Solid waste default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC 2000) as no clinical-waste-specific values are provided. The N_2O emissions for a given site were therefore calculated using the stoker default emission factors for continuous incineration (50 g N_2O/t waste incinerated) and batch-type incineration (60 g N_2O/t waste incinerated) provided in IPCC 2006. Emissions of N_2O from sewage sludge incineration have been updated using the IPCC 2006 default emission factor 0.99 kg/t of dried sewage sludge incinerated (IPCC 2006). Hazardous waste N_2O emission factors were derived using the same methodology as CH_4. Direct measurements of 0.56 tonnes N_2O for 177 tonnes of hazardous waste burned in 2007 result in an emission factor of 3164 gN_2O/tonne HW.

Note that although the 2006 IPCC Guidelines provide a MSW incinerator emission factor for open burning, it is assumed that no MSW incineration facilities in Canada practice open burning. The most appropriate emission factor was chosen for each facility.

Equation A3.6–12 **(modified from 2006 IPCC Guidelines Equation 5.5)**

$$N_2O\ Emissions = \sum(W_f \times EF_f)$$

$N_2O\ Emissions$	=	N_2O emissions from MSW incineration in inventory year
W_f	=	total amount of MSW incinerated at facility *f*
EF_f	=	emission factor most appropriate for facility *f*

The full list of emission factors used can be found in Table A3.6–12.

Table A3.6–12 **Default CH_4 and N_2O Emission Factors for Incineration Facilities**

Waste Type	Feed Type	Incinerator Type	CH_4 Emission Factor	N_2O Emission Factor	Units
Municipal Solid Waste	Continuous	Stoker	0.20	50.00	g/t
Municipal Solid Waste	Continuous	Fluidized Bed	0.00	50.00	g/t
Municipal Solid Waste	Semi Continuous	Stoker	6.00	50.00	g/t
Municipal Solid Waste	Semi Continuous	Fluidized Bed	188.00	50.00	g/t
Municipal Solid Waste	Batch	Stoker	60.00	60.00	g/t
Municipal Solid Waste	Batch	Fluidized Bed	237.00	60.00	g/t
Hazardous Waste	Continuous	Stoker	169.49	3 163.84	g/t
Hazardous Waste	Batch	Stoker	169.49	3 163.84	g/t
Sewage Sludge	Continuous	Fluidized Bed	9.70	990.00	g/t
Sewage Sludge	Continuous	Stoker	9.70	990.00	g/t
Clinical Waste	Continuous	Stoker	0.20	50.00	g/t
Clinical Waste	Batch	Stoker	60.00	60.00	g/t
Clinical Waste	Semi Continuous	Stoker	0.20	50.00	g/t
Other Sludge	Continuous	Stoker	0.20	450.00	g/t
Other Sludge	Batch	Stoker	60.00	450.00	g/t
Fossil Liquid Waste	Continuous	Stoker	0.20	100.00	g/t
Fossil Liquid Waste	Batch	Stoker	60.00	100.00	g/t
Industrial Waste	Continuous	Stoker	0.20	50.00	g/t
Industrial Waste	Continuous	Fluidized Bed	0.00	50.00	g/t
Industrial Waste	Semi Continuous	Stoker	6.00	50.00	g/t
Industrial Waste	Semi Continuous	Fluidized Bed	188.00	50.00	g/t
Industrial Waste	Batch	Stoker	60.00	60.00	g/t
Industrial Waste	Batch	Fluidized Bed	237.00	60.00	g/t

Total Emissions

Table A3.6–13 summarizes emissions from EFW and non-EFW facilities. The EFW emissions are reported under the Energy sector, while the non-EFW emissions are reported under the Waste sector.

A3.6.3.2. Open Burning of Waste (5.C.2)

Canada does not currently estimate GHG emissions from open burning of waste. While open burning at landfills is banned by regulation in most provinces and territories, there is anecdotal evidence that some open burning still occurs in rural areas of the country. However, this is a minor source of emissions relative to other activities. The likely level of emissions from open burning of MSW in Canada (as estimated for 2010) was nearly 100 kt or 0.015% of total national emissions. This is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines. As this emissions value can be considered representative for all years, this source can be considered insignificant.

Table A3.6–13 **National Summary of Kilotonnes of CO_2e Emissions from Incineration (1990–2019)**

Year	Non-EFW Facilities				EFW Facilities
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	MSW
1990	41	1	192	39	371
1991	40	1	202	42	370
1992	41	1	216	44	431
1993	40	2	214	46	394
1994	41	2	243	51	335
1995	37	2	280	51	337
1996	37	2	251	56	346
1997	36	2	227	54	332
1998	33	2	258	54	336
1999	33	2	260	57	341
2000	33	2	275	57	338
2001	33	2	288	58	332
2002	33	2	266	62	341
2003	33	2	269	59	298
2004	28	3	262	59	305
2005	23	3	255	58	303
2006	23	3	236	59	286
2007	23	2	241	59	283
2008	21	4	253	57	286
2009	15	6	209	58	283
2010	12	4	230	58	260
2011	8	5	226	62	286
2012	9	5	99	61	341
2013	8	5	105	73	334
2014	8	5	83	79	297
2015	7	5	110	76	373
2016	8	5	115	77	414
2017	8	5	114	64	395
2018	8	5	100	67	394
2019	8	5	104	70	399

A3.6.4. Emissions from Wastewater Treatment and Discharge (5.D)

The emissions estimates for the Wastewater Treatment and Discharge category includes CH_4 and N_2O emissions resulting from transformation of organics and nutrients in wastewater systems. CO_2 emissions are not included in totals for this sector because wastewater organics are considered to be of biogenic origin grown in the same year as emissions occur.

CH_4 emissions occur from the treatment of municipal and industrial wastewater, from anaerobic digestion of sludge on-site at wastewater treatment facilities and from the emission of organics remaining in wastewater effluent are estimated in accordance with the methods provided in the 2006 IPCC Guidelines and 2019 Refinement using Tier-2 country-specific factors. N_2O emissions are currently estimated as a function of the total nitrogen in wastewater in accordance with the methods described in the 2006 IPCC Guidelines. Estimates of N_2O emission totals are currently independent of the treatment technology used.

Emissions from municipal wastewater treatment are determined on a per-capita basis. The per-capita organics loading to wastewater and the population served by treatment type are the primary activity data for CH_4 emissions. Nitrogen loading to wastewater, estimated from per-capita protein consumption, is the primary activity data for N_2O emissions.

Most wastewater treatment in Canada occurs at centralized municipal wastewater treatment plants (78% in 1990, 83% in 2019, which receive influent from domestic, commercial and industrial users. There are some coastal municipalities that collect and discharge untreated wastewater to sea. Many Canadians in rural and remote areas, but also in portions of urban centres, use private or communal septic systems for wastewater treatment. Larger industries treat or pre-treat their wastewater on-site and are considered separately from municipal wastewater treatment facilities in the Industrial On-Site Wastewater Treatment category, section A3.6.4.2.

A3.6.4.1. Municipal Wastewater Treatment/ Discharge – CH_4

Emissions estimates for municipal wastewater treatment facilities are calculated using the Tier 2 methods provided in the 2006 IPCC Guidelines and 2019 Refinement, with country-specific factors (IPCC 2006; IPCC 2019). The 2019 Refinement provides updated emission factors and methods for estimating emissions from receiving water bodies.

CH_4 emissions estimates are based on population-based organic loadings, treatment technology used, and receiving water-body characteristics (Figure A3.6–4 Diagram of Wastewater Organics Flow). CH_4 emissions occur from microbial activity under anaerobic condition that occur during treatment, anaerobic digestion of sludge, and the receiving water body.

The treatment technology used influences the emissions from treatment, the removal of organics as sludge and the quantity of organics remaining in the effluent (which then contributes to emissions from the receiving water bodies). The first-step in estimating CH_4 emission from wastewater is determining the population using each type of treatment technology.

Methane emissions from wastewater treatment facilities occur at three distinct steps (Figure A3.6–4):

- Wastewater treatment
- Anaerobic digestion of sludge
- Discharge to receiving water body

The organics entering the wastewater stream (activity data) are converted to CH_4 (or CO_2) by microbial activity at each of these three steps. The emissions from the wastewater treatment process and the organics removed as sludge or passing to the receiving body with the effluent are a function of the treatment technology.

The total CH_4 emissions from wastewater facilities for each province or territory can be determined from the sum of emissions from each of the three steps, as shown in Equation A3.6–13. National emissions are the sum of all provincial and territorial emissions.

Equation A3.6–13

$$CH_4 = CH_{4\ Treatment} + CH_{4\ AD} + CH_{4\ Receiving\ water\ body}$$

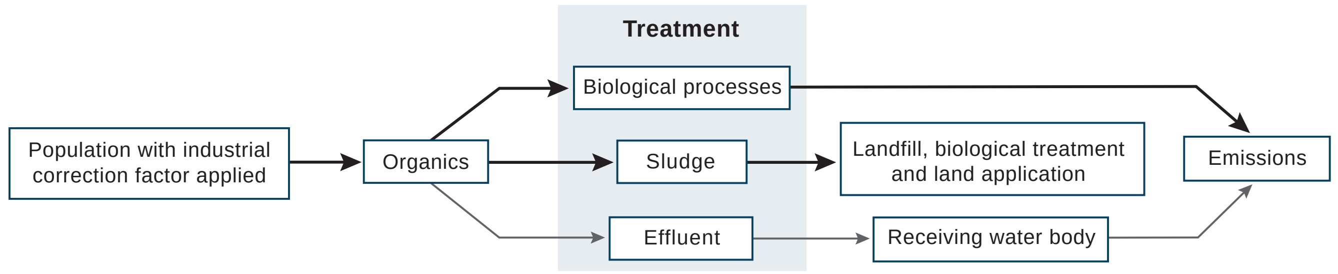
CH_4	=	CH_4 emissions from wastewater, for province, p
$CH_{4\ Treatment}$	=	CH_4 emissions from the process of wastewater treatment (tonne CH_4)
$CH_{4\ AD}$	=	CH_4 emissions from anaerobic digestion of sludge on-site at wastewater treatment facilities (tonne CH_4)
$CH_{4\ Receiving\ water\ body}$	=	CH_4 emissions from the wastewater discharged to receiving water bodies (tonne CH_4)

Methodology

Emissions are ultimately a function of population and treatment technology used. The organic load—the mass of organic material introduced to wastewater—is a function of the population served. The treatment technology to which a wastewater treatment system is connected (if any) dictates the degree of emissions from the treatment process, the amount of organics removed as sludge and the amount of organics remaining in the wastewater effluents. The organics remaining in the effluents also contribute to methane emissions (IPCC 2019). The organics removed as sludge are sometimes processed in anaerobic digesters on-site at the wastewater treatment facilities. In these cases, methane emissions from the anaerobic digestion are included in the wastewater totals.

Organics removed as sludge (after any reductions from on-site anaerobic digestion) may then become inputs for accounting and emissions calculations in other sections, including Biological Treatment of Waste (section A3.6.2), Solid Waste Disposal (Landfills) (section A3.6.1), Incineration (section A3.6.3). Sewage sludge accounting—determining the amounts transferred to each of the aforementioned fates or sections—is discussed in this section.

Figure A3.6–4 **Diagram of Wastewater Organics Flow**



Wastewater system is the term used to denote a sewershed or wastewater collection system. It does not necessarily have a wastewater treatment facility. In some cases, wastewater is collected but discharged to sea. Treatment systems may also employ more than one type of treatment technology, such as different kinds of lagoons cells run in series or in parallel.

Emissions from Wastewater Treatment

Methane emissions are estimated for each province based on organics loading to wastewater, organics removed as sludge and treatment-technology-specific emission factors, as shown in Equation A3.6–14.

Equation A3.6–14

$$CH_{4\ Treatment} = \sum_t [EF_{CH4,t} \times OrganicLoad_t - OrganicsRemovedAsSludge_t]$$

$CH_{4\ Treatment}$	=	CH_4 emissions from wastewater treatment, tonne CH_4
t	=	treatment technology type or category (e.g., facultative lagoon)
$EF_{CH4,t}$	=	CH_4 emission factor for wastewater treatment technology of type t, tonne CH_4/tonne BOD_5
$OrganicLoad_t$	=	organic load to the wastewater treatment/ discharge systems of type t, tonne BOD_5
$Organics\ Removed\ As\ Sludge_t$	=	the organics that are removed from wastewater as sludge, measured as tonne BOD_5

Emission Factor

The emission factor for wastewater treatment and discharge is a function of the theoretical maximum CH_4 production capacity (B_0) for wastewater and a treatment technology-specific methane correction factor (MCF), as shown in Equation A3.6–15 and Table A3.6–14. The maximum methane producing capacity was determined to be 0.36 kg CH_4 per kg BOD_5 by AECOM (2011). The MCF is the fraction of the potential methane that is produced by each treatment type and ranges from 0 to 1 (IPCC 2006), depending on the treatment system type.

Equation A3.6–15

$$EF_{CH4,t} = B_0 \times MCF$$

$EF_{CH4,\ t}$	=	emission factor for treatment type t, tonne CH_4/tonne BOD_5
B_0	=	theoretical maximum CH_4 producing capacity, tonne CH_4/tonne BOD_5
MCF	=	methane correction factor for treatment type t, fraction

Organic Load

Emissions of CH_4 from municipal wastewater treatment systems are determined based on the organic loading to wastewater, by province (measured as biogeochemical oxygen demand, 5-day test, or BOD_5). The organic loading is determined from the per-capita organics loading rate (BOD_5/capita/day) of 0.06 kg/person/day, and an industrial and commercial input correction factor of 1.25 (IPCC 2006).

The total annual organic loading of each type of wastewater treatment technology in a province is calculated as shown in Equation A3.6–16.

Equation A3.6–16

$$OrganicLoad_t = Pop_t \times IndCor \times PerCapBOD_5 \times 365 \times 0.001$$

$OrganicLoad_{(t)}$	=	annual organic load to the wastewater treatment systems of type t, tonne BOD_5
Pop_t	=	population using (connected to) wastewater systems of technology type t
$IncCor$	=	correction factor for industrial and commercial inputs to municipal wastewater, with value of 1.25 (IPCC 2006)
$PerCapBOD_5$	=	per-capita organic loading to the wastewater system, kg BOD_5/capita/day
365	=	conversion from day to year
0.001	=	conversion from kg BOD_5 to tonne BOD_5

Population Using Each Treatment Technology, By Province

There are over 3800 municipal wastewater treatment or discharge systems (wastewater system) in Canada. On top of that, much of the population uses private septic systems.

The total population using each treatment technology of each province can be determined by summing the number of people served by (connected to) each wastewater system (i.e., sewershed or facility) having each type of treatment. However, few wastewater treatment systems have direct measures of the number of people that they serve. Instead, the population served by each wastewater system must be estimated.

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Table A3.6–14 **Emission Factors for CH_4 from Wastewater Treatment and Discharge**

Treatment Category	MCF	EF	Source: MCF	BOD_5 Removal Efficiency	Source: BOD_5 Removal Efficiency	Sludge BOD_5 per BOD_5 Removed from Wastewater	Source: Sludge BOD_5 per BOD_5 Removed from Wastewater
No Treatment	0.1	0.036	IPCC 2006	0	IPCC 2019	0	
Primary	0.018	0.0036	IPCC 2019	0.4	IPCC 2019	1	Envirosim, Table 3
Aerobic Lagoon	0	0	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Anaerobic Lagoon	0.8	0.288	IPCC 2006	0.85	ECCC Internal Analysis	0.02	Envirosim, Table 6
Facultative Lagoon	0.2	0.072	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Other / Unspecified Lagoon	0.2	0.072	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Secondary Anaerobic	0.8	0.288	IPCC 2006	0.85	ECCC Internal Analysis	0.46	Modeling as Secondary Aerobic
Secondary Activated Sludge	0.01	0.0036	IPCC 2019	0.95	IPCC 2019	0.46	Envirosim, Table 2, Secondary with Primary & Nitrification
Trickling Filter	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.6	Envirosim, Table 5
Trickling Filter – High Rate	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.75	Envirosim, Table 5
Rotating Biological Contactor	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.23	Surampalli and Baumann 1995
Sequencing Batch Reactor	0.05	0.018	Taseli 2018	0.9	Literature Review	0.46	Assuming similar to Secondary Activated Sludge. See Mahvi 2008
Secondary Biofiltration	0.018	0.0036	IPCC 2019	0.95	Literature Review	0.46	Assuming similar to Secondary Activated Sludge
Secondary with Biological Nutrient Removal	0.018	0.0036	IPCC 2019	0.98	Literature Review / IPCC 2019 / Envirosim 2019 Assuming primary treatment included	0.46	Envirosim, Table 2, Secondary with Primary & Nitrification
Septic	0.5	0.18	IPCC 2006	1	Assuming dispersal field	0.5	IPCC 2019, Equation 6.3
Septic with Marine Outfall	0.5	0.18	IPCC 2006	0.625	IPCC 2019, Table 6.6B	0.5	IPCC 2019, Equation 6.3
Wetland	0.17	0.0612	IPCC 2014 Wetland Supplement	0.975	Estimate	0	Assuming no dredging
Other / Unknown	0.2	0.072	Modeling as facultative lagoon	0.85	Modeling as facultative lagoon	0.01	Modelling as facultative lagoon

To estimate the population served by each facility, a geographic approach is taken:

1. Map population in each census metropolitan area (CMA) and each census division (CD), excluding overlapping areas with CMA, from 1990 onward, taking account of changing geographic boundaries with each census (Statistics Canada census population from 1991, 1996, 2001, 2006, 2011, 2016 censuses; Statistics Canada census administrative area boundaries [shapefiles or geodatabases] from 1996, 2016 and 2016 censuses).
2. Determine population in each region connected to municipal wastewater treatment systems and population using private or communal septic systems.
3. Distribute the CMA or CD population that discharges to municipal sewer systems between the wastewater treatment systems in that region according to the relative volume of wastewater that the systems process in a year. For example, a facility that treats 30% of the total annual wastewater of a CMA in a given year is assumed to serve 30% of the population of that CMA that is connected to the municipal sewer systems in that year.

The total population using each treatment technology for each province in each year is determined by summing the population of the wastewater treatment system having that technology, according to Equation A3.6–17.

Equation A3.6–17

$$Population\_Using\_System_{t,y} = \sum_{i,y} \frac{Volume\ Treated_{i,t,y}}{TotalVolumeTreated_{region,y}} * Population_{mun\ sewer,region,y}$$

$Population\_Using\_System_{t,y}$	=	the estimated population served by the municipal wastewater treatment system of type t in year y
$VolumeTreated_{i,t,y}$	=	the volume of wastewater treated by, or discharged from, facility *i*
$region$	=	the region (census metropolitan area or census division) in which system *i* is located (note: census geography boundaries change over time)
$TotalVolumeTreated_{region,y}$	=	the total volume of wastewater treated by all municipal wastewater systems in the region in which system *i* is located.
$Population_{mun\_sewer,r,y}$	=	the population of the region in which system *i* is located in year y that live in residences connected to municipal sewer systems (as opposed to private septic systems)

The population discharging their wastewater to municipal sewer systems versus those discharging to private or small communal septic systems is determined from an analysis of the Households and Environment Survey (Statistics Canada. No date [c]). The septic versus sewer use can only be determined at the spatial resolution of census metropolitan area and “the rest of the province.” In other words, all census divisions in a province are treated as one for determining septic or municipal treatment use.

The volume of wastewater discharged (volume treated) from most (>2500) wastewater treatment systems in Canada and the treatment technology used are reported through the Effluent Regulatory Reporting Information System (ERRIS) under the *Wastewater Systems Effluent Regulations* of the *Fisheries Act* (Canada 2012). Records from this source begin in 2013. To complete the time series and fill any data gaps, the reported volumes, treatment technology, and details of facility construction, upgrade and decommissioning were also gathered from older national inventories, provincial inventories and reports, annual reports of treatment facilities, municipal websites, engineering reports, scholarly articles, news articles, and other available sources. Notable data sources, in addition to data gathered through ERRIS, include the national inventory of municipal waterworks and wastewater systems in Canada, 1996 (Minister of Supply and Services Canada 1987), the Government of Quebec (Québec 2003, 2005 and 2013), the Ontario Ministry of the Environment (1985), and the Newfoundland Water Resources Portal (accessed 2018).

The data for septic use (and municipal wastewater system use), and volumes treated are not available for every year. Gaps in the time series of provincial and census metropolitan area septic use are linearly interpolated and extrapolated by holding values constant. Gaps in the time series of wastewater volumes are linearly interpolated and extrapolated by scaling from the nearest known value according to regional population changes.

Many small systems have no reported volumes for any year (1426 systems). This may be because the systems are below the mandatory reporting threshold of 100 m^3/day for the *Wastewater System Effluent Regulations* or because they closed before the regulations came into effect in 2014. These systems are given a token treatment volume of 50 m^3/day (which corresponds to populations of approximately 50 to 200 people, varying by region). Even with token volumes assigned, these ‘small’ systems represent a negligible contribution to the overall volume of wastewater treated in Canada.

The treatment technology of a given wastewater system is extrapolated by holding the earliest and last known technology constant. When the treatment technology of a given system has changed over time and the precise year of change is unknown, the technology type is interpolated by carrying the earlier technology forward until the first recorded of year of the newer technology (i.e., it is assumed that the first instance or record of the newer technology likely corresponds to the year of upgrade).

The estimated population connected to each treatment technology type, by province and territory is shown in Figure A3.6–5. Percentages of Canadian population connected to the wastewater systems of each treatment technology are shown in Table A3.6–15.

Organics Removed As Sludge

Sludge removal is not measured directly at all facilities across Canada and is therefore estimated by modelling it as a function of the treatment technology. In addition to treatment technology, there are many factors at play that will impact sludge removal, from operating temperatures to flow rates. However, on aggregate, and using “typical” operating practices and configurations, average sludge removals across the various treatment technologies in use in Canada can be estimated.

Organics removed from the wastewater as sludge, measured as units of BOD_5, are estimated according to Equation A3.6–18 and Equation A3.6–19, using parameters shown in Table A3.6–14.

Equation A3.6–18

$$Organics\_Removed\_Via\_Treatment_t = OrganicLoading_t \times BOD_5\_Removal\_Efficiency_t$$

$Organics\_Removed\_Via\_Treatment$	=	total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t, tonne BOD_5
$OrganicLoading_t$	=	organic load to the wastewater treatment/discharge system, tonne BOD_5
BOD_5 $Removal\ Efficiency_t$	=	average or typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14), fraction

Equation A3.6–19

$$BOD_5\_Removed\_As\_Sludge_t = Organics\_Removed\_Via\_Treatment_t \times SludgeBOD_5\_Per\_BOD_5\_Removed_t$$

$BOD_5\_Removed\_As\_Sludge_t$	=	quantity of BOD_5 (t BOD_5) removed from the wastewater as sludge for treatment type t
$Organics\_Removed\_Via\_Treatment_t$	=	total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t
$SludgeBOD_5\_Per\_BOD_5\_Removed_t$	=	treatment technology-specific factor for amount of BOD_5 removed from wastewater as sludge per unit of BOD_5 removed from wastewater during treatment (not 1:1 because of other BOD_5 removal mechanisms such as emissions)

Figure A3.6–5 **Population Served by Each Treatment Technology, by Province**

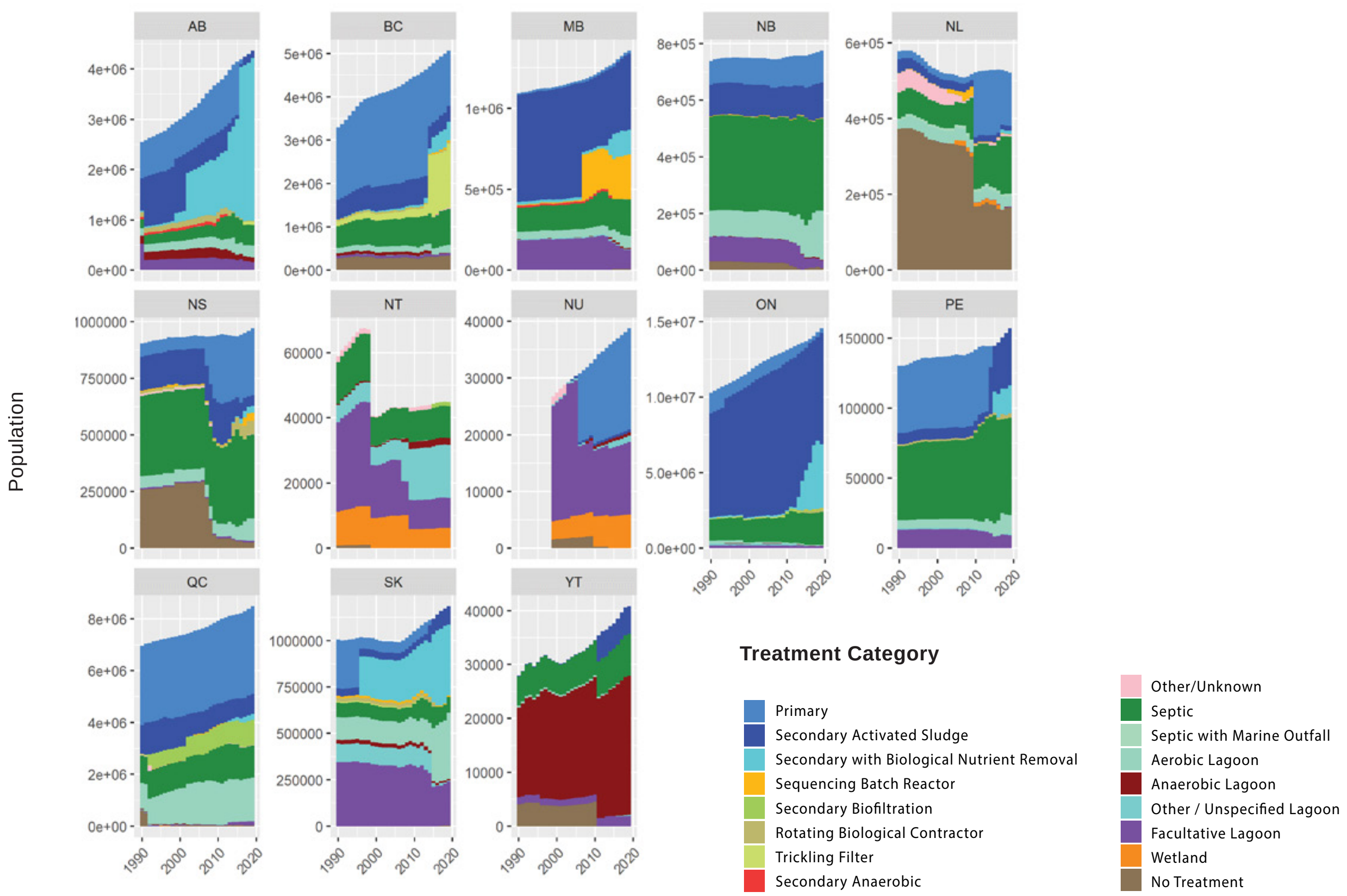

Table A3.6–15 **Percentage of Canadian Population Using Each Wastewater Treatment Technology**

Treatment Category	Year						
	1990	1995	2000	2005	2010	2015	2019
Aerobic Lagoon	6.39	6.7	6.84	7.48	7.12	7.3	7.72
Anaerobic Lagoon	1.05	1.07	1.03	1.01	0.94	0.5	0.45
Facultative Lagoon	5.39	4.13	3.92	3.79	3.47	2.75	2.63
No Treatment	5.61	3.4	3.15	3.06	1.64	1.58	1.54
Other / Unknown	0.32	0.25	0.21	0.11	0.03	0.1	0.14
Other / Unspecified Lagoon	0.9	0.87	0.81	0.75	0.73	0.21	0.08
Primary	26.41	24.34	23.41	23.1	23.66	18.73	14.84
Rotating Biological Contactor	0.58	0.56	0.53	0.55	0.56	0.53	0.53
Secondary Activated Sludge	36.46	39.97	41.02	38.06	36.81	28	25.06
Secondary Anaerobic	0.21	0.21	0.22	0.22	0.21	0	0
Secondary Biofiltration	0.01	1.96	1.8	2.42	2.68	2.77	2.76
Secondary with Biological Nutrient Removal	0.52	0.53	1.81	4.23	4.54	15.54	23.19
Septic	15.24	15.07	14.33	14.17	15.78	16.87	15.73
Septic with Marine Outfall	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Sequencing Batch Reactor	0.15	0.15	0.14	0.25	0.98	0.94	1.13
Trickling Filter	0.71	0.66	0.72	0.7	0.77	4.05	4.14
Wetland	0.04	0.1	0.04	0.08	0.07	0.08	0.04

Note: Values may not add up to 100% because of rounding.

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Emissions from Receiving Water Body (Organics Remaining in Effluent)

Canada uses a Tier 1 approach from the 2019 IPCC Refinement (IPCC 2019). The emissions are calculated using Equation A3.6–20 to Equation A3.6–22. The receiving water body types are unknown, but a country specific value for B_0 (of 0.36) is used to determine the emission factor, of 0.0396 kg CH_4 per kg BOD_5 in wastewater effluent discharged to receiving water bodies.

Equation A3.6–20

$$CH_{4,receiving\ wtr\ body} = EF_{CH4,receiving\ wtr\ body} \times OrganicLoad_{effluent}$$

$CH_{4,receiving\ wtr\ body,\ p}$ = CH_4 emissions from receiving water bodies in province p

$EF_{CH4,receiving\ wtr\ body}$ = CH_4 emission factor for wastewater treatment technology, tonne CH_4 / tonne BOD_5

$OrganicLoad_{effluent}$ = organic load to the passing through wastewater treatment and discharged to the receiving water body as effluent, tonne BOD_5

Equation A3.6–21

$$EF_{CH4\ Receiving\ water\ body} = B_0 \times MCF$$

$EF_{CH4\ Receiving\ water\ body}$ = emission factor, kg CH_4/kg BOD_5 for wastewater discharged to receiving water bodies

B_0 = theoretical maximum CH_4 producing capacity, 0.36 kg CH_4/kg BOD_5 (AECOM 2011).

MCF = methane correction factor (MCF), fraction. IPCC 2019 Refinement Tier 1 default value of 0.11, for unspecified receiving water body type.

The BOD_5 discharged to receiving water bodies varies by treatment technology. The total BOD_5 discharged to receiving water bodies can be determined as a mass balance based on the removal efficiency of the treatment technology.

Equation A3.6–22

$$OrganicLoad_{effluent} = \sum_t [OrganicLoading_t \times Organics\_Removed\_Via\_Treatment_t]$$

$OrganicLoad_{Effluent}$ = quantity of organics, measured as BOD_5 discharged to receiving water bodies from treatment technology of type t, tonne BOD_5

$OrganicLoad_t$ = organic load to the wastewater treatment/discharge systems of type t, tonne BOD_5

$BOD\ Removal\ Efficiency_t$ = typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14)

Emissions from Anaerobic Digestion of Sludge at Wastewater Treatment Facilities

Emissions from anaerobic digestion occurring at wastewater treatment plants are reported under Wastewater, in accordance with the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019). Anaerobic digestion and composting of sludge occurring off-site from the wastewater treatment plants, however, are reported under Biological Treatment (section A3.6.2).

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To calculate emissions from anaerobic digestion, the BOD_5 removed as sludge must be converted to a mass of total suspended solids (TSS), and the fraction of volatile suspended solids (VSS) must be determined. The ratio of TSS sludge produced per unit BOD_5 removed from wastewater as sludge (TSS/BOD_5) and the VSS content of the sludge (VSS/TSS ratio) can be estimated based on the treatment technology used. The TSS/BOD_5 and VSS/TSS ratios are approximate and averaged for a given technology (Equations A3.6–23 to A3.6–27). They are not representative of facility-level operations, which can have a wide variety of operating conditions (temperature, solids retention time, etc.). On aggregate, however, these values are believed to provide a reasonable approximation of the mean sludge characteristics from all facilities in a region of a given type.

Equation A3.6–23

$$TSS_{Sludge} = BOD_5\ Removed\ as\ Sludge \times Sludge\ TSS\ Per\ BOD_5\ Removed$$

TSS_Sludge	=	mass of total suspended solids in sludge removed from wastewater, tonne
BOD_5 Removed as Sludge	=	BOD_5 removed from wastewater as sludge, tonne BOD_5
Sludge TSS Per BOD_5 Removed	=	conversion factor, mass of TSS per unit of wastewater BOD_5 removed as sludge (tonne / tonne BOD_5); a function of treatment technology (Table A3.6–16)

To date, 89 municipal wastewater treatment facilities have been identified as having on-site anaerobic digestion of sludge. The emissions from anaerobic digestion are calculated at the facility level, based on the estimated population served by that facility and the sludge generated based on the treatment technology employed, then aggregated by province. Uncertainty at the facility level is considered high (not yet quantified) because the parameters used represent general technology averages and not facility-specific configurations. Estimates are likely unreliable until they are aggregated to the provincial level.

Sludge transfers between facilities are also accounted for. In some municipalities sludge may be transferred from smaller wastewater treatment facilities to be processed at larger ones.

Equation A3.6–24

$$CH_{4\ AD\ produced} = TSS_{ReductionAD} \times BiogasGen_{Frac} \times FCH_{4\ Biogas} \times Density_{Biogas} \times 0.01$$

$CH_{4\ ADProduced}$	=	methane generated from anaerobic digestion of sludge (tonne)
$TSS_{ReductionAD}$	=	mass of total suspended solids reduced by anaerobic digestion (kg)
$BiogasGen_{Frac}$	=	volume of biogas generated per unit of TSS consumed in anaerobic digestion (m³ / tonne)
$FCH_{4Biogas}$	=	fraction of biogas this is CH_4, by mass
$Density_{Biogas}$	=	density of biogas (kg/m³)
0.01	=	unit conversion kg/m³ to tonne/m³

Table A3.6–16 **Sludge Characteristics (Conversion from BOD_5 to Total Suspended Solids and Volatile Solids Fraction)**

Treatment Category	SludgeTSS / BOD_5 (kg/kg)	VSS/TSS	Source
No Treatment	N/A		
Primary	1.75	0.83	Envirosim 2019
Aerobic Lagoon	0.17	0.35	Envirosim 2019
Anaerobic Lagoon	0.55	0.45	Envirosim 2019
Facultative Lagoon	0.33	0.33	Envirosim 2019
Other / Unspecified Lagoon	0.33	0.33	Modelling as Facultative Lagoon
Secondary Anaerobic	0.95	0.815	Modelling as Secondary Activated Sludge
Secondary Activated Sludge	0.95	0.815	Envirosim 2019
Trickling Filter	1.08	0.83	Envirosim 2019
Trickling Filter – High Rate	1.23	0.84	Envirosim 2019
Rotating Biological Contactor	1.08	0.83	Modelling as Trickling Filter
Sequencing Batch Reactor	0.95	0.815	Modelling as Secondary Activated Sludge; Mahvi 2008; EPA 1999
Secondary Biofiltration	0.95	0.815	
Secondary with Biological Nutrient Removal	0.95	0.815	Envirosim 2019
Septic	0.25	0.5	ECCC Estimate based on IPCC 2019 and Washington State 2004
Septic with Marine Outfall	0.25	0.5	ECCC Estimate based on IPCC 2019 and Washington State 2004
Wetland	N/A		Assuming no sludge removal
Other / Unknown	0.33		Modelling as facultative lagoon

Anaerobic digestion of sludge consumes the volatile suspended solids portion (VSS) of sludge. The reduction in sludge quantity (mass) is based on the volatile suspended solids fraction.

Equation A3.6–25

$$TSS_{Reduction_{AD}} = TSS_{Sludge} \times \frac{VSS}{TSS} ratio \times FracVSSRemoval_{AD}$$

$TSS_{Reduction_{AD}}$	=	mass of total suspended solids reduced by anaerobic digestion (tonne)
TSS_{Sludge}	=	mass of total suspended solids in sludge (tonne)
$FracVSS$	=	fraction of sludge mass that is volatile suspended solids. FracVSS is a function of the treatment technology from which the sludge originates (Table A3.6–16)
$FracVSSRemoval_{AD}$	=	fraction of VSS that is consumed by anaerobic digestion (fraction)

Methane Recovery

Methane recovery for anaerobic digestion of sludge is universally practiced in Canada. Net emissions will be the result of recovery inefficiencies (combustion inefficiency for flaring or utilization) and fugitive loss. Fugitive loss and methane emissions from recovery inefficiency are assumed to be 2.1% of the methane produced, for anaerobic digestion of sludge at wastewater treatment facilities.

Equation A3.6–26 **Fugitive Emissions from Wastewater Anaerobic Digesters**

$$CH_{4\ AD\ Emission} = CH_{4\ AD\ Produced} \times (1 - FugitiveLoss_{percent}/100)$$

$CH_{4AD\ Emission}$	=	methane emitted from anaerobic digestion of sludge at wastewater treatment facilities (tonne)
$CH_{4\_AD\_Produced}$	=	methane produced from anaerobic digestion of sludge (tonne)
$FugitiveLoss_{percent}$	=	percentage of biogas (and methane) emitted from fugitive loss and combustion inefficiencies

Sludge Available for Other Fates (Sludge Accounting)

Secondary to the wastewater treatment emissions, sludge produced and remaining after anaerobic digestion on-site is used to estimate the quantities of sludge landfilled. The sludge remaining after on-site anaerobic digestion is determined as shown in Equation A3.6–27. Because anaerobic digestion only consumes the VSS portion of sludge, the VSS fraction is updated as shown in Equation A3.6–28.

Equation A3.6–27 **Sludge Mass Total Suspended Solids (Dry Weight) Available After On-Site Anaerobic Digestion**

$$TSS_{Available} = TSS_{Sludge} - TSS_{ReductionAD}$$

$TSS_{Available}$	=	The mass of sludge total suspended solids (in other words the dry weight of sludge) available after wastewater treatment and on-site anaerobic digestion of sludge (kg TSS or kg Dry Weight Sludge).
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$TSS_{ReductionAD}$	=	mass of TSS reduced by anaerobic digestion (kg)

Equation A3.6–28 **Sludge Volatile Suspended Solids Fraction After Anaerobic Digestion**

$$VSS_{updated} = \frac{TSS_{Sludge} * FracVSS - TSS_{Reduction_{AD}}}{TSS_{SLudge} - TSS_{Reduction_{AD}}}$$

$VSS_{updated}$	=	volatile suspended solids fraction of sludge having undergone anaerobic digestion (fraction)
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$FracVSS$	=	fraction of sludge mass that is VSS, before anaerobic digestion (fraction)
$TSS_{Reduction_{AD}}$	=	mass of TSS reduced by anaerobic digestion (kg)

The VSS fraction of all sludge produced in a province or territory is determined from the weighted average of sludge produced from each treatment technology after accounting for any on-site anaerobic digestion.

Sludge Distribution

Quantities of sludge incinerated and composted are reported directly from the facilities. Sludge sent to these fates are discussed in section A3.6.2 (Biological Treatment of Solid Waste) and A3.6.3 (Incineration). Sludge sent to landfill or land-applied for agriculture or land-restoration must be estimated. Sludge remaining after point source fates (compost and incineration) is distributed to landfill or land-application according to provincial ratios estimated by Cheminfo (Cheminfo 2018). Estimated fates of wastewater treatment sludge are shown in Figure A3.6–6.

Equation A3.6–29 **Calculation of Sludge Distribution to Landfills As Part of Sludge Flow Accounting**

$$\textit{Sludge Landfilled} = [SS_{Available} - SS_{BiolTrtmt} - SS_{Incinerated} - SS_{Exported}] \times Prop_{LF}$$

$SS_{Available}$ = mass of sewage sludge available from wastewater treatment, after accounting for reductions from on-site anaerobic digestion at the wastewater treatment facilities

$SS_{BioTrtmt}$ = mass of sludge sent to biological treatment, which includes composting and anaerobic digestion (the product of which is assumed to not re-enter the pool of sludge potentially destined for landfill)

$SS_{Incinerated}$ = mass of sludge incinerated, tonne

$SS_{Exported}$ = mass of sludge exported, tonne

$Prop_{LF}$ = proportion of sewage sludge remaining that is landfilled, as opposed to land-applied on agricultural land, forest or as part of land-reclamation (varies by province and over time), ratio.

Estimated fates of wastewater treatment sludge are shown in Figure A3.6–6.

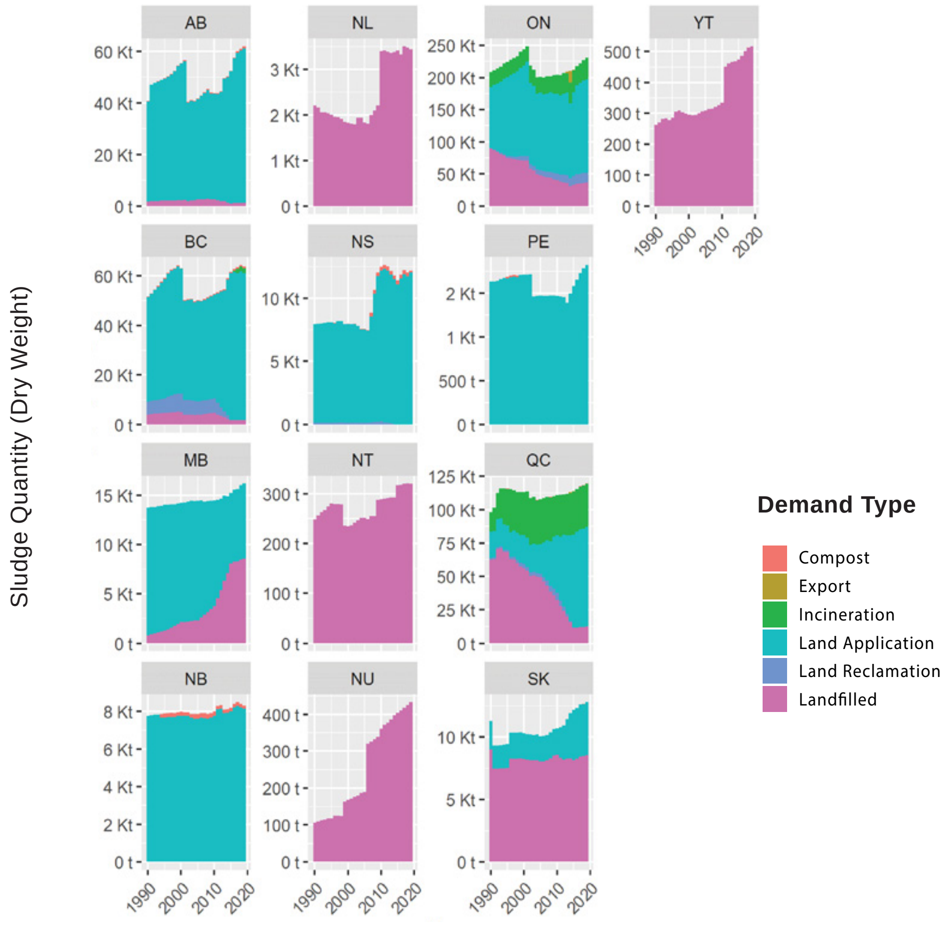
A3.6.4.1.1. N_2O Emissions from Municipal Wastewater Treatment/Discharge

Methodology

Nitrous oxide (N_2O) emissions are estimated using the 2006 IPCC Tier 1 method (IPCC 2006). N_2O is associated with the degradation of nitrogen components in wastewater, which are introduced from urea, nitrate and protein in human sewage as well as inputs from other household wastewater, including inputs from shower drains, sink drains, washing machines, etc. (IPCC 2006).

The N_2O emissions from municipal wastewater treatment facilities are estimated using the amount of nitrogen discharged to the aquatic environment, based on nitrogen introduced to the wastewater stream and an emission factor of 0.005 kg N_2O-N / kg N_2O-N in wastewater, as shown in Equation A3.6–30.

Figure A3.6–6 **Sludge Flow Accounting, Estimated Sludge Fates by Province**



Equation A3.6–30

$$N_2O = EF_{N_2O-N} \times N_{wastewater} \times \frac{44}{28}$$

N_2O	=	N_2O emissions in the inventory year, kg N_2O/year
EF_{N2O-N}	=	emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N.
$N_{wastewater}$	=	nitrogen in wastewater, kg N/yr
$44/28$	=	stoichiometric factor to convert nitrogen to N_2O

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen, namely 0.005 kg N_2O-N/kg N (from a range of 0.0005 to 0.25), is used.

The amount of nitrogen introduced to wastewater sewage is determined on a per-capita basis, based on protein consumption and factors for industrial inputs and other household inputs, as shown in Equation A3.6–31.

Table A3.6–17 **Canadian Protein Consumption**

Year	Protein Consumption (g/capita per day)
1990	66.17
1991[a]	66.17
1992	66.65
1993	67.14
1994	67.62
1995	68.11
1996[a]	68.59
1997	69.46
1998	70.34
1999	71.21
2000	72.09
2001[a]	72.96
2002	73.42
2003	73.88
2004	74.34
2005[a]	71.12
2006[a]	71.03
2007[a]	71.79
2008[a]	70.25
2009[a]	69.85
2010	69.85
…	69.85
2019	69.85

Notes:

Values for intermediary years without data from Statistics Canada are estimated by linear interpolation. Values extrapolated by holding the nearest value constant.

a. Statistics Canada (2009), Food Statistics, Catalogue Number 21-020-X: Total nutrients available adjusted for losses from the Canadian food supply.

Equation A3.6–31

$$N_{wastewater} = (Protein_{Consm} \times Population \times FRAC_{N-PR} \times F_{NON-CON} \times F_{IND-CON}) - N_{SLUDGE}$$

$N_{wastewater}$	=	nitrogen in wastewater, kg N/yr
$Protein_{Consum}$	=	annual per capita protein consumption, kg/capita per year, kg/person/yr
$Population$	=	the human population
$FRAC_{N-PR}$	=	fraction of nitrogen in protein (0.16 kg N/kg protein)
$F_{NON-CON}$	=	factor for non-consumed protein added to the wastewater
$F_{IND-COM}$	=	factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE}	=	nitrogen removed with sludge (taken as the 2006 IPCC Guidelines default value of 0 because of limited data), kg N/yr

Protein consumption is determined from Canadian protein consumption data, which are obtained from the annual food statistics publication (Statistics Canada 2009). Statistics Canada data are provided for the years 1991, 1996 and 2001–2009 from the protein (nutrients) available adjusted for losses from the Canadian food supply, as shown in Table A3.6–17. It is assumed that protein is 16% nitrogen.

Protein consumed accounts for retail, household, and cooking and plate loss, which generally goes to municipal solid waste and composting streams, rather than wastewater. Use of protein available without adjusting for losses would result in an overestimate of wastewater N_2O emissions (AECOM 2012).

The factor for industrial and commercial co-discharged protein to the sewer system ($F_{IND-COM}$) is taken as the 2006 IPCC Guidelines default value of 1.25. The factor for non-consumed protein added to the wastewater ($F_{NON-CON}$), which represents nitrogen inputs from other household sources, such as shower drains, sink drains, washing machines etc., is taken as the IPCC default value of 1.1, for countries with no garbage disposal, interpreted as meaning no in-sink garbage disposal such as garburators. (Although garburators are used in some Canadian districts, most regions do not permit in-sink waste disposal).

Nitrogen removed from sludge is not estimated because of a lack of data on nitrogen concentration in sewage sludge. The 2006 IPCC Guidelines default value of 0 is used.

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A3.6.4.1.2. CO_2 Emissions from Municipal Wastewater Treatment/Discharge

CO_2 emissions from wastewater are of biogenic origin. According to the 2006 IPCC Guidelines, CO_2 from the combustion or decay of short-lived biogenic material removed from where it was grown is reported as zero in the Waste sector. Therefore, these emissions are not considered for wastewater treatment.

A3.6.4.2. Industrial Wastewater Treatment – CH_4 and N_2O

Estimates for CH_4 emissions from industrial facilities with on-site wastewater treatment are handled facility by facility following a Tier 3 approach (IPCC 2006). Industrial on-site wastewater treatment systems can receive varying organics loads, depending on industry type, facility size and production levels. Methane recovery varies facility by facility. Therefore, industries with on-site anaerobic systems are estimated individually.

Emissions are not estimated for on-site anaerobic sludge digesters at industrial facilities. N_2O emissions from industrial wastewater treatment are not currently estimated.

A3.6.4.2.1. Data Sources and Methodology

Preliminary inquiries indicated that anaerobic industrial wastewater units were relatively few in Canada. A Tier 3 approach based on information directly collected from individual facilities was deemed more accurate than the default approach. Volumes of wastewater treated, COD or BOD_5 levels, and volumes of biogas flared, used and vented were collected through surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site, conducted every two years from 2008 to 2016. Industry sectors considered for the survey include pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

Nineteen facilities were identified through email exchanges with facility operators and industry associations as having anaerobic systems. The facilities surveyed provided volumes of biogas vented, flared and used for heat or energy purposes. The CH_4 mass of each biogas stream (used, flared, vented) was determined from the facility-reported biogas methane concentration (or a default value of 60% CH_4 if not reported) and the reported biogas density, pressure and temperature. Fugitive losses were estimated to be 0.5%. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. The CH_4 destruction efficiencies were estimated to be 99.5% for an enclosed flare and 98% for a boiler (Climate Action Reserve 2009). The total emissions were determined from the sum of CH_4 in vented biogas, CH_4 in piping (fugitive) losses and the quantities of CH_4 circumventing combustion in the flare and boiler.

In the absence of survey-reported data for two facilities known to have anaerobic wastewater treatment systems, design parameters (process wastewater volumes and COD) were used from the engineering firm that supplied the units to these facilities to estimate methane production values. As it is known that the gas is collected, it was assumed that the losses, i.e., emissions, would consist of piping losses and utilization by a boiler.

ANNEX 4

COMPARISON OF SECTORAL AND REFERENCE APPROACHES, AND THE NATIONAL ENERGY BALANCE

This annex covers the energy and the CO_2 emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA. Section A4.4 contains a general discussion on the merits of using implied emission factors.

A4.1. Comparison of Reference Approach with Sectoral Approach

A comparison of results from the RA and the SA serve as a check of energy available versus that consumed by all sectors, and the corresponding CO_2 emissions from fossil fuel combustion. Checks of RA and SA results for all years from 1990 to 2019 are an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy consumption in the RA and SA shows significant discrepancies, since the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows an 11.3% or larger variation in energy. Excluding the non-combustion energy of certain feedstocks and fossil fuels ensures that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of fossil fuels and feedstocks, the difference between the SA and adjusted RA varies from -2.15 to 1.25%. Table A4–1 shows a comparison of the original and adjusted RA and SA.

No adjustments were necessary for the emissions estimate in the RA since online CRF Reporting software, supplied by the UNFCCC, correctly removes emissions associated with non-energy and feedstock use and allocates them to industrial processes and product use sectors. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -2.05% to 2.43% variation.

A4.2. Reference Approach Methodology

The RA follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guideline's designated method with the use of country-specific fuel energy contents (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. Canada and the United States use HHVs to report the energy content of fuels. Fuel supply and demand reported by industries to the various surveys that feed into the compilation of the *Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada 1990–) are in physical units. Chapter 3, section 3.2.2 International Bunker Fuels, and annex sections A3.2.2.1 Civil Aviation, and A3.2.2.2 Navigation presents fuel allocation for International bunkers.

For primary fuels (crude oil, ethane, natural gas liquids, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, all of which are reported separately in the RESD and all of which directly impact fuel availability. Apparent consumption is determined using this adjusted stock change number. Similarly, the stock change data for secondary fuels takes into consideration inter-product transfers, international bunkers, stock variation and other adjustments.

Once the apparent consumption is determined, country-specific fuel energy contents and carbon emission factors allow for the calculation of carbon content and emissions. Energy content values come from the following sources: RESD (Statistics Canada 1990–), the *1998 Fossil Fuel and Derivative Factors* (McCann 2000) and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from McCann (2000), and the 2006 IPCC Guidelines.

Table A4–2 presents the applied emission factor, energy content and oxidation value in the RA. The RESD supplies the energy content values, with the exceptions of bituminous coal, lignite, crude oil, heavy fuel oil, LPGs, natural gas, NGLs, petroleum coke and still gas, where weighted factors, calculated yearly, account for the quantity and variation of energy content at the point

Table A4–1 **Comparison of Adjusted Reference Approach and Sectoral Approach for Canada**

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Overall Energy Comparison															
Reference Approach (PJ)	7 189	7 010	7 231	7 322	7 552	7 698	8 068	8 301	8 305	8 638	8 964	8 878	9 015	9 229	9 220
Sectoral Approach (PJ)	6 322	6 174	6 403	6 440	6 654	6 825	7 047	7 198	7 256	7 559	7 922	7 817	7 924	8 167	8 095
Percent Difference without Adjustment (%)	13.7	13.5	12.9	13.7	13.5	12.8	14.5	15.3	14.5	14.3	13.1	13.6	13.8	13.0	13.9
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6 384	6 184	6 389	6 455	6 682	6 804	7 007	7 188	7 213	7 456	7 875	7 771	7 892	8 059	7 967
Percent Difference with Adjustment – 100% x (RA-SA)/SA	**0.97**	**0.17**	**-0.22**	**0.23**	**0.43**	**-0.31**	**-0.57**	**-0.14**	**-0.60**	**-1.37**	**-0.59**	**-0.59**	**-0.41**	**-1.32**	**-1.58**
Adjusted Non-Energy Fossil Fuels and Feedstocks															
Non-Energy Use of Gaseous Fuels (PJ)	*163*	*181*	*172*	*193*	*200*	*198*	*241*	*260*	*255*	*267*	*243*	*205*	*152*	*159*	*171*
Non-Energy Use of Liquid Fuels (PJ)	*539*	*529*	*555*	*561*	*565*	*586*	*711*	*746*	*727*	*803*	*731*	*795*	*865*	*904*	*972*
Non-Energy Use of Solid Fuels (PJ)	*103*	*116*	*115*	*113*	*105*	*110*	*108*	*107*	*110*	*112*	*115*	*107*	*106*	*107*	*111*
Overall Emission Comparison															
Reference Approach (Gg CO_2)	419 240	405 467	417 062	418 302	431 266	438 522	450 470	465 661	469 221	481 821	508 595	502 551	508 708	519 272	511 333
Sectoral Approach (Gg CO_2)	411 271	401 807	414 864	413 524	425 774	437 000	450 507	463 735	469 474	484 887	508 064	502 443	506 166	522 027	518 220
Percentage Difference (%)	**1.94**	**0.91**	**0.53**	**1.16**	**1.29**	**0.35**	**-0.01**	**0.42**	**-0.05**	**-0.63**	**0.10**	**0.02**	**0.50**	**-0.53**	**-1.33**
Liquid Fuels															
Reference Approach (Gg CO_2)	209 694	193 190	195 336	200 058	205 716	204 874	207 480	216 486	218 779	216 805	223 127	224 994	227 998	237 682	241 346
Sectoral Approach (Gg CO_2)	203 146	190 901	194 016	195 791	200 795	203 413	208 250	215 849	219 441	221 492	224 071	227 450	226 862	240 889	248 914
Percentage Difference (%)	**3.22**	**1.20**	**0.68**	**2.18**	**2.45**	**0.72**	**-0.37**	**0.30**	**-0.30**	**-2.12**	**-0.42**	**-1.08**	**0.50**	**-1.33**	**-3.04**
Solid Fuels															
Reference Approach (Gg CO_2)	87 307	90 621	92 759	84 378	88 517	89 620	92 244	99 920	104 642	105 134	114 168	113 663	110 162	108 309	101 156
Sectoral Approach (Gg CO_2)	87 009	90 261	92 689	84 924	89 346	90 769	92 754	99 911	105 744	105 923	115 548	113 826	111 514	110 523	102 787
Percentage Difference (%)	**0.34**	**0.40**	**0.07**	**-0.64**	**-0.93**	**-1.27**	**-0.55**	**0.01**	**-1.04**	**-0.75**	**-1.19**	**-0.14**	**-1.21**	**-2.00**	**-1.59**
Gaseous Fuels															
Reference Approach (Gg CO_2)	121 772	121 254	128 472	133 327	136 370	143 432	150 135	148 807	145 273	159 355	170 741	163 349	169 859	172 643	168 150
Sectoral Approach (Gg CO_2)	120 648	120 243	127 662	132 268	134 970	142 222	148 891	147 523	143 760	156 943	167 882	160 620	167 099	169 975	165 837
Percentage Difference (%)	**0.93**	**0.84**	**0.63**	**0.80**	**1.04**	**0.85**	**0.84**	**0.87**	**1.05**	**1.54**	**1.70**	**1.70**	**1.65**	**1.57**	**1.40**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall Energy Comparison															
Reference Approach (PJ)	9 074	9 103	9 518	9 307	8 845	9 136	9 419	9 478	9 541	9 708	9 814	9 614	9 692	10 029	9 803
Sectoral Approach (PJ)	8 079	7 995	8 382	8 225	7 886	8 027	8 274	8 240	8 367	8 422	8 497	8 288	8 472	8 752	8 808
Percent Difference without Adjustment (%)	12.3	13.9	13.6	13.2	12.2	13.8	13.8	15.0	14.0	15.3	15.5	16.0	14.4	14.6	11.3
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	7 943	7 877	8 300	8 178	7 762	7 918	8 125	8 114	8 282	8 528	8 553	8 318	8 508	8 852	8 618
Percent Difference with Adjustment – 100% x (RA-SA)/SA	**-1.68**	**-1.47**	**-0.98**	**-0.56**	**-1.57**	**-1.35**	**-1.80**	**-1.53**	**-1.02**	**1.25**	**0.66**	**0.36**	**0.42**	**1.14**	**-2.15**
Adjusted Non-Energy Fossil Fuels and Feedstocks															
Non-Energy Use of Gaseous Fuels (PJ)	*158*	*162*	*161*	*128*	*142*	*142*	*162*	*165*	*150*	*126*	*154*	*149*	*157*	*134*	*123*
Non-Energy Use of Liquid Fuels (PJ)	*871*	*953*	*948*	*899*	*864*	*990*	*1 026*	*1 098*	*1 021*	*962*	*1 032*	*1 065*	*942*	*956*	*983*
Non-Energy Use of Solid Fuels (PJ)	*102*	*112*	*110*	*101*	*77*	*86*	*106*	*100*	*88*	*92*	*75*	*83*	*85*	*88*	*79*
Overall Emission Comparison															
Reference Approach (Gg CO_2)	511 584	504 979	531 349	519 534	487 668	497 124	502 415	499 905	508 805	522 818	524 466	507 808	518 208	532 746	513 087
Sectoral Approach (Gg CO_2)	516 716	509 573	533 576	520 461	494 144	502 525	510 173	504 917	511 049	510 417	513 957	501 341	511 882	521 221	523 806
Percentage Difference (%)	**-0.99**	**-0.90**	**-0.42**	**-0.18**	**-1.31**	**-1.07**	**-1.52**	**-0.99**	**-0.44**	**2.43**	**2.04**	**1.29**	**1.24**	**2.21**	**-2.05**
Liquid Fuels															
Reference Approach (Gg CO_2)	243 305	237 023	246 596	239 425	231 726	235 425	234 194	238 396	237 847	250 202	248 353	242 703	247 290	260 376	239 909
Sectoral Approach (Gg CO_2)	245 210	242 173	249 404	241 066	236 965	241 447	242 431	241 580	242 276	238 626	240 526	238 517	243 359	250 841	252 627
Percentage Difference (%)	**-0.78**	**-2.13**	**-1.13**	**-0.68**	**-2.21**	**-2.49**	**-3.40**	**-1.32**	**-1.83**	**4.85**	**3.25**	**1.75**	**1.62**	**3.80**	**-5.03**
Solid Fuels															
Reference Approach (Gg CO_2)	102 790	99 277	104 593	99 282	81 101	84 629	74 649	68 858	69 646	64 143	67 901	61 712	62 089	49 224	47 516
Sectoral Approach (Gg CO_2)	104 219	100 545	105 628	99 784	83 472	85 174	75 172	69 578	69 127	65 337	67 086	61 451	61 579	49 082	47 328
Percentage Difference (%)	**-1.37**	**-1.26**	**-0.98**	**-0.50**	**-2.84**	**-0.64**	**-0.70**	**-1.03**	**0.75**	**-1.83**	**1.21**	**0.43**	**0.83**	**0.29**	**0.40**
Gaseous Fuels															
Reference Approach (Gg CO_2)	164 926	168 129	179 507	180 173	174 271	176 501	193 006	191 964	200 681	207 916	207 565	202 763	208 221	222 536	225 050
Sectoral Approach (Gg CO_2)	166 721	166 303	177 888	178 954	173 135	175 333	192 001	193 071	199 013	205 895	205 698	200 744	206 336	220 688	223 239
Percentage Difference (%)	**-1.08**	**1.10**	**0.91**	**0.68**	**0.66**	**0.67**	**0.52**	**-0.57**	**0.84**	**0.98**	**0.91**	**1.01**	**0.91**	**0.84**	**0.81**

of consumption, such as commercial usage or self-generated usage. For example, in provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, sold to consumers, and non-marketable natural gas, combusted by the producers of natural gas. The composition of non-marketable natural gas includes more complex hydrocarbons unlike marketable natural gas which, typically, contains over 95% CH_4.

A4.3. National Energy Balance

This section provides a general background on the national energy balance and its data quality framework. In Canada, the Energy and Environment Statistics Division (EESD) of Statistics Canada is responsible for the collection, compilation and dissemination of energy data under the authority of the *Statistics Act*.[1] The RESD is the primary source of activity data used to estimate GHG emissions for the Energy sector and is available on Statistics Canada's website.[2] Emission estimates for the Industrial Processes and Product Use sector also use the non-energy and feedstock information from the RESD as a source of activity data. The RESD is an accounting of energy forms in Canada from import and export activities through to production, stock change and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). It consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Energy and fossil fuel data are collected using a mix of annual and monthly surveys, along with census data from industry, federal agencies (such as the Canadian Energy Regulator [CER]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Energy and Emissions Data Centre (CEEDC). Refer to Figure A4–2, RESD Data Input, for a sample of the energy and fossil fuel data input. The oil and gas information provided by the AER is considered accurate, since it is tied to, oil and gas exploitation permits and federal and provincial royalty schemes.

Various federal departments use the RESD for energy efficiency programs, policy development, energy and emission forecasting, and reporting to the UNFCCC. As such, EESD's quality management system for the RESD includes an internal and external stakeholder review process. Documentation of the quality assurance framework and methodological reports are contained in Statistics Canada's Integrated Meta Database.[3] EESD has also established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with their quality assurance process.

1 Statistics Canada. Statistics Act. http://laws-lois.justice.gc.ca/eng/acts/S-19/.

2 Statistics Canada. *Report on Energy Supply and Demand in Canada* (Annual). Catalogue No. 57-003-X http://www.statcan.gc.ca/pub/57-003-x/2017002/tablesectlist-listetableauxsect-eng.htm.

3 Statistics Canada. Quality Assurance Framework. http://www.statcan.gc.ca/pub/12-539-x/manage-gestion/4058322-eng.htm.

Figure A4–1 **Sample of an Energy Balance Flow Diagram for Canada (RESD)**

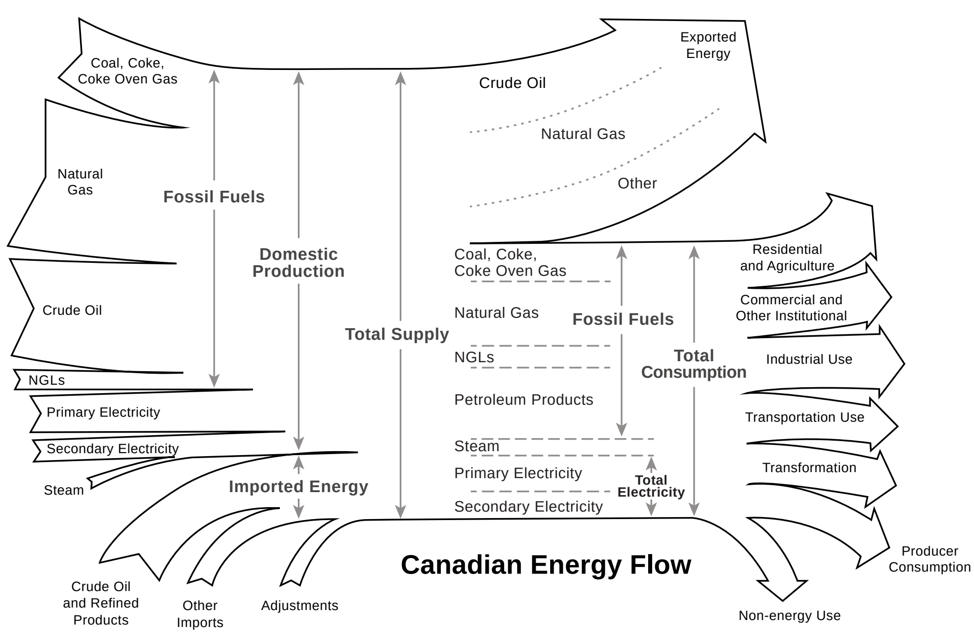


Table A4–2 Reference Approach Energy Contents and Emission Factors for Canada

Fuel Types			Energy Content, GCV			Carbon Emission Factor – 2019 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2019 Value	Unit	Reference				
Liquid	Primary Fuels	Crude Oil	39.5	TJ/ML	See Comments	18.83	Refer to Comments	1.0	Weighted energy content and emission factor are based on country-specific data.
		Ethane	17.22	TJ/ML	4	15.46	2	1.0	Total available ethane is consumed as a feedstock in industrial processes.
		Orimulsion	NA	–	–	NA	–	1.0	
		Natural Gas Liquids	25.34	TJ/ML	–	16.33	–	1.0	Propane and butane from natural gas liquids.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	1.0	Use of asphalt.
		Gas/Diesel Oil	38.35	TJ/ML	4	19.07	2	1.0	Use of diesel fuel oil.
		Gasoline	33.45	TJ/ML	4	18.81	2	1.0	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	27.13	TJ/ML	4	16.59	2	1.0	Country-specific weighted factors for propane and butane from petroleum refineries.
		Lubricants	39.16	TJ/ML	4	19.66	3	1.0	
		Naphtha	35.17	TJ/ML	4	19.33	3	1.0	
		Other Kerosene	37.68	TJ/ML	4	18.53	2	1.0	
		Other Oil	38.8	TJ/ML	4	19.15	2	1.0	Use of light fuel oil.
		Petroleum Coke	44.95	TJ/ML	4	22.23	4	1.0	Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil).
		Refinery Feedstocks	35.17	TJ/ML	4	19.33	3	1.0	Use of petrochemical feedstock in industrial processes
		Residual Fuel Oil	42.5	TJ/ML	4	20.27	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas	40.98	TJ/ML	4	14.74	4	1.0	Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.24	3	1.0	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	
Solid	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.45	3	0.988	
		Other Bituminous Coal	28.37	TJ/kt	4	22.04	6	0.995	Use of Canadian bituminous coal
		Sub-bituminous Coal	18.48	TJ/kt	4	26.00	6	0.994	
		Lignite	16.29	TJ/kt	4	24.39	5, 6	0.996	
		Oil Shale	NA	–	–	NA	–	–	
		Peat	NA	–	–	NA	–	–	
	Secondary Fuels	Coke	28.83	TJ/kt	4	30.02	2	1.0	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	
		Coke Oven Gas	19.14	TJ/GL	4	12.52	2	–	
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.54	5, 6	0.989	
Gaseous	Primary Fuels	Natural Gas	39.86	TJ/GL	4	13.45	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Municipal Solid Waste	–	–	1	23.94	1	1.0	1) Consists of biomass combustion, for energy purposes, at landfills.
		Solid Biomass	17.87	TJ/kt	4	24.81	7	1.0	1) Consists of industrial and residential biomass consumption.
		Liquid Biomass	16.34	TJ/kt	4	18.82	3, 8	1.0	1) Consists of spent pulping liquor, ethanol and biodiesel.
		Gas Biomass	36.35	TJ/Gl	1	13.54	1	1.0	1) Consists of methane from landfill gas.

Notes:

References – (1) IPCC (2006); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2015 data); (5) ECCC (2016); (6) ECCC (2019); (7) US EPA (2003); (8) ICFPA/NCASI (2019).

NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

The following quality criteria are essential to the development of the RESD as set out by Statistics Canada: relevance, accuracy and reliability, timeliness and punctuality, accessibility and clarity, coherence and comparability, and interpretability and metadata.

There are also other internal data quality checks of the information collected through provincial energy departments and various supply, disposition and consumption surveys. For example, the quantities of crude oil reported by the producer are compared to reported receipts from pipeline companies, and the volume data reported by pipelines is verified against refinery receipts. EESD also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy (ICE) survey to verify the quality of the data for manufacturing industries. The ICE survey collects fuel consumption data directly from manufacturing industries following the North American Industry Classification System. In addition, an annual Survey of Secondary Distributors of Refined Petroleum Products (SSDRPP) collects data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel, biodiesel blended diesel fuel, and ethanol blended gasoline to the appropriate consuming sectors. The SSDRPP survey was necessary due to the deregulation of allowable sales of these products from only primary producers (refineries) to include secondary resellers/distributers. Prior to this improvement, fuel volumes reported in the commercial sector incorrectly included all sales by refineries to secondary distributors. The deregulation of the sale of these four fuels started around the year 2000. A consistent approach was applied to the historical dataset to address the misallocated fuel volumes between 2000 and 2008 since the SSD only started collecting sale volumes from 2009 onward.

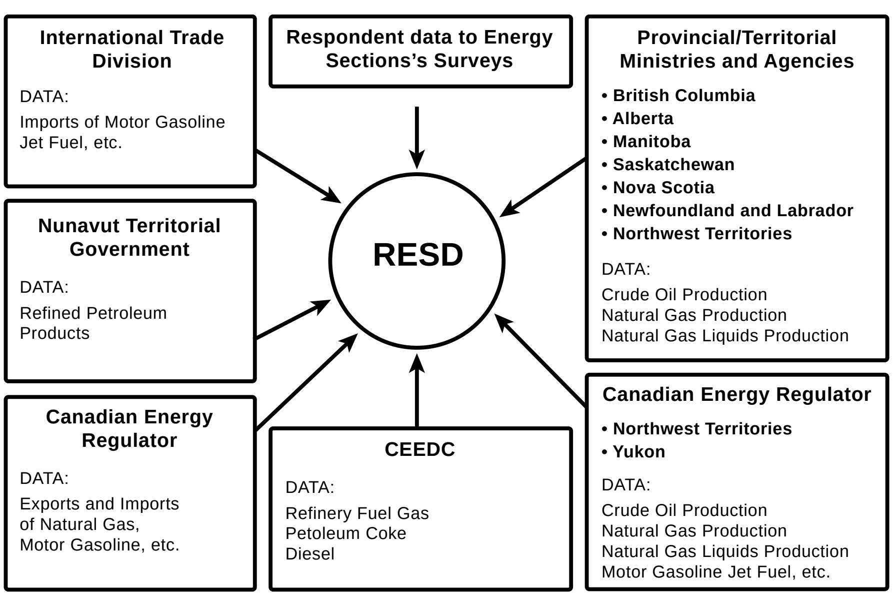
Also, as part of EESD's quality framework, an annual "work-in-progress" review has been established with Environment and Climate Change Canada and Natural Resources Canada to review the ICE estimates and the RESD prior to their official release. Industrial stakeholders also participate in the review of ICE data through the Canadian Industry Program for Energy Conservation group. CEEDC also participates in the review of refinery data and the industrial energy statistics.

A4.4. CRF Implied Emission Factors

The CRF reporting software generates implied emission factors (IEFs) which are used by UNFCCC expert reviewers as an initial check for possible outliers. There is merit in the use of IEF checks, especially for a direct comparison of the same commercial fuel between countries, since each of these fuels meets standardized specifications for quality and composition, with an accepted range of carbon content and heating value. Commercial fuels like motor gasoline, diesel and light fuel oil have similar specifications globally, resulting in IEFs that differ by only a few percentage points. However, the percentage difference for fuels like non-marketable (raw) natural gas, crude oil or coal (i.e. bituminous, sub-bituminous, etc.) can vary greatly due to differences in local geology, deposits or fuel categorizations (the latter being especially true in the case of coal).

These checks for IEF outliers are less reliable when fuels are grouped as solid, liquid, gaseous and biomass in CRF Tables 1A1 to Table 1A4. For countries consuming both

Figure A4–2 **Fossil Fuel and Energy Data Input into the RESD**



commercial and non-commercial fuels, and particularly for energy producing nations where non-commercial/non-marketable fuels are readily available and consumed in significant quantities, IEF checks can result in more outliers for certain sectors and fuel groupings (i.e. gaseous and liquid fuels). Generally, countries with large primary energy production (crude oil, synthetic oil, natural gas, etc.) will consume a greater proportion of non-commercial fuels compared to countries with little or no primary energy production and who mostly consume commercial fuels. For these situations, recognizing the impact on IEFs of national circumstances by either increasing its range or conducting IEF checks on a fuel by fuel basis would provide more relevant quality checks.

In Canada's case, shifting the focus of IEF checks from groups of fuels to individual fuels allows a better understanding of their influence on the generation of outliers.

- It allows for an appreciation of the relative proportion of commercial and non-commercial fuel consumed within each fuel grouping.
- It demonstrates how the mix of commercial and non-commercial fuels with wide ranging carbon and energy densities affects the IEF for each fuel.

For example, Canada's implied emission factors can be relatively high for liquid fuels due to the combustion of significant quantities of crude oil, petroleum coke and still gas. In the case of gaseous fuels IEFs can also be high, a result of certain energy producers consuming large quantities of non-marketable natural gas.

Information presented in Table A4–2, illustrates the range of carbon content between each group of fuels, and where even within the group of commercial secondary liquid fuels, the carbon content ranges from 14.74 to 22.62 t C/TJ. For CRF categories consuming a greater portion of still gas or petroleum coke (refinery and upgrader fuels) relative to commercial grade refined petroleum products, the overall IEF for liquid fuels will appear to be an outlier since it will be higher than international averages.

As Canada is a country producing large quantities of fossil fuels, the following categories will most likely generate IEF outliers; 1A1b Petroleum Refining, 1A1ci Manufacture of Solid Fuels, and 1A1cii Oil and Gas Extraction. As mentioned, IEF category checks should be on a fuel by fuel basis or by assessing Parties that have a similar industry makeup; this would generate more comparable results and analysis.

ASSESSMENT OF COMPLETENESS

Overall, this inventory report serves as a comprehensive assessment of anthropogenic greenhouse gas (GHG) emissions and removals in Canada. However, emissions for some categories are not estimated (NE) or have been included elsewhere (IE) with other categories for reasons explained in Table A5–1 and Table A5–2. These tables are consistent with Table 9 (Completeness – Information on Notation Keys), for the latest year of the Common Reporting Format (CRF) tables available online here:

https://unfccc.int/ghg-inventories-annex-i-parties/2021

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated**

GHG	Sector	Source/Sink Category	Explanation
$C_{10}F_{18}$	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_2F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_3F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_4F_{10}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_5F_{12}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_6F_{14}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
CF_4	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock / Other (please specify) / Fur-bearing Animals	No default emission factors available for Fox and Mink.
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock / Other (please specify) / Rabbit	No default emission factors available for Rabbit.
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock/Poultry	No default emission factor available for Poultry.
CH_4	Agriculture	3.D Agricultural Soils	Methane emissions from agricultural soils are not estimated because no methodology is available in the 2006 IPCC Guidelines.
CH_4	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
CH_4	Industrial Processes and Product Use	2.B Chemical Industry / 2.B.1 Ammonia Production	CH_4 emissions assumed negligible.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable; CH_4 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 14.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	CH_4 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CH_4 emissions from this category are assumed to be negligible.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Mineral Soils / Rewetted Mineral Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Drained Organic Soils	There is no guidance in 2006 IPCC guidelines to report CH_4 emissions from drained organic soils in Cropland.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Rewetted Organic Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CH_4	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
CH_4	LULUCF	4.E Settlements / 4.E.1 Settlements Remaining Settlements	Currently neither country-specific activity data is available nor methodology exists to estimate this source category.
CH_4	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CH_4	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CH_4	Waste	5.D Wastewater Treatment and Discharge / 5.D.1 Domestic Wastewater	Not available at this time.
CO_2	Agriculture		CO_2 emissions from indirect sources of non-agricultural origin are not estimated.
CO_2	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
CO_2	Industrial Processes and Product Use	2.A Mineral Industry / 2.A.4 Other Process Uses of Carbonates / 2.A.4.a Ceramics	Emission considered insignificant as defined in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.
CO_2	Industrial Processes and Product Use	2.B Chemical Industry / 2.B.6 Titanium Dioxide Production	Based on a study conducted in 2010, CO_2 emissions from this facility's chloride process is very small, less than 0.01% of the national level, and is therefore considered insignificant (level for insignificance is below 0.05% of national total and below 50.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable; CO_2 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 29.

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Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	Only aggregated CO_2 emissions are included under 2.D.3.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	CO_2 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CO_2 emissions from this category are assumed to be negligible.
CO_2	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Mineral Soils / Rewetted Mineral Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Rewetted Organic Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
CO_2	LULUCF	4.G Harvested Wood Products / Approach B / Information Item / HWP in SWDS	Country-specific information on wood and paper waste in solid waste disposal sites is currently unavailable.
CO_2	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CO_2	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CO_2	Waste	5.F Memo Items / 5.F.1 Long-term Storage of C in Waste Disposal Sites	Work is ongoing to incorporate long term storage of C in waste disposal sites.
CO_2	Waste	5.F Memo Items / 5.F.2 Annual Change in Total Long-term C Storage	Work is ongoing to incorporate long term storage of C in waste disposal sites.
CO_2	Waste	5.F Memo Items / 5.F.3 Annual Change in Total Long-term C Storage in HWP Waste	Work is ongoing to incorporate long term storage of C in waste disposal sites.
N_2O	Agriculture		N_2O emissions from indirect sources of non-agricultural origin are not estimated.
N_2O	Agriculture	3.D Agricultural Soils / 3.D.1 Direct N_2O Emissions From Managed Soils / 3.D.1.2 Organic N Fertilizers / 3.D.1.2.c Other Organic Fertilizers Applied to Soils	The amount of N in Other Organic Fertilizers Applied to Soils is not available.
N_2O	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
N_2O	LULUCF		N_2O emissions from indirect sources of non-agricultural and non-LULUCF origin are not estimated as country-specific information is currently not available.
N_2O	LULUCF	4.A Forest Land 4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization	Direct N_2O emissions associated with loss of soil organic matter in FLFL are not considered to be significant.
N_2O	LULUCF	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.A.2.1 Cropland converted to forest land	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.

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Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
N_2O	LULUCF	4.C Grassland 4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization	Management-induced changes in soil organic carbon from GLGL are not available because country-specific activity data is currently unavailable for the time series.
N_2O	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
N_2O	LULUCF	4.E Settlements 4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(III) Direct N_2O Emissions from N Mineralization/ Immobilization	Emissions of N_2O from urban trees are not reported as country-specific information on net carbon stock change in soils is not currently available.
N_2O	LULUCF	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.E.2.1 Forest land converted to settlements	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.
N_2O	LULUCF	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.E.2.3 Grassland converted to settlements	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.
N_2O	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
N_2O	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
N_2O	Waste	5.D Wastewater Treatment and Discharge / 5.D.2 Industrial Wastewater	There is no methodology provided in the 2006 GL for N_2O emissions from industrial wastewater where there is primary discharge.
SF_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
Unspecified mix of PFCs	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
c-C_3F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
c-C_4F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).

Note:
"Not Estimated" includes sources and sinks which are considered in the 2006 IPCC Guidelines (IPCC, 2006) but are not considered in this inventory.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere**

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG)	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.a Coal Mining and Handling / 1.B.1.a.1 Underground Mines / 1.B.1.a.1.ii Post-Mining Activities	1.B.1.a.1.ii Underground Mines – Mining Activities	1.B.1.a.1.i Underground Mines – Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.a Coal Mining and Handling / 1.B.1.a.2 Surface Mines / 1.B.1.a.2.ii Post-Mining Activities	1.B.1.a.2.ii Surface Mines – Post-Mining Activities	1.B.1.a.2.i Surface Mines – Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.1 Exploration	1.B.2.a.1 Oil – Exploration	1.B.2.a.2 Oil – Production	Only aggregated data were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil – Distribution of Oil Products	1.B.2.a.3 Oil – Transport	Only aggregated data were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.b Natural Gas / 1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas – Exploration	1.B.2.b.2 Natural Gas – Production	Only aggregated data were available.
CH_4	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b. Ethylene	Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Methanol Production – N_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.a Steel	2.C.1.a	2.C.1.b Pig Iron	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.d Sinter	2.C.1.d	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.e Pellet	2.C.1.e	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.2 Ferroalloys Production	2.C.2	2.C.1.b	Disaggregated data currently not available.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.8	Only aggregated CO_2 emissions are included under 2.D.3.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregate data are unavailable.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are unavailable.
CH_4	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CH_4	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and mineral soils.
CH_4	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Wildfires / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.E Settlements / 4.E.2 Land Converted to Settlements	Table 4, if possible to differentiate	Table 4(V)	Emissions of CH_4 are reported in Table 4(V) Biomass Burning.
CH_4	5.B Biological Treatment of Solid Waste / 5.B.1 Composting / 5.B.1.b Other (please specify)	Included under 5.b.1.a as a single value.	Included under 5.b.1.a as a single value.	Included under 5.b.1.a as a single value.
CH_4	5.B Biological Treatment of Solid Waste / 5.B.2 Anaerobic Digestion at Biogas Facilities / 5.B.2.a Municipal Solid Waste		Included under 5.b.1.a as a single value.	
CH_4	5.B Biological Treatment of Solid Waste / 5.B.2 Anaerobic Digestion at Biogas Facilities / 5.B.2.b Other (please specify)	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.
CO_2	3.G Liming / 3.G.2 Dolomite $CaMg(CO_3)2$	3.G.1 Limestone $CaCO_3$	3.G.1 Limestone $CaCO_3$	Dolomite is included in Limestone.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG)	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.1 Exploration	1.B.2.a.1 Oil – Exploration	1.B.2.a.2 Oil – Production	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil – Distribution of Oil Products	1.B.2.a.3 Oil – Transport	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.b Natural Gas / 1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas – Exploration	1.B.2.b.2 Natural Gas – Production	Only aggregated data were available.
CO_2	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b. Ethylene	Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Methanol Production – N_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black2.B.8.f	2.D.3 Other – Other and Undifferentiated	CO_2 emission from category 2.D are estimated based on non-energy fuel use by fuel / feedstock type and not by industrial activity (refer to Annex 3, Section A.3.3.3 for further detail).

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.D.3 Other and Undifferentiated	Refer to 2.D.3 Other and Undifferentiated. Disaggregated data currently not available.
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.g Other / Other (please specify) / Styrene	2.B.8.g Other	2.D.3 Other – Other and Undifferentiated	Disaggregated data currently not available
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.g Other / Other (please specify) / Styrene	Other (please specify) / Styrene	2.D.3 Other – Other and Undifferentiated.	Other (please specify) / Styrene.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.d Sinter	2.C.1.d	1.A.2.a, 2.D.28	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.e Pellet	2.C.1.e	1.A.2.a, 2.D.23	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.2 Ferroalloys Production	2.C.2	2.C.1.a and 2.C.1.b	Emissions from Ferroalloy Production are included in Steel Production (2C1a) since it is a direct production of specialty steels from iron ore via EAF process using reductants. However, the reductant portion is not disaggregated in Statistics Canada's Rep.
CO_2	2.C Metal Industry / 2.C.5 Lead Production	2.C.5	2.D.3	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.6 Zinc Production	2.C.6	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.1 Lubricant Use	2.D.3	2.D.3	2D3 disaggregated data unavailable.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.1 Lubricant Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.2 Paraffin Wax Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are currently unavailable.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are unavailable.
CO_2	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CO_2	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Drained Organic Soils	If data are available, under the specific LULUC category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUC category.
CO_2	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CO_2	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CO_2	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CO_2	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	3.D Agricultural Soils / 3.D.1 Direct N_2O Emissions From Managed Soils / 3.D.1.7 Other	Not present in the IPCC 2006 Guidelines	3.D.1.1 Inorganic N Fertilizers / 3.D.1.2.a Animal Manure Applied to Soils / 3.D.1.4 Crop Residues	Three country-specific sources / removals of N_2O (conservation tillage, summerfallow and irrigation) are reported with emissions from agricultural soils under 3.D.1.1, 3.D.1.2.a, 3.D.1.2.b and 3.D.1.4. As a result of limitations with the current CRF Reporter Software, it is not currently possible to report these country-specific source / sink categories individually.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG)	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.10	Only aggregated CO_2 emissions are included under 2.D.3.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.8	Only aggregated CO_2 emissions are included under 2.D.3.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregate data are unavailable.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Atmospheric Deposition	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture sector. N_2O emissions associated with nitrogen leaching ad runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Nitrogen Leaching and Run-off	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture sector. N_2O emissions associated with nitrogen leaching ad runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available does do not allow the disaggregation of activity into the specific LULUCF category.
N_2O	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
N_2O	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and mineral soils.
N_2O	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Wildfires / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.D Wetlands / 4.D.1 Wetlands Remaining Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization 4.D Wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II). Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands / 4.D.2 Land Converted to Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.D.2.1 Forest land converted to wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands / 4.D.2 Land Converted to Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.D.2.5 Other land converted to wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUCF category.
N_2O	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUCF category.
SF_6	2.C Metal Industry / 2.C.7 Other (please specify)	2.C.7	2.C.4	SF_6 emissions for Mg Casting were included in 2.C.4 as per IPCC guidelines and ERT recommendations.
SF_6	2.G Other Product Manufacture and Use / 2.G.1 Electrical Equipment / SF_6	2.G.1 disaggregated from stocks and from disposal	2.G.1 Electrical Equipment / SF_6 (from stocks)	disaggregation from stocks and from disposal data is not available and the total is reported as "from stocks."

Note:
"Included Elsewhere" includes sources and sinks in this inventory that are allocated to a sector other than that indicated by the 2006 IPCC Guidelines (IPCC, 2006).

A5

ANNEX 6

EMISSION FACTORS

This annex summarizes the development and selection of emission factors used to estimate Canada's annual greenhouse gas (GHG) inventory. Details[1] on sector-specific methodological use of these factors are presented in Annex 3.

A6.1. Fuel Combustion

A6.1.1. Natural Gas and Natural Gas Liquids

A6.1.1.1. Carbon Dioxide (CO_2)

CO_2 emission factors for fossil fuel combustion depend primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two principal fuel types combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). There are regional variations in marketable and non-marketable natural gas use, with nine regions consuming marketable fuel and seven regions consuming non-marketable fuel. Provincial and territorial emission factors (Table A6.1–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann, 2000). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis. Generally, non-marketable natural gas emission factors are higher than those of marketable fuels as a result of their raw/unprocess nature; in addition to methane, non-marketable natural gas may include ethane, propane and butane in the fuel mix.

Non-marketable natural gas emission factors for Alberta (Table A6.1–2) were updated using over 400 000 raw gas samples, ranging in date from 1913 to 2016, obtained from the Alberta Energy Regulator (AER) by the Energy and Emissions Research Laboratory (EERL) of Carleton University (EERL, 2020). EERL compiled and analysed the data to provide average gas compositions by township. Gas composition data by township were weighted by township-level fuel gas consumption volumes obtained from Petrinex in 2020, to produce annual average CO_2 emission factors for the province.

CO_2 emission factors (Table A6.1–4) for natural gas liquids (NGL), such as ethane, propane and butane, were developed based on chemical analysis data for marketable fuels (McCann, 2000).

A6.1.1.2. Methane (CH_4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6.1–3 and Table A6.1–4) have been developed based on technologies typically used in Canada. The factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy, 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP, 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (U.S. EPA, 1996).

Table A6.1–1 **CO_2 Emission Factors for Natural Gas**

Province	Emission Factor[a] (g/m^3)	
	Marketable[b]	Non-Marketable[c]
NL	1 901	2 494
NS	1 901	2 494
NB	1 901	NO
QC	1 887	NO
ON	1 888	NO
MB	1 886	NO
SK	1 829	2 441
AB	1 928	See NIR Table A6.1–2
BC	1 926	2 162
YK	1 901	2 401
NT (prior to 2012)[d]	2 466	2 466
NT (since 2012)[d]	1 901	2 466

Notes:

NO = Not occurring

a. McCann (2000)
b. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing Industries, Residential/Commercial and Transport subsectors.
c. The term "non-marketable" applies to raw/unprocessed gas consumption, mainly by natural gas producers.
d. Prior to 2012, natural gas consumption was locally-produced non-marketable natural gas. Since 2012, marketable natural gas has been imported from outside the territory.

1 For details, see the *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada* online: http://www.publications.gc.ca/pub?id=9.506002&sl=0.

Table A6.1–2 **Alberta CO_2 Emission Factors for Non-Marketable Natural Gas**

Year(s)	Emission Factor (g/m^3)
1990 to 2009	2 080
2010	2 054
2011	2 062
2012	2 068
2013	2 071
2014	2 075
2015	2 081
2016	2 089
2017	2 093
2018	2 102
2019	2 107

Note: Adapted from EERL (2020) using Petrinex (2020) volumetric data

Table A6.1–3 **CH_4 and N_2O Emission Factors for Natural Gas**

Source	Emission Factor (g/m^3)[a]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[b]	0.060
Pipelines	1.900	0.050
Cement	0.037	0.034
Manufacturing Industries	0.037	0.033
Residential, Construction, Commercial/Institutional, Agriculture	0.037	0.035

Notes:

a. SGA Energy (2000)

b. Adapted from U.S. EPA (1996) and CAPP (1999)

Table A6.1–4 **Emission Factors for Natural Gas Liquids**

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[a]	0.027[b]	0.108[b]
All Other Uses	1 515[a]	0.024[b]	0.108[b]
Ethane	986[a]	0.024[b]	0.108[b]
Butane	1 747[a]	0.024[b]	0.108[b]

Notes:

a. McCann (2000)

b. SGA Energy (2000)

A6.1.1.3. Nitrous Oxide (N_2O)

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A6.1–3 and Table A6.1–4) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

A6.1.2. Refined Petroleum Products

A6.1.2.1. CO_2

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Emission factors have been developed for each major class of refined petroleum products (RPP) based on their heating value, carbon content and density (McCann, 2000), to ensure consistency with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006).

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A6.1–6) have been developed using emissions and energy content data provided by industry to the Canadian Energy and Emissions Data Centre (CEEDC).[2] The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors.

Emission factors for still gas (Table A6.1–6) from refining operations and upgrading facilities were also derived from data provided by industry and reported by CEEDC.

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6.1–5) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities.

The emission factor for still gas from upgraders (Table A6.1–5) was based on the 2006 IPCC default emission factor and was adapted using energy conversion factors published by Statistics Canada (2014). The still gas emission factors for refineries and other industries (Table A6.1–8) were based on the 2006 IPCC default emission factor, which was calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

2 Griffin, B. 2020. Personal communication (email from Griffin, B., CEEDC to Tracey, K., Program Engineer, PIRD dated September 25, 2020). Canadian Energy and Emissions Data Centre (CEEDC).

A6.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for RPP, with the exception of petroleum coke, have been developed (Table A6.1–5) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Emission factors for petroleum coke (Table A6.1–7) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

Table A6.1–5 **Emission Factors for Refined Petroleum Products**

Source	Emission Factor (g/L)		
	CO_2[a]	CH_4[b]	N_2O[b]
Light Fuel Oil			
Electric Utilities	2 753	0.18	0.031
Industrial	2 753	0.006	0.031
Producer Consumption	2 670	0.006	0.031
Residential	2 753	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 753	0.026	0.031
Heavy Fuel Oil			
Electric Utilities	3 156	0.034	0.064
Industrial	3 156	0.12	0.064
Producer Consumption	3 190	0.12	0.064
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 156	0.057	0.064
Kerosene			
Electric Utilities	2 560[c]	0.006	0.031
Industrial	2 560[c]	0.006	0.031
Producer Consumption	2 560[c]	0.006	0.031
Residential	2 560[c]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[c]	0.026	0.031
Diesel – Refineries and Others[d]	2 681	0.078	0.022
Diesel – Upgraders[d]	2 681	0.078	0.022
Petroleum Coke	See Table A6.1–6	0.12	See Table A6.1–7
Still Gas – Refineries and Others	See Table A6.1–6	See Table A6.1–8	0.00002
Still Gas – Upgraders	See Table A6.1–6	0.000039	0.00002
Motor Gasoline[e]	2 307	0.100	0.02

Notes:

a. McCann (2000); except Kerosene, Diesel and Motor Gasoline

b. SGA Energy (2000); except Diesel and Motor Gasoline

c. Assumed McCann (2000) aviation turbo-fuel emission factor

d. CO_2 from ECCC (2017b); CH_4 and N_2O from Oak Leaf Environmental Inc. (2017)

e. CO_2 from ECCC (2017b); CH_4 and N_2O adapted from IPCC (2006)

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Table A6.1–6 **CO_2 Emission Factors for Petroleum Coke and Still Gas**

	Emission Factor																	
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Petroleum Coke	g/L																	
Upgrading Facilities[a]	3 556	3 551	3 481	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494
Refineries and Others[b]	3 766	3 790	3 706	3 767	3 778	3 806	3 829	3 836	3 853	3 812	3 828	3 801	3 725	3 749	3 753	3 776	3 737	3 761
Still Gas	$g/10^3m^3$																	
Upgrading Facilities[a]	2 310	2 090	2 120	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140
Refineries and Others[b]	1 740	1 800	1 680	1 707	1 741	1 749	1 690	1 711	1 825	1 818	1 718	1 738	1 741	1 762	1 781	1 796	1 847	1 797

Notes:

a. CEEDC (2003)

b. Griffin B. 2020. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 25, 2020). Canadian Emissions and Energy Data Centre.

Table A6.1–7 **N_2O Emission Factors for Petroleum Coke**

	Emission Factor											
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001–2019
Petroleum Coke	g/m³											
Upgrading Facilities[a, b]	21.9	22.1	22.3	22.5	22.7	22.7	22.7	23.0	23.5	23.7	24.2	24.0
Refineries and Others[a, b]	24.6	24.8	25.0	25.2	25.5	25.5	25.4	25.8	27.0	27.1	27.6	27.5

Notes:

a. Adapted from IPCC (2006)

b. Energy content from Statistics Canada (2014)

Table A6.1–8 **CH_4 Emission Factors for Still Gas (Refineries and Others)**

	Emission Factor[a]																	
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Still Gas	g/m³																	
Refineries and Others[a]	0.033	0.033	0.034	0.032	0.032	0.032	0.032	0.032	0.032	0.033	0.031	0.031	0.031	0.033	0.032	0.033	0.032	0.032

Note:

a. Adapted from IPCC (2006) using energy content taken from Griffin B. 2019. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 26, 2019). Canadian Emissions and Energy Data Centre.

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A6.1.3. Coal and Coal Products

A6.1.3.1. CO_2

CO_2 emission factors for coal combustion depend largely on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A6.1–9) were developed for each province on the basis of the rank of the coal and the region of supply. Emission factors were based on data from chemical analysis of coal samples for electric utilities, which account for the vast majority of coal consumption.

Some factors for Canadian bituminous coal presented in Table A6.1–9 were developed based on a statistical analysis, by ECCC (Radovan et al., 2012), of over 3000 analytical samples for a variety of coal types and producing/consuming regions. The analysis and uncertainty calculations were conducted using the @Risk software package. The coal emission factors are presented with uncertainty estimates, since the supply and quality of coal can vary over time. The average coal carbon and moisture content for each coal type was used to develop CO_2 emission factors.

An additional study to determine country-specific coal oxidation factors and further investigate the carbon content of coal burned at electric generation facilities was conducted for ECCC by GHD Limited in 2016 (ECCC, 2017a). Based on an analysis of this study and Radovan et al. (2012), updated emission and oxidation factors as well as uncertainty estimates for many coal-types have been determined (ECCC, 2019).

Factors for anthracite imported from the United States are from Annex 2 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (U.S. EPA, 2010). All coal emission factors in Table A6.1–9 now incorporate Canada-specific oxidation factors (ECCC, 2017a).

Coke and coke oven gas emission factors are presented in Table A6.1–10. The coke emission factor was developed from an iron and steel industry study completed in 2014 (CRA, 2014). It is representative of coke use in the cement, non-ferrous metal and other manufacturing industries. The coke oven gas emission-factor value is from McCann (2000) and represents use in the iron and steel industry.

A6.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–11) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–11) have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Table A6.1–9 **CO_2 Emission Factors for Coal**

Province	Coal Type	Source	Emission Factor (kg CO_2 / tonne)[a, b, c, d]			Moisture (wt %)
			Mean	Uncertainty (95% CI)		
				Low	High	
NL, PEI (Prior to 2000)	Canadian Bituminous[b]	NS	2 315	-33%	22%	3.2
NL, PEI (2000 onward)	Canadian Bituminous[b]	AB	2 185	-26%	26%	7.7
QC (Prior to 2000)	Canadian Bituminous[b]	NS	2 329	-33%	22%	3.2
QC (2000 onward)	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
NS	Canadian Bituminous[b]	NS	2 329	-33%	22%	3.2
NB (Prior to 2010)	Canadian Bituminous[b]	NB	2 319	-14%	14%	3.2
NB (2010 on)	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
ON, AB, SK, BC	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
NB, NS, PEI and NL	Foreign Bituminous[b]	Non-U.S.	2 540	-7%	7%	8.3
ON, MB	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 651	-7%	7%	N/A
QC, AB, BC	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 662	-7%	7%	N/A
All Provinces and Territories, except SK	Lignite[c]	SK	1 462	-13%	13%	24
SK	Lignite[c]	SK	1 457	-13%	13%	36
QC, ON, MB, NB, NS, PEI	Sub-bituminous[c]	Foreign	1 865	-8%	8%	24
AB, SK, BC	Sub-bituminous[c]	AB	1 763	-11%	11%	21
All Provinces and Territories	Anthracite	--	2 382	-6%	6%	N/A

Notes:

N/A = Not available

a. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
b. Carbon content, Radovan et al. (2012), oxidation factor, ECCC (2019).
c. Carbon content and oxidation factor, ECCC (2019).
d. 95 % Confidence Intervals, which were determined through statistical analysis of Canadian coal data.

Table A6.1–10 **CO_2 Emission Factors for Coal Products**

Coal Product – Fuel Type	Emission Factor
Coke Oven Gas[a]	687 g/m^3
Coke[b]	3 173 g/kg

Notes:
a. McCann (2000)
b. CRA (2014)

Table A6.1–11 **CH_4 and N_2O Emission Factors for Coal**

Source	Emission Factor	
	CH_4	N_2O
	g/kg	
Coal		
Electric Utilities	0.02	0.03
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4.00	0.02
Coke	**0.03**	**0.02**
	g/m^3	
Coke Oven Gas	**0.04**	**0.04**

Note: Source – SGA Energy (2000)

A6.1.4. Fugitive Emission Factors for Coal Mining

The factors in Table A6.1–12 are for fugitive emissions from coal mining only. Although derived from measurements at individual mines or coal seams, these emission factors are aggregated and weighted, province-wide averages for a given mine type. These weighted emission factors are updated yearly account for the change in production of particular coal types, at individual mines. They should be applied to total gross (not net) quantities of coal mined which includes small quantities of minerals, stone and other inert materials mined with the coal, but later removed before sale or consumption.

Table A6.1–12 **Fugitive Emission Factors for Coal Mining**

Area	Coal Type	Mine Type	Emission Factor	Units
NS	Bituminous	Surface	0.07	t CH_4/kt coal mined
NS	Bituminous	Underground	14.5	t CH_4/kt coal mined
NS	Bituminous	Surface	0.07	t CH_4/kt coal mined
SK	Lignite	Surface	0.07	t CH_4/kt coal mined
AB	Bituminous	Surface	0.53	t CH_4/kt coal mined
AB	Bituminous	Underground	1.69	t CH_4/kt coal mined
AB	Sub-bituminous	Surface	0.24	t CH_4/kt coal mined
BC	Bituminous	Surface	0.93	t CH_4/kt coal mined
BC	Bituminous	Underground	2.78	t CH_4/kt coal mined

Note: Adapted from King (1994), and Cheminfo and Clearstone Engineering Ltd (2014).

A6.1.5. Other Fuels

A6.1.5.1. CO_2

Alternative fuels such as tires, refuse, and waste oil and solvents are used in the cement industry to offset combustion of purchased fuels like coal, oil or natural gas. CO_2 emissions associated with the stationary combustion of waste fuels are included in the National Inventory Report where data are available. Fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD, 2005), were used to generate the emission factors in Table A6.1–13.

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.5.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC, 2006).

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.5.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC, 2006).

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.6. Mobile Combustion

A6.1.6.1. CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

A6.1.6.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Mode-specific CH_4 emission factors have been developed based on technologies typically used in Canada, and are summarized in Table A6.1–14. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. A number of on-road CH_4 emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al., 2008).

Table A6.1–13 **Emission Factors for Alternative Fuels**

Source/Fuel	GHG	Emission Factor (kg/GJ)												
		1990–1994	1995–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011–2019
Cement Industry Waste Fuel	CO_2[a]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1	81.5
	CH_4[b]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	N_2O[b]	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

Notes:

a. Adapted from WBSCD (2005)

b. Adapted from IPCC (2006)

Table A6.1–14 Emission Factors for Energy Mobile Combustion Sources

Mode†	Emission Factors (g/L fuel)		
	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.23 [e]	0.47 [e]
Tier 0	2 307.3 [a]	0.32 [f]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.52 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.46 [h]	0.028 [f]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.24 [e]	0.58 [e]
Tier 0	2 307.3 [a]	0.21 [h]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.43 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.56 [f]	0.028 [f]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 307.3 [a]	0.068 [h]	0.20 [h]
Non-catalytic Controlled	2 307.3 [a]	0.29 [f]	0.047 [f]
Uncontrolled	2 307.3 [a]	0.49 [f]	0.084 [f]
Motorcycles			
Non-catalytic Controlled	2 307.3 [a]	0.77 [c]	0.041 [c]
Uncontrolled	2 307.3 [a]	2.3 [f]	0.048 [f]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 680.50 [a]	0.051 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.10 [f]	0.16 [f]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 680.50 [a]	0.068 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.085 [f]	0.16 [f]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 680.50 [a]	0.11 [i]	0.151 [i]
Moderate Control	2 680.50 [a]	0.14 [f]	0.082 [f]
Uncontrolled	2 680.50 [a]	0.15 [f]	0.075 [f]
Natural Gas Vehicles	1.9 [b]	9E-03 [f]	6E-05 [f]
Propane Vehicles	1 515 [b]	0.64 [f]	0.028 [f]
Off-road			
Off-road Gasoline 2-stroke	2 307.3 [a]	10.61 [l]	0.013 [m]
Off-road Gasoine 4-stroke	2 307.3 [a]	5.08 [l]	0.064 [m]
Off-road Diesel <19kW	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 1–3	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 4	2 680.50 [a]	0.073 [l]	0.227 [l]
Off-road Natural Gas	1.9 [b]	0.0088 [f]	0.00006 [f]
Off-road Propane	1 515 [b]	0.64 [f]	0.087 [l]
Railways			
Diesel Train	2 680.50 [a]	0.149 [m]	1.029 [m]
Marine			
Gasoline	2 307.3 [a]	0.21931 [m]	0.06266 [m]
Diesel	2 680.50 [a]	0.25193 [m]	0.07198 [m]
Light Fuel Oil	2 753 [b]	0.2555 [m]	0.073 [m]
Heavy Fuel Oil	3 156 [b]	0.2856 [m]	0.0816 [m]
Kerosene	2 559.70 [p]	0.2471 [m]	0.0706 [m]
Aviation			
Aviation Gasoline	2 325.40 [j]	2.19 [j]	0.23 [j]
Aviation Turbo Fuel	2 559.70 [b]	0.029 [k]	0.0711 [m]
Renewable Fuels			
Ethanol	1 508.04 [a,n]	**	**
Biodiesel	2 472.2 [a, n, o]	***	***

Notes:

† In the context of Transportation Modes, Tiers refer to increasingly stringent emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies.

* Advanced control diesel emission factors are used for Tier 2 diesel vehicle populations.

** Gasoline CH_4 and N_2O emission factors (by mode and technology) are used for ethanol.

*** Diesel CH_4 and N_2O emission factors (by mode and technology) are used for biodiesel.

a. ECCC (2017b)
b. McCann (2000)
c. Adapted from Environment Canada (2006)
d. Adapted from Environment Canada (2006) and Graham et al. (2009)
e. Adapted from Environment Canada (2009)
f. SGA Energy (2000)
g. Adapted from Barton & Simpson (1994)
h. ICF Consulting (2004)
i. Graham et al. (2008)
j. Jaques (1992)
k. National overall average emission factor for the whole time series based on 2006 IPCC Guidelines (IPCC 2006). Refer to section A3.1.4.2.3 of Annex 3.1 for further information.
l. Oak Leaf Environmental Inc (2017)
m. IPCC (2006) Converted into g/L using gross calorific value where necessary.
n. Refer to section 3.5.1 Chapter 3 for further information.
o. BioMer (2005)
p. Assumed McCann (2000) aviation turbo-fuel emission factor.

Over 50 aircraft-specific aviation turbo fuel CH_4 emission factors from the 2006 IPCC Guidelines (IPCC, 2006) are used in the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model – AGEM). Table A6.1–14 displays a national overall average implied emission factor (refer to section A3.4.2.3 for more information on AGEM).

A6.1.6.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Mode-specific N_2O emission factors have been developed based on technologies typically used in Canada. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. A number of on-road N_2O emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada, 2006, 2009; Graham et al., 2008, 2009).

In particular, the updated test data highlighted the effect of high-sulphur gasoline on N_2O emission factors. Vehicles fuelled with high-sulphur gasoline for the majority of their useful lives generally emitted higher levels of N_2O than those run on low-sulphur gasoline (Environment Canada, 2009).

A6.2. Industrial Processes

A6.2.1. Mineral Products

Emission factors used to estimate emissions from the production and use of mineral products are listed in Table A6.2–1.

A6.2.2. Chemical Industry

Table A6.2–2, Table A6.2–3, Table A6.2–4 and Table A6.2–5 present the emission factors used for categories included under the Chemical Industry subsector, as well as the sources from which these factors were obtained.

Table A6.2–1 **Range of Carbon Dioxide (CO_2) Emission Factors for Mineral Products**

Category	Mineral Product	Emission Factor (g CO_2 / kg of mineral product)
Cement Production	Clinker	521–533[a]
	Total Organic Carbon (TOC)	10.6–13.2[a]
Lime Production	High-Calcium Lime	751–754[b]
	Dolomitic lime	872–889[b]
Other Limestone and Dolomite Use	Limestone	418[c]
	Dolomite	468[c]
Other Uses of Soda Ash	Soda Ash	415[c]
Non-Metallurgical Magnesia Production	Magnesite	522[c]

Notes:
a. Range of year-specific emission factors provided by the Cement Association of Canada (CAC) (2015) and ECCC (2020).
b. Range of year-specific emission factors developed based on information from the Canadian Lime Institute (CLI) (2008) and ECCC (2020).
c. AMEC Earth & Environmental (2006)

Table A6.2–2 **Emission Factors for Ammonia Production**

	Average Ammonia-to-Feed Fuel Factor[a] m^3 natural gas / tonne of NH_3	Emission Factor g CO_2 / m^3 of natural gas	Emission Recovery Factor g CO_2 / kg of urea
Ammonia Production	671	Marketable natural gas emission factors found in NIR Table A6.1–1 are used.	728

Note:
a. Facility-specific fuel factors are used and these are confidential.

Table A6.2–3 N_2O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description[a]	N_2O Emission Factor (kg/t)
Nitric Acid Production	Dual-pressure plants with extended absorption “Type 2”	12[b]
	High-pressure plants with non-selective catalytic reduction	0.66[b]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	300[c]

Notes:

a. Emissions from a dual-pressure plant with extended absorption “Type 1” and a high-pressure plant with selective catalytic reduction are estimated using confidential plant-vendor emission factors. Emissions from these two plants after the installation of process-gas catalytic decomposition N_2O abatement systems are estimated using confidential plant-specific annual continuous emission monitoring systems (CEMS) data.

b. Collis G. 1992. *Estimates of Nitrous Oxide (N_2O) Emissions from Canadian Nitric Acid Industry*. Personal communication (letter from Collis G to Jaques A, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.

c. IPCC (2000)

Table A6.2–4 Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[a]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from CH_4 emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 emission factor to IPCC default Silicon Carbide CO_2 emission factor (i.e. 11.6 (kg CH_4 / t SiC) * (1.09 tCO_2 / $tCaC_2$ / 2.62 tCO_2 / tSiC))
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[b]
	0.032 kg N_2O / t product	Sector-wide weighted average[b]
Ethylene	0.039 kg CH_4 / t product	Sector-wide weighted average[b]
	0.0055 kg N_2O / t product	Sector-wide weighted average[b]
	0.411 t CO_2 / t product	Sector-wide weighted average[c]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[a]
Ethylene Oxide	0.5202 t CO_2 / t product	Sector-wide weighted average[b]
	1.79 kg CH_4 / t product	IPCC default[d]
Styrene	4 kg CH_4 / t product	IPCC default[a]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[b]
	0.010 kg N_2O / t product	Sector-wide weighted average[b]
	0.790 t CO_2 / t product	Sector-wide weighted average[c]
Other Uses of Urea	0.733 t CO_2 / t product	IPCC default[d]

Notes:

a. Default value from IPCC/OECD/IEA (1997)

b. Cheminfo Services (2010)

c. Cheminfo Services (2015); emission factors may vary if changes are made to the composition of feed.

d. IPCC (2006)

Table A6.2–5 Emission Factor for By-Product Emissions from Fluorochemical Production

Process	Emission Factor
HCFC-22 production	0.04 t HFC-23 emitted / t HCFC-22 produced[a]

Note:

a. IPCC (2006)

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Table A6.2–6 **Range of CO_2 Emission Factors for the Iron and Steel Industry**

Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.1–3.3[a]	t CO_2 / t (tonne) coke used
Electrode consumption in electric arc furnaces	4.5–7.8[b]	kg CO_2 / t steel
Electrode consumption in basic oxide furnaces	0.2–0.3[b]	kg CO_2 / t steel
Limestone use	418[c]	CO_2 / kg $CaCaO_3$
Dolomite use	468[c]	CO_2 / kg $MgCO_3$

Notes:

a. Range of year-specific emission factors provided in Cheminfo Services (2010) and ECCC (2020).

b. Provided by the Canadian Steel Producers Association and ECCC (2020). Chan K. (2009). Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

c. AMEC Earth & Environmental (2006)

A6.2.3. Metal Production

The range of the metallurgical coke emission factors and other parameters used for estimating emissions from Iron and Steel Production are found in Table A6.2–6, Table A6.2–7 and Table A6.2–8.

Tier 1-type emission factors for the category of Aluminium Production and the sources from which these emission factors were obtained are shown in Table A6.2–8.

Table A6.2–7 **Range of Carbon Contents for the Iron and Steel Industry**

Parameter	Carbon Contents (%)[a]
Pig iron (production of pig iron) from BFs and DRI plants	4.0–4.7
Pig iron (includes hot metal, cold iron, DRI and pig iron) for steel making	3.2–3.9
Crude steel produced in BOF	0.13
Crude steel produced in EAF	0.14–0.34
Scrap steel	0.1–0.7

Note:

a. Range of values from CSPA (2009) and ECCC (2020).

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Table A6.2–8 **Tier 1 Emission Factors for Aluminium Production**

Cell Technology Type	Emission Factors[a] (kg / t product)		
	CO_2	Carbon Tetrafluoride (CF_4)	Carbon Hexafluoride (C_2F_6)
Side-worked pre-baked	1 600	1.6	0.4
Centre-worked pre-baked	1 600	0.4	0.04
Horizontal stud Söderberg	1 700	0.4	0.03
Vertical stud Söderberg	1 700	0.8	0.04

Note:

a. International Aluminium Institute (IAI) (2006)

A6.2.4. Non-Energy Products from Fuels and Solvent Use

The use of fossil fuels as feedstock or for other non-energy use (NEU) may result in emissions during the life of manufactured products. To estimate CO_2 emissions from NEU of natural gas, an emission factor of 38 g CO_2/m^3 was used. This emission factor excludes the feedstock use of natural gas to produce ammonia, and it is derived from the NEU of natural gas data found in the 2005 Cheminfo Study (Cheminfo Services, 2005).

Table A6.2–9 shows the emission factors used to develop CO_2 emission estimates for non-energy applications of natural gas liquids and non-energy petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A6.1–5. The 2011 emission factor value for Upgrading Facilities in Table A6.1–5 has been used for Ontario across the time series. For the other provinces, the 2011 emission factor value for Refineries and Others is used across the time series. The emission factors associated with NEU of coal are referenced in Table A6.1–8.

Table A6.2–9 **CO_2 Emission Factors for Non-Energy Use of Natural Gas Liquids and Petroleum Products**

Product	Fraction of Carbon Stored in Product	CO_2 Emission Factor (g CO_2 / L)
Natural Gas Liquids		
Propane	0.8[a]	303[b]
Butane	0.8[a]	349[b]
Ethane	0.8[a]	197[b]
Petroleum Products		
Petrochemical Feedstocks[d]	0.8[a]	500[h]
Naphthas[e]	0.75[a]	625[h]
Lubricating Oils and Greases[f]	0.2[c]	2 260[h]
Petroleum Used for Other Products[g]	0.5[a]	1 450[h]

Notes:

a. IPCC/OECD/IEA (1997)
b. McCann (2000)
c. IPCC (2006)
d. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992).
e. Carbon factor for Napthas is 680 g C/L (Jaques 1992).
f. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992).
g. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992).
h. The resulting CO_2 emission factor is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO_2 and carbon (44/12) and by (1-fraction of carbon stored in product).

A6.2.5. Electronics Industry

The use of perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in integrated circuit or semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing create GHG emissions of their respective source gases. The use of PFCs and NF_3 in the integrated circuit or semiconductor manufacturing industry can also lead to by-product PFC emissions. The emission factors used for the use of PFCs, SF_6 and NF_3 in the electronics industry is summarized in Table A6.2–10.

A6.2.6. Product Uses as Substitutes for Ozone Depleting Substances

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents and fire extinguishing, result in hydrofluorocarbon (HFC) and PFC emissions.

Table A6.2–11 and Table A6.2–12 summarize emission rates used to estimate HFC and PFC emissions, respectively.

Table A6.2–10 **Emission Factors for the use of PFCs, SF_6 and NF_3 in the Electronics Industry**

Application	GHG Source	IPCC Tier	Emission Rate (%)[a]	By-Product Emission Rate
Integrated Circuit or Semiconductor Manufacturing[b]	CF_4	T2A	90	N/A
	CF_4	T2B – CVD	90	N/A
	CF_4	T2B – Etching	70	N/A
	C_2F_6	T2A	60	0.2 kg CF_4 / kg C_2F_6
	C_2F_6	T2B – CVD	60	0.1 kg CF_4 / kg C_2F_6
	C_2F_6	T2B – Etching	40	0.4 kg CF_4 / kg C_2F_6
	c-C_4F_8	T2A	10	0.1 kg CF_4 / kg c-C_4F_8, 0.1 kg C_2F_6 / kg c-C_4F_8
	c-C_4F_8	T2B – Etching	20	0.2 kg CF_4 / kg c-C_4F_8, 0.1 kg C_2F_6 / kg c-C_4F_8
	SF_6	T2A	20	N/A
	NF_3	T2A	20	0.09 kg CF_4 / kg NF_3
	NF_3	T2B – Etching	20	N/A
Other Emissive Applications	PFCs	T2	50% first year / 50% second year	N/A

Notes:

N/A = Not available

a. IPCC (2006)
b. When available, confidential company/gas/process-specific values are used for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively, ai and di in the IPCC Guidelines).

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Table A6.2–11 **HFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Aerosols[d]	0	50% of orginal charge	100% of remaining charge	2
Blowing agent in foams[d]				
Open-cell foam	100	-	-	-
Closed-cell foam	10	4.5	100	23
Air conditioning (equipment manufactured in Canada)[e]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (manufactured elsewhere)[e]				
Air conditioner units in motor vehicles	-	10	75	13
Chillers (specify centrifugal or reciprocating)	-	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	-	4	20	17
Refrigeration (equipment manufactured in Canada)[e]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	1.0	10.8	30	15
Refrigeration (manufactured elsewhere)[e]				
Commercial transport	-	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	-	10	30	17
Industrial (warehouses, processes, etc.)	-	10	30	17
Residential (refrigerators, freezers, etc.)	-	0.5	30	15
Other equipment (specify)	-	10.1	30	15
Solvent[d]	0	50% of orginal charge	100% of remaining charge	2
Fire suppression/extinguishing systems[d]				
Portable (mobile) systems	-	4	5	18
Total flooding (fixed) systems	-	2	5	18
Miscellaneous[d]	-	50% of orginal charge	100% of remaining charge	2
Other (specify)[d]	-	50% of orginal charge	100% of remaining charge	2

Notes:

a. Percentage of losses of the HFC charged into new equipement

b. Release percentage of HFC bank (by application) during operation

c. Release percentage of HFC bank (by application) during disposal

d. IPCC (2006)

e. Environment Canada (2015)

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Table A6.2–12 **PFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)**				
Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Air Conditioning				
Mobile A/C	0.35	15	100	12
Residential and Commercial A/C, including Heat Pumps	0.6	5.5	100	15
Foam Blowing Agents				
Closed-Cell Foam	10% of original charge	4.5% of original charge	-	20
Refrigeration				
Industrial Refrigeration including Food Processing and Cold Storage	1.75	16	100	15
Medium and Large Commercial Refrigeration	1.75	22.5	100	15
Solvents	0	50% of original charge	100% of remaining charge	2

Notes:
a. Percentage of losses of the PFC charged into new equipment
b. Annual release percentage of PFC bank (by application) during operation
c. Release percentage of PFC bank (by application) during disposal
Source – IPCC (2006)

A6.3. Other Product Manufacture and Use

The uses of N_2O as an anaesthetic and as a propellant result in N_2O emissions. The emission factors used are shown in Table A6.3–1.

The use of perfluorocarbons (PFC) in contained applications (such as use in power transformers, as an electronic insulator, as a dielectric coolant, and as a heat transfer medium) results in PFC emissions. The emission factors used are shown in Table A6.3–2.

The use of urea-based diesel exhaust fluid (DEF) in diesel vehicles equipped with selective catalytic reduction (SCR) systems results in CO_2 emissions, the rate of which is dependent on the purity factor of urea in DEF as well as the dosing rate of urea to diesel consumption as per Table A6.3–3.

Table A6.3–1 **Emission Factors for N_2O Usage (Medical and Propellant)**		
Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Note: Source – IPCC (2006)

Table A6.3–2 **Emission Factor for PFC Emissions from Other Contained Product Uses**	
Process	PFC Emissions from Other Contained Sources
Assembly	1% of charge
Annual Leakage Rate	2% of stock
Disposal	100% of remaining stock
Product Lifespan	15 years

Note: Source – IPCC (2000)

Table A6.3–3 **Emission Factors for Use of Urea in SCR Vehicles**		
Product	DEF Purity	Dosing Rate
Urea use in SCR Vehicles	32.50%	2% of diesel consumption

Note: Source – IPCC (2006)

A6.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues, agricultural soils (including nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter), and agricultural use of lime, urea and other-carbon containing fertilizers. The most significant sources use country-specific Tier 2 methodologies. Carbon dioxide emissions from liming, urea application and other carbon-containing fertilizers are calculated based on the total quantity of carbon (C) contained in these products. Ammonia emissions from synthetic nitrogen (N) application are estimated using a country specific modelling method as noted in Annex 3.4. Finally, indirect emissions from ammonia volatilization and nitrogen leaching are calculated based on the IPCC default emission factors provided in Table A6.4–27.

Those emission factors for agriculture calculated based on country-specific methodologies are described in detail in Annex 3.4. In certain cases, implied emission factors for these methologies are included below for reference. For enteric fermentation emissions from cattle, weighted national emission factors and the methodology for generating emission factors are detailed in section A3.4.2.1. In the case of manure management CH_4, the methodology for generating emission factors is described in A3.4.3, and weighted national emission factors are presented in A3.4.3.5. For manure management N_2O emissions, the methodologies for calculating direct and indirect N_2O emissions are described in sections A3.4.4.1 and A3.4.4.2, respectively. Finally, the methodologies for generating N_2O emission factors for direct emissions from agricuiltural soils and pasture, range and paddock (PRP), are described in A3.4.5.1. Cattle are described using an approach consistent with common reporting format (CRF) tables.[3] For enteric fermentation, Dairy Cattle includes only dairy cows, while for manure management and PRP, Dairy Cattle includes dairy cows and dairy heifers.

A compilation of emission factors for agriculture are provided here in Table A6.4–1 to Table A6.4–29.

3 Canada's 2021 CRF tables are available online at: https://unfccc.int/ghg-inventories-annex-i-parties/2021

A6.4.1. Enteric Fermentation

Table A6.4–1 **CH_4 Emission Factors (EF) for Enteric Fermentation for Cattle from 1990 to 2019**

Year	$EF_{(EF)T}$ – (kg CH_4/head/year)[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8
2019	142.2	76.6	124.0	120.3	91.0	53.9	49.0	43.7

Notes:

a. Enteric emission factors are derived from Boadi et al. (2004), modified to take into account trends in milk production in dairy cows and carcass weights for several beef cattle categories.

b. Reported as kg/head/yr; however, emissions are calculated based on time to slaughter.

Table A6.4–2 **Methane Emission Factors (EF) for Enteric Fermentation for Non-Cattle Animals**

Non-Cattle Animal Category	Enteric Fermentation EF[a] (kg CH_4/head/year)
Pigs	
Boars	1.5
Sows	1.5
Pigs < 20 kg	1.5
Pigs 20–60 kg	1.5
Pigs > 60 kg	1.5
Other Livestock	
Sheep	8
Lambs	8
Goats	5
Horses	18
Bison	55
Llamas & Alpacas	8
Elk & Deer	20
Wild Boars	1.5
Fox	N/A
Mink	N/A
Rabbits	N/A
Mules and Asses	10
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:

N/A = Not available

a. Data source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.10)

A6.4.2. Manure Management

Table A6.4–3 **Maximum Methane-Producing Potential (B_0) by Animal Category**

Animal Category	Maximum CH_4-Producing Potential (B_0) (m^3/kg VS)
Dairy Cattlea	0.24
Non-dairy Cattleb	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:

VS = Volatile solids

a. Dairy cattle include dairy cows and dairy heifers.

b. The non-dairy cattle value is also used for bison.

Data source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9)

Table A6.4–4 **Methane Conversion Factors (MCFs) by Animal Category and Manure Management System**

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Drylot (MCF_{SSD})	Pasture, Range and Paddock (MCF_{PRP})	Other Systems (MCF_O)
Non-dairy Cattle[a]	0.2	0.02	0.01	0.01
Poultry	0.2	0.015	0.015	0.015
Horses	NA	0.01	0.01	0.01
Goats	NA	0.01	0.01	NA
Sheep	0.2	0.01	0.01	0.01
Lambs	0.2	0.01	0.01	0.01

Notes:

NA = Not applicable

a. Non-dairy cattle values are also used for bison.

Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 – cool climate, average annual temperature 12°C)

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Table A6.4–5 **Methane Conversion Factors (MCF) for Dairy Cattle and Swine**

Manure Management System	Manure Management Subsystem	Crust Formation	MCF
Liquid	Earthen Basin	No crust	0.2
	Earthen Basin	Crust	0.13
	Tank	No crust	0.2
	Tank	Crust	0.13
	Slatted floor	N/A	0.2
Solid	Exercise Yard	N/A	0.01
	Pack	N/A	0.01
	Pile	N/A	0.02
Compost		N/A	0.005
Pasture Range Paddock		N/A	0.01
		N/A	0.01

Notes:

N/A = Not available

Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.17 – cool climate, average annual temperature 12°C)

Table A6.4–6 **Emission Factors (EF) to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2019**

Year	$EF_{(MM)T}$ (kg CH_4/head/year)							
	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0
2019	39	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:

a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.

b. Reported as kg/head/year, but emissions are calculated based on time to slaughter.

Table A6.4–7 **Emission Factors (EF) to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2019**

Year	$EF_{(MM)T}$ (kg CH_4/head/year)				
	Boars	Sows	Pigs (< 20 kg)	Pigs (20-60 kg)	Pigs (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0
2019	7.0	7.0	2.1	4.2	9.2

Table A6.4–8 **2019 CH_4 Emission Factors (EF) for Manure Management for Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars[a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and Asses	0.76
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.10

Note:

a. Emission factor based on swine volatile solids, assuming 100% solid manure.

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Table A6.4–9 **Dairy Cattle and Swine Emission Factors for Manure Nitrogen (N) Lost as N_2O-N by Animal Waste Management Systems**

Manure Management System	Manure Management Subsystem	Crust Formation	Emission Factor
Liquid	Earthen Basin	No crust	0
	Earthen Basin	Crust	0.005
	Tank	No crust	0
	Tank	Crust	0.005
	Slatted floor	NA	0.002
Solid	Exercise Yard	NA	0.02
	Pack	NA	0.02
	Pile	NA	0.005
Other	Compost	NA	0.01

Notes:

NA = Not applicable

Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

Table A6.4–10 **Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems**

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	0.001	0.02	0.005
Goats	0.001	0.02	0.005
Horses	0.001	0.02	0.005
Mules and Asses	0.001	0.02	0.005
Buffalo	0.001	0.02	0.005

Note: Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

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Table A6.4–11 **Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Cattle and Swine Manure**

Year	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Cattle					
Dairy Cows[a]	1 268	1 128	956	930	920
Beef Cows	862	999	1 016	1 093	1 099
Bulls	1 305	1 495	1 665	1 641	1 576
Dairy Heifersa	938	906	775	745	740
Beef Heifers	680	769	784	838	841
Heifers for Slaughter	320	425	435	458	463
Steers	336	426	439	468	477
Calves	382	383	382	382	379
Swine[b]					
Sows	74	29	25	24	24
Boars	95	58	53	58	59
Pigs (<20 kg)	7	3	3	2	2
Pigs (20–60 kg)	32	15	13	12	12
Pigs (>60 kg)	66	32	29	28	28

Notes:

Emission factors are derived from information in Boadi et al. (2004), Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

a. For dairy cows and heifers, nitrogen excretion rates are derived from feed intake information from Lactanet (2020), and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

b. For swine, nitrogen excretion rates are calculated using default IPCC parameters and country-specific animal mass time series, and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

Table A6.4–12 **2019 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Non-Cattle and Non-Swine Manure**

Livestock Category	Emission Factors (EF)[a] (g N_2O head^{-1} year^{-1})
Poultry	
Turkey	54
Hens	12
Pullets	6
Broiler	11
Other Livestock	
Sheep	45
Goat	139
Buffalo	991
Horse	485
Llama and alpacas	150
Lamb	44
Deer	219
Elk	219
Wild boars	350
Rabbit	149
Mink	95
Fox	250
Mules and Asses	259

Note:

a. Emission factors are derived from information in Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–13 **Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage**

	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Volatilization[a]					
Dairy Cow	207	209	186	175	174
Beef Cow	140	161	164	176	177
Bull	213	241	269	264	253
Dairy heifer	155	150	136	128	127
Beef heifer-bred	111	124	127	135	136
Beef heifer-slaughter	52	70	72	75	76
Steer	55	70	72	77	78
Calf	61	61	61	61	60
Sow	58	58	52	51	51
Boar	58	56	50	50	50
Pig (<20 kg)	6	6	5	5	5
Pig (20–60 kg)	25	25	22	21	21
Pig (>60 kg)	50	51	47	48	49
Leaching[b]					
Dairy Cow	23	15	11	10	9
Beef Cow	0	0	0	0	0
Bull	0	0	0	0	0
Dairy heifer	16	12	10	9	9
Beef heifer-bred	0	0	0	0	0
Beef heifer-slaughter	0	0	0	0	0
Steer	0	0	0	0	0
Calf	0	0	0	0	0
Sow	1.2	0.2	0.1	0.1	0.1
Boar	1.6	0.7	0.6	0.7	0.8
Pig (<20 kg)	0.13	0.03	0.02	0.02	0.02
Pig (20–60 kg)	0.6	0.2	0.1	0.1	0.1
Pig (>60 kg)	1.2	0.4	0.3	0.2	0.2

Notes:

a. Indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. A tier 2 method for the calculation of swine and dairy cattle leaching is based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–14 **Annual Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage**

	EF (kg NH_3 head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Cattle					
Dairy Cow	16	16	14	14	13
Beef Cow	11	12	13	14	14
Bull	16	19	21	20	20
Dairy heifer	12	12	11	10	10
Beef heifer-bred	8.6	10	10	10	10
Beef heifer-slaughter	4.0	5.4	5.5	5.8	5.9
Steer	4.2	5.4	5.6	5.9	6.1
Calf	4.7	4.7	4.7	4.7	4.6
Swine					
Sow	4.5	4.5	4.0	3.9	3.9
Boar	4.4	4.3	3.9	3.8	3.8
Pig (<20 kg)	0.5	0.5	0.4	0.4	0.4
Pig (20–60 kg)	1.9	1.9	1.7	1.6	1.6
Pig (>60 kg)	3.9	4.0	3.7	3.7	3.8

Note: Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–15 **2019 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage**

Livestock Category	Volatilization Emission Factor (EF)[a] (g N_2O head^{-1} year^{-1})	Leaching Emission Factor (EF)[b] (g N_2O head^{-1} year^{-1})
Poultry		
Turkey	13	0
Hens	4	0
Pullets	2	0
Broiler	3	0
Other Livestock		
Sheep	3	0
Goat	8	0
Buffalo	159	0
Horse	31	0
Llama and alpacas	9	0
Lamb	3	0
Deer	33	0
Elk	33	0
Wild boars	52	0
Rabbit	22	0
Mink	6	0
Fox	15	0
Mules and Asses	17	0

Notes:

a. Volatilization and indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. Leaching is not calculated as there are no tier 1 leaching factors available in the 2006 IPCC Guidelines.

Table A6.4–16 **2019 Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage**

Livestock Category	Emission Factor (EF) (kg NH_3 head^{-1} year^{-1})
Poultry	
Turkey	1.0
Hens	0.3
Pullets	0.1
Broiler	0.2
Other Livestock	
Sheep	0.2
Goat	0.6
Buffalo	12
Horse	2.4
Llama and alpacas	0.7
Lamb	0.2
Deer	2.6
Elk	2.6
Wild boars	4.1
Rabbit	1.7
Mink	0.4
Fox	1.2
Mules and Asses	1.3

Note: Volatilization factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the emission factors is explained in NIR Annex 3.4.

A6.4.3. Pasture, Range and Paddock

Table A6.4–17 **Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O From Deposition of Cattle Manure on Pasture, Range and Paddock**

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)[a, b, c, d]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.68	0.68	0.68	8.8	9.4	8.8	9.7	7.5	9.5	0.68
2005	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68
2010	0.68	0.68	0.68	8.8	9.6	8.8	9.6	7.5	9.4	0.68
2019	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68

Notes:

a. Emission factors are derived from Rochette et al. (2014) for eastern Canada, and Lemke et al. (2012) for western Canada.

b. The proportion of excreted manure deposited on pasture is taken from Marinier et al. (2005), for all livestock except dairy cows and heifers.

c. The proportion of excreted manure deposited on pasture by dairy cows and heifers is based on a farm size relationship derived from Sheppard et al. (2011a), as described in NIR Annex 3.4.

d. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–18 **Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Deposited on Pasture, Range and Paddock**

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Volatilization[a]										
1990	2.4	2.0	2.6	2.5	3.2	2.5	2.5	2.7	3.0	2.3
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	2.2	2.8	2.0	2.3	1.7	2.5	2.3	2.3	1.6	1.9
2019	3.2	2.7	3.2	2.0	1.2	2.0	2.3	1.8	1.7	3.2
Leaching[b]										
1990	1.9	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2005	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2010	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2019	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.5

Notes:

a. For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016), and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate indirect N_2O emission factors from volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.

b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–19 **Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as NH_3 Due to Volatilization of Manure Deposited on Pasture, Range and Paddock**

Year	EF (kg NH_3 kg N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.19	0.17	0.18	0.13	0.10	0.13	0.13	0.12	0.10	0.19
2005	0.20	0.18	0.19	0.14	0.09	0.14	0.15	0.13	0.12	0.20
2010	0.20	0.18	0.19	0.13	0.08	0.13	0.15	0.12	0.12	0.20
2019	0.20	0.18	0.19	0.13	0.09	0.13	0.14	0.12	0.11	0.20

Note:

For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016). For all livestock except dairy cattle, the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

A6.4.4. Agricultural Soils

Table A6.4–20 Emission Factors (EF) for Crop Residue, Organic and Inorganic Fertilizer Nitrogen (N) Lost as N_2O Following Application to Agricultural Soils

Year	EF (g N_2O kg^{-1} N year^{-1})[a]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	14	16	14	25	26	24	23	21	26	12
2005	13	16	15	25	26	24	23	21	26	11
2010	13	16	14	25	26	24	23	21	26	11
2019	13	16	14	25	26	24	23	21	26	12

Note:
a. Country-specific Tier 1 soil N_2O emission factors are calculated as described in NIR Annex 3.4.

Table A6.4–21 Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 from Agricultural Soils

Year	EF (g NH_3 kg^{-1} N year^{-1})									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	225	209	219	291	262	290	250	291	267	229
2005	225	198	187	261	249	253	237	275	256	224
2010	224	193	181	249	245	241	234	264	252	225
2019	223	191	172	246	245	240	233	261	254	224

Notes:
For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016).
For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–22 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Applied to Agricultural Soils

	EF (g N_2O kg^{-1} N applied year^{-1})									
Volatilization[a]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	2.9	2.7	2.8	3.8	3.4	3.8	3.2	3.8	3.5	3.0
2005	2.9	2.6	2.4	3.4	3.2	3.3	3.1	3.6	3.3	2.9
2010	2.9	2.5	2.3	3.2	3.2	3.1	3.0	3.4	3.3	2.9
2019	2.9	2.5	2.2	3.2	3.2	3.1	3.0	3.4	3.3	2.9
Leaching[b]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	1.9	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2005	1.8	2.3	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2010	1.8	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2019	1.8	2.5	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6

Notes:
a. For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016) and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.
b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–23 Fraction of N Volatilized ($FRAC_{GASM}$) as Ammonia Resulting from the Application of Biosolid N to Agricultural Soils

IPCC default emission factor, $FRAC_{GASM}$	0.2 kg NH_3-N volatilized / kg N applied

Note: Source – IPCC (2006)

Table A6.4–24 N_2O Emission Factor for Mid-latitude Cultivation of Organic Soils

IPCC default emission factor for mid-latitude cultivation of organic soils	8.0 kg N_2O-N/ha-year

Note: Source – IPCC (2006)

Table A6.4–25 **Emission Factors (EF) for Biosolid Nitrogen (N) Lost Indirectly as N_2O Due to Leaching of Biosolids Applied to Agricultural Soils**

	EF (g N_2O kg^{-1} N applied $year^{-1}$)									
Leaching[a]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	2.0	2.0	2.1	3.5	N/A	3.5	3.1	3.5	3.4	1.5
2005	2.0	2.1	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5
2010	2.0	2.1	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5
2019	2.0	2.0	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5

Notes:

N/A = not available

a. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–26 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized/kg inorganic fertilizer N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.08	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.07	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.07	0.07	0.05	0.07	0.06
2019	0.06	0.08	0.07	0.06	0.07	0.08	0.07	0.05	0.07	0.06

Table A6.4–27 **Indirect N_2O Emissions from Agricultural Soils**

Emission factor due to volatilization and redeposition of Nitrogen	0.01 kg N_2O-N/kg N
Emission factor due to leaching/runoff	0.0075 kg N_2O-N/kg N

Note: Source – IPCC (2006)

A6.4.5. Other Sources

Table A6.4–28 **CH_4 and N_2O Emissions from Field Burning of Agricultural Residues**

CH_4 emission factor	2.7 g CH_4 kg^{-1} dry matter burnt
N_2O emission factor	0.07 g N_2O kg^{-1} dry matter burnt

Note: Source – IPCC (2006)

Table A6.4–29 **CO_2 Emissions from Liming and Urea Fertilization**

Dolomite emission factor	0.13 Mg C / Mg dolomite applied
Limestone emission factor	0.12 Mg C / Mg limestone applied
Urea emission factor	0.20 Mg C / Mg urea

Note: Source – IPCC (2006)

A6.5. Land Use, Land-Use Change and Forestry

The IPCC Tier 2 and Tier 3 methods and country-specific parameters are used for generating estimates for most of the LULUCF sector. The CBM-CFS3 model is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land and the emissions due to forest conversion to other land uses. For Cropland, a process model (CENTURY) is used for estimating CO_2 emissions and removals as influenced by management activities, based on the National Soil Database of the Canadian Soil Information System.[4] More details on methods, emission factors and parameters for Forest Land, forest conversion and Cropland is provided in Annex 3.5 of this report, specifically in sections A3.5.2 and A3.5.4.

A country-specific model (NFCMARS-HWP) is used to estimate the emissions from the use and disposal of wood products reported under the Harvested Wood Products (HWP) category. For details on the methods and parameters used in the model, see section A3.5.3.

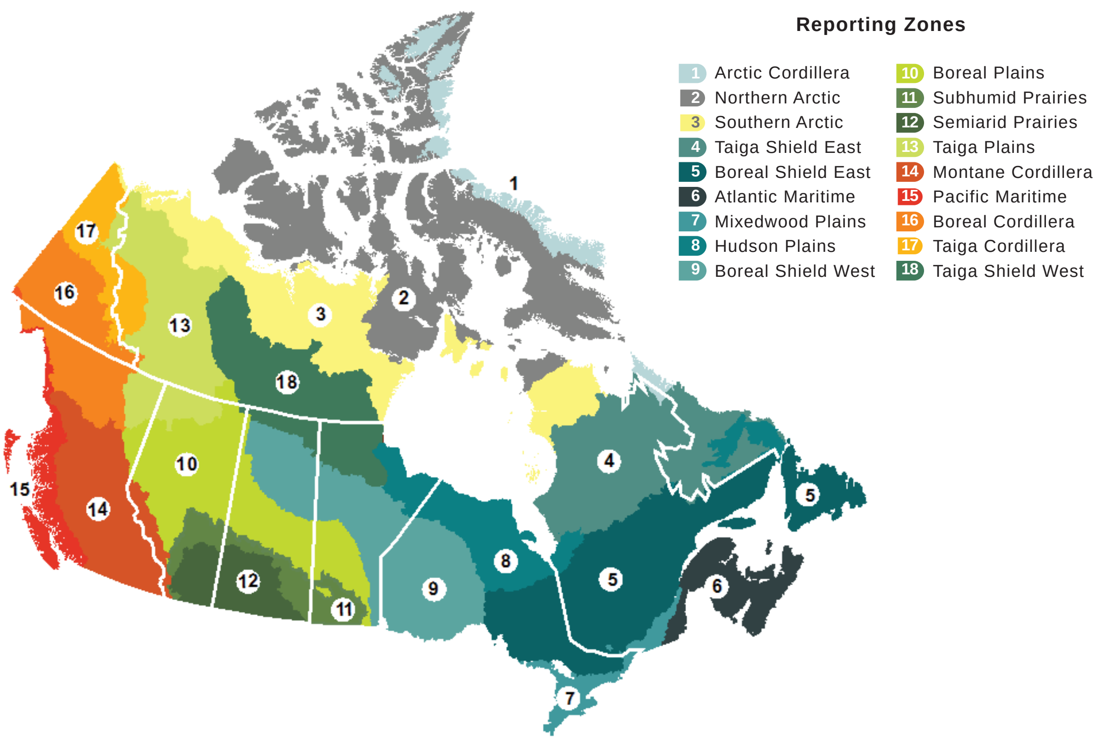
Emissions due to the conversion and management of peatlands for peat extraction, the creation of flooded lands (reservoirs) on areas with no evidence of forest clearing and from the conversion of grasslands to Settlements, are estimated using IPCC Tier 2 methods and country-specific parameters (see sections A3.5.6.1, A3.5.6.2 and A3.5.7.3). Net CO_2 removals from the growth of urban trees are estimated using an IPCC Tier 2A approach (see section A3.5.7.1). In addition, emissions due to the occasional burning of grassland are estimated using an IPCC Tier 1 method and default emissions factors (see section A3.5.5.1).

A compilation of the spatial framework and parameters used to develop and report the LULUCF estimates is provided in this annex (see figures A6.5–1 to A6.5–6 and tables A6.5–1 to A6.5–6).

4 Available online at: https://sis.agr.gc.ca/cansis/nsdb/index.html

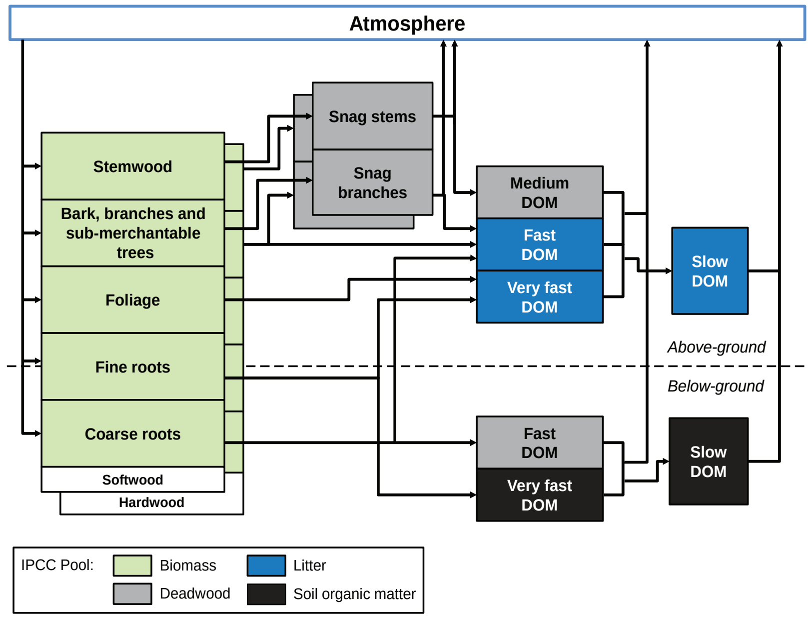
A6.5.1. Reporting Zones

Figure A6.5–1 **Reporting Zones for LULUCF estimates**



A6.5.2. Forest Land

Figure A6.5–2 **Carbon Transfers Between Forest Pools**

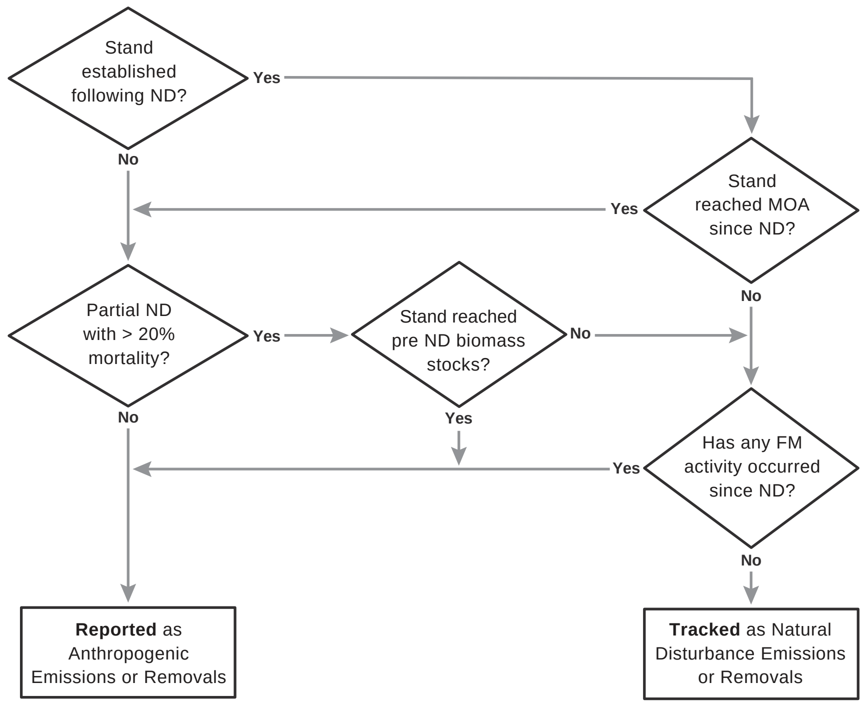


Note: Source – White et al. (2008), updated

Figure A6.5–3 **Disturbance Matrix Parameters for Carbon Modelling (Selected Examples)**

Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-Cut Harvesting and Salvage Logging Applicable in all Ecozones Except Those in Alberta and Quebec	13	14	15	16	17	18	19	24	25	Products
1. Softwood merchantable					0.15					0.85
2. Softwood foliage	1									
3. Softwood others			1							
4. Softwood sub-merchantable			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merchantable					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood sub-merchantable			1							
11. Hardwood coarse roots			0.5	0.5						
12. Hardwood fine roots	0.5	0.5								
13. Above-ground very fast soil C	1									
14. Below-ground very fast soil C		1								
15. Above-ground fast soil C			1							
16. Below-ground fast soil C				1						
17. Medium soil C					1					
18. Above-ground slow soil C						1				
19. Below-ground slow soil C							1			
20. Softwood stem snag					0.5					0.5
21. Softwood branch snag			1							
22. Hardwood stem snag					0.5					0.5
23. Hardwood branch snag			1							
24. Black C								1		
25. Peat									1	

Figure A6.5–4 **Decision Tree for Managed Forest**



Notes:
ND = Natural disturbance
MOA = Minimum operable age
FM = Forest management

A6.5.3. Harvested Wood Products

Table A6.5–1 **Default Parameter Values Used in HWP Analysis**

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC, 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne [a]	0.5	IPCC, 2006 (Vol. 4, Table 12.4)

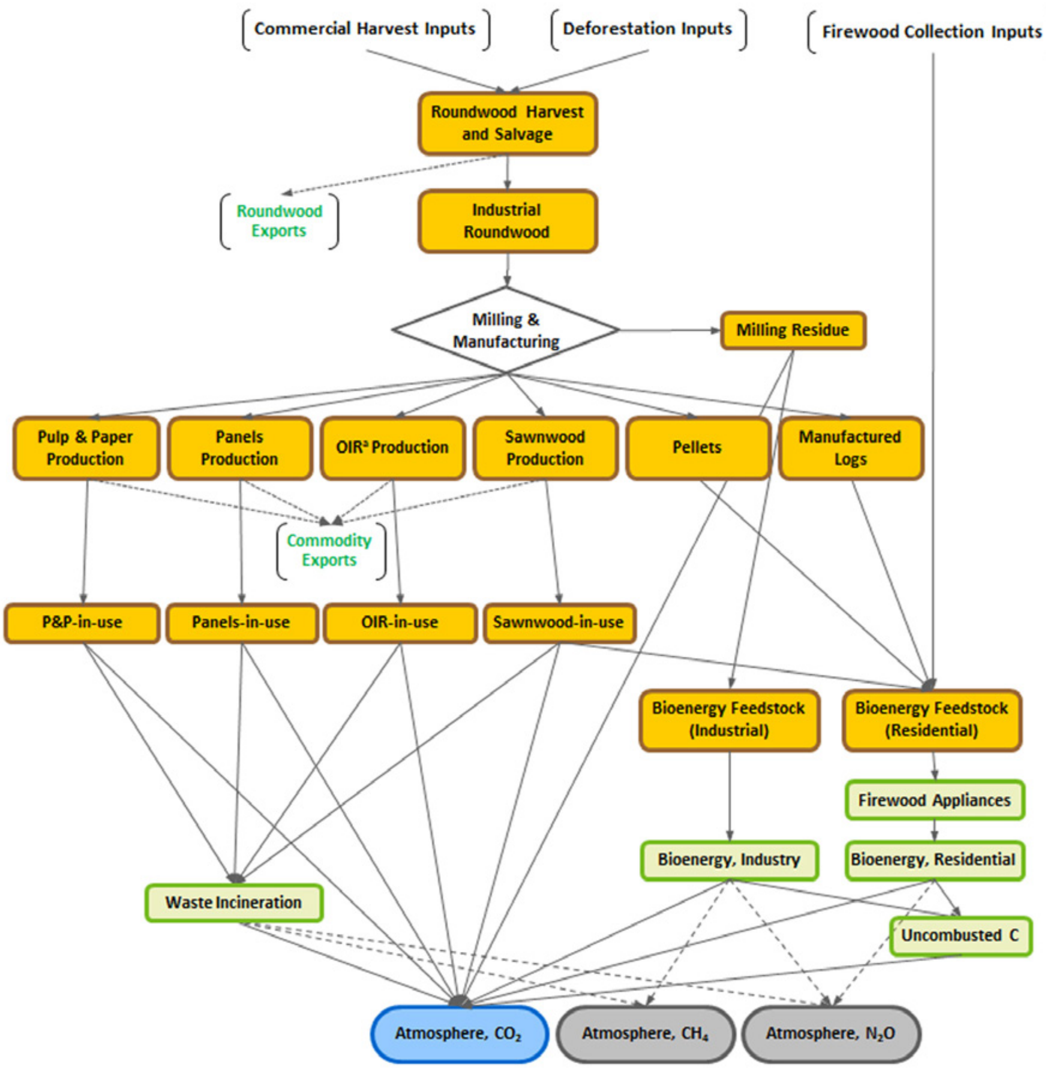
Note:
a. Tonnes carbon per oven dry tonne of wood material.

Table A6.5–2 **Wood Densities of Commodities**

Country/Countries	Description	Units	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m^3	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m^3	0.481	Derived
Canada	Species-weighted average density, Other industrial roundwood	od tonne/m^3	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m^3	0.643	Derived
Canada	Species-weighted average density, Bioenergy	od tonne/m^3	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m^3	0.455	FAO, 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m^3	0.527	FAO, 2010
U.S.	C+NC roundwood	od tonne/green m^3	0.465	FAO, 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m^3	0.28	Skog, 2008
U.S.	Softwood (SW) lumber	tonnes C/m^3	0.22	Skog, 2008
U.S.	HW lumber	tonnes C/m^3	0.26	Skog, 2008
U.S.	Particle board	tonnes C/m^3	0.29	Skog, 2008
U.S.	Hardboard	tonnes C/m^3	0.42	Skog, 2008
U.S.	Medium density fibreboard	tonnes C/m^3	0.32	Skog, 2008
U.S.	Fibreboard, compressed	tonnes C/m^3	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog, 2008
U.S.	Insulating board	tonnes C/m^3	0.45	Skog, 2008
All	Sawnwood – C	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Sawnwood – NC	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)
All	Wood pulp	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)

Notes:
od tonne = oven dry tonne of wood material
ad tonne = air dry tonne of product

Figure A6.5–5 **Carbon Flows in Harvested Wood Products**



Note:
OIR = Other Industrial Roundwood

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Table A6.5–3 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description [a]	Value	Source
Canada	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)

Note:

a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

A6.5.4. Cropland

Table A6.5–4 **Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)**

Zone [a]	LMC [b, c]	k/year	ΔCLMCmax (Mg/ha)	Final Year of Effect after LMC [d]	Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 Years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.025	5	65	0.06	0.1
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0233	29.4	142	0.2	0.55
Semi-arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.1
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0	0
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:

Effective Linear Coefficients of Soil Organic Carbon were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.

a. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in NL; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in ON and QC; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.

b. For LMCs in the opposite direction to that listed, the FLMCmax will be the negative of the value listed.

c. IT = intensive tillage, RT = reduced tillage, NT = no-till

d. No further C changes once the absolute value of the rate of change is less than 25 kg C/ha per year.

A6.5.5. Wetlands

Table A6.5–5 Parameters and Emission Factors for Estimating Emissions from Peat Extraction

Emission Factor/Parameter	Unit	EF Value	Sources
Biomass Clearing			
Forest land biomass cleared	t C ha^{-1}	19.2	Hayne and Verbicki, 2011
Other land biomass cleared	t C ha^{-1}	2.8	Hayne and Verbicki, 2011
Drainage			
CO_2 from drained areas	t CO_2 ha^{-1} yr^{-1}	11.4	Moore et al., 2002, as cited in Cleary, 2003; Glatzel et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2 -DOC from drained areas	t CO_2 ha^{-1} yr^{-1}	0.60	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from drained fields	t CH_4 ha^{-1} yr^{-1}	0.008	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from drainage ditches	t CH_4 ha^{-1} yr^{-1}	0.15	Waddington and Day, 2007
N_2O from drained areas	t N_2O ha^{-1} yr^{-1}	0.00047	IPCC, 2014 (Table 2.5, Default value for Boreal & Temperate climate zone)
CO_2 from abandoned block-cut areas	t CO_2 ha^{-1} yr^{-1}	8.6	Waddington and Price, 2000; Waddington and Warner, 2001; Waddington et al., 2002; McNeil and Waddington, 2003
CH_4 from abandoned block-cut areas	t CH_4 ha^{-1} yr^{-1}	0.012	Waddington and Price, 2000
CO_2 tree plantation biomass uptake	t CO_2 ha^{-1} yr^{-1}	-0.32	Garcia Bravo, 2015
Peat Stockpiling and Product Production			
Amount of stockpiled peat	t C ha^{-1}	50	Cleary, 2003
Exponential decay constant, stockpiled peat		0.05	Cleary, 2003
Carbon fraction of peat products	t C t air-dry peat-1	0.26	Hayne et al., 2014
Rewetting and Restoration			
CO_2 from restored areas	t CO_2 ha^{-1} yr^{-1}	7.60	Moore et al., 2002 as cited in Cleary, 2003; Petrone et al., 2001; Petrone et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2-DOC from restored areas	t CO_2 ha^{-1} yr^{-1}	0.13	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from restored fields	t CH_4 ha^{-1} yr^{-1}	0.03	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from restored ditches	t CH_4 ha^{-1} yr^{-1}	0.28	Waddington and Day, 2007; Strack and Zuback, 2013
N_2O from restored areas	t N_2O ha^{-1} yr^{-1}	N/A	IPCC, 2014, Default assumption of no N_2O emissions from rewetted/ restored areas

Note: All units where the greenhouse gas (GHG) is specified use units of the relevant GHG (CO_2, CH_4 or N_2O) instead of C and N.

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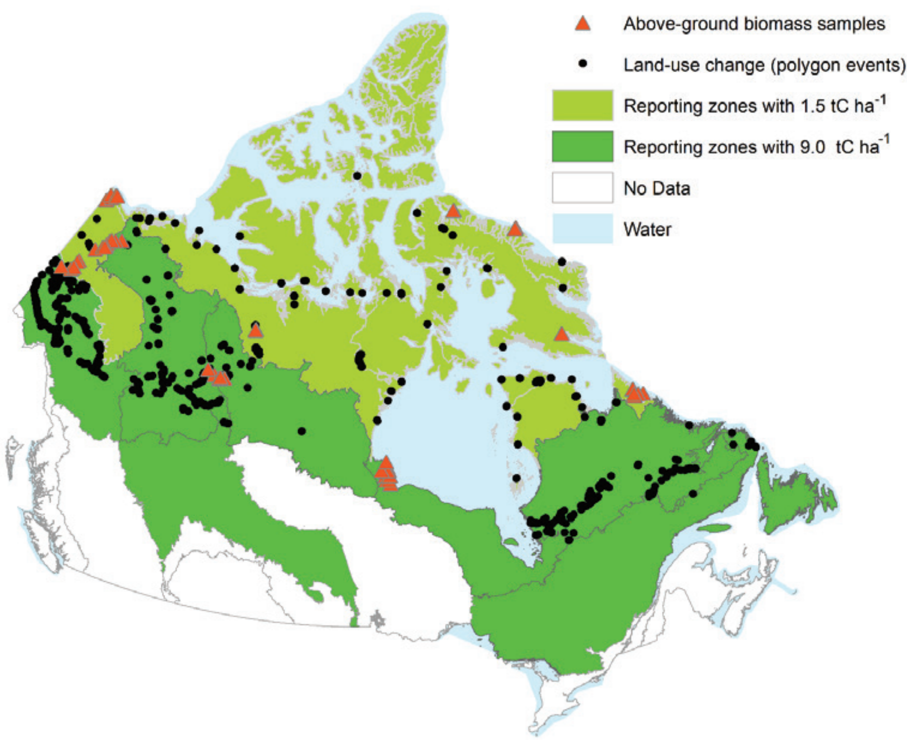
A6.5.6. **Settlements**

Table A6.5–6 **Carbon Storage and Sequestration in Urban Trees**

Reconcilliation Unit (RU)	Carbon Storage (t C ha⁻¹ yr⁻¹)	Carbon Sequestration (t C ha⁻¹ yr⁻¹)
1 NF – Boreal Shield East	40	3.0
5 NS – Atlantic Maritime	62	3.4
6 PE – Atlantic Maritime	62	3.4
7 NB – Atlantic Maritime	62	3.4
11 QC – Atlantic Maritime	62	3.4
12 QC – Mixedwood Plains	58	2.4
15 QC – Boreal Shield East	40	3.0
16 ON – Boreal Shield West	40	3.0
17 ON – Mixedwood Plains	58	2.4
19 ON – Boreal Shield East	40	3.0
24 MB – Subhumid Prairies	55	2.9
28 SK – Boreal Plains	40	3.0
30 SK – Semiarid Prairies	55	2.9
34 AB – Boreal Plains	40	3.0
35 AB – Subhumid Prairies	55	2.9
37 AB – Semiarid Prairies	55	2.9
41 BC – Pacific Maritime	97	6.9
42 BC – Montane Cordillera	23	1.4

Note: Source – Steenberg et al., 2021

Figure A6.5–6 **Map of Sample Points and Land-Use Change Events in Canada's North**



Note: More southerly reporting zones are attributed to the 9 tC ha⁻¹ biomass class, as some sites border on the northernmost boundary of these reporting zones.

A6.5.7. Forest Conversion

Table A6.5–7 **Soil Organic Carbon in Forest and Agricultural Land (0- to 30-cm soil depth)**

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[a]	Cropland[a]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:

a. Standard deviation in parentheses.

A6.6. Biomass Combustion

A6.6.1. CO_2

Emissions of CO_2 from the combustion of biomass (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. Emissions from prescribed burning and from the combustion of biomass for energy use are estimated and reported in the Land Use, Land-use Change and Forestry (LULUCF) sector, in common reporting format (CRF) Tables 4(V) and 4.G respectively. Forest wildfires are considered uncontrollable natural disturbances in the modelling and reporting approach used in the LULUCF sector by which these emissions and subsequent removals are estimated and tracked separately from emissions/removals resulting from commercially managed forest stands, more details on his approach can be found in Annex A3.5.2.4.

The emissions related to energy use are reported as memo items in the CRF tables of the Energy sector, as required by the United Nations Framework Convention on Climate Change (UNFCCC).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2 emission factor (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected

Table A6.6–1 **Emission Factors for Biomass**

Source[a]	Description	Emission Factor (g/kg fuel)		
		CO_2	CH_4	N_2O
Wood Fuel / Wood Waste	Industrial Combustion	1 715[b]	0.1[c]	0.07[c]
Forest Wildfires	Open Combustion	NA	NA[d]	NA[e]
Controlled Burning	Open Combustion	NA	NA[d]	NA[e]
Spent Pulping Liquor	Industrial Combustion	1 250[f]	0.03[g]	0.005[g]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 539[h]	12.9[h]	0.12[h]
Conventional Fireplaces and Inserts		1 539[h]	12.9[h]	0.12[h]
Stoves/Fireplaces with Advanced Technology		1 539[h]	5.9[h]	0.12[h]
or Catalytic Control				
Pellet Stove		1 652[b]	4.12[h]	0.059[h]
Other Wood-burning Equipment		1 539[h]	4.12[h]	0.059[h]

Notes:

NA = Not applicable

a. CO_2 emissions from biomass combusted for energy or agricultural purposes are not included in inventory totals, whereas CH_4 and N_2O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO_2 emissions from biomass burned in managed forests (wildfires and controlled burning), are reported under Land-Use, Land-use Change and Forestry (LULUCF) and excluded from national inventory totals.

b. Adapted from U.S. EPA (2003).

c. Adapted from U.S. EPA (2003) and NCASI TB998 (2012).

d. Emission ratio for CH_4 is 1/90th CO_2. See NIR Annex 3.4.

e. Emission ratio for N_2O is 0.017% CO_2. See NIR Annex 3.4.

f. Adapted from NCASI (2011).

g. Adapted from NCASI (2012).

h. Adapted from IPCC (2006).

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by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA, 2003). The U.S. EPA data were converted to kg/tonne at 0% moisture content (m.c.) using a higher heating value (HHV) of 20.44 MJ/kg, which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI, 2010). The NCASI emission factors were reported in units of kg/GJ HHV, which was converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg (Tran, 2014).

CO_2 emission factor for residential combustion (Table A6.6–1) is based on the default 2006 IPCC guidelines. The IPCC data were converted to g/kg at 19% moisture content using a lower heating value (LHV) of 13.2 MJ/kg, which was calculated based on the assumption that LHV is 20% less than the HHV (FPL, 2004). The HHV was developed from an internal review of available moisture content and heating value data.

CO_2 emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO_2 (CO_2-C) during forest fires is considered in the forest carbon balance, whereas the CO_2-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO_2 emission factor applicable to all fires, as the proportion of CO_2-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see section A3.5).

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A6.6.2. CH_4

Emissions of CH_4 from residential combustion of firewood are technology-dependent. The CH_4 emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A6.6–1) for CH_4 from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA, 2003) and collected by the NCASI in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for CH_4 from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors from landfill gas (Table A6.6–2) are adapted from the IPCC (2006).

Emissions of carbon as CH_4 (CH_4-C) from wildfires and controlled burning are always equal to 1/90th of CO_2-C emissions.

A6.6.3. N_2O

Emissions of N_2O from residential combustion of firewood are technology-dependent. The N_2O emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. Emission factors (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA, 2003) and collected by the National Council for Air and Stream Improvements (NCASI) in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for N_2O from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors for landfill gas (Table A6.6–2) are adapted from the IPCC (2006).

N_2O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO_2 emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see section A3.5.2).

Table A6.6–2 **Emission Factors for Landfill Gas Combustion**

Source	Description	Emission Factor			Emissin Factor Units
		CO_2	CH_4	N_2O	
Landfill Gas	Industrial combustion (for energy)	2 752[a]	0.05[a]	0.05[a]	kg/t CH_4 utilized for energy
Landfill Gas	Flaring	NE	30[b]	NE	kg/t CH_4 flared

Notes:
NE = Not estimated
a. Adapted From IPCC (2006) (Vol. 2, Table 2.2)
b. U.S. EPA (1995)

A6.7. Waste

A6.7.1. Municipal Wastewater Handling

A6.7.1.1. CH_4

Emissions from municipal wastewater handling are dependent on the organic loading of the effluent stream (which is a function of population), and the type of wastewater treatment provided. Emission factors (EF) are the product of the methane correction factor (MCF), which is the technology-specific estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically, and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. The IPCC default value of 0.6 kg CH_4/kg BOD for B_0 was not used. The AECOM (2011) study commissioned by Environment Canada confirmed that its derivation from the 0.25 kg CH_4/kg COD was erroneous, where COD is the chemical oxygen demand. A Canada specific value of 0.36 CH_4/kg BOD for B_0 was used (AECOM, 2011).

The MCF and EF values for CH_4 emissions from wastewater treatment and discharge, by treatment technology are shown in Table A6.7–1.

A6.7.1.2. N_2O

N_2O emissions from wastewater are a function of the nitrogen entering the wastewater stream, which is, in turn a function of protein consumption per capita, population, nitrogen content in protein, and adjustment factors for input of non-consumed nitrogen (e.g. from washing) and industrial inputs. The emission factor used is the IPCC 2006 Guideline default value of 0.005 kg N_2O-N/kg N (IPCC, 2006). The emission factor for N_2O from wastewater treatment and discharge is shown in Table A6.7–2.

Table A6.7–2 **Emission Factors for N_2O from Wastewater Treatment and Discharge**

N_2O Emission Factor	Units	Source
0.005	kg N_2ON/kg N	IPCC (2006) (Vol. 5, Chapter 6)

Table A6.7–1 **Methane Correction Factors (MCF) and Emission Factors (EF) for CH_4 from Wastewater Treatment and Discharge**

Treatment	MCF	EF	Source
No Treatment	0.1	0.036	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Primary	0.018	0.0036	IPCC (2019) Guideline Refinement
Aerobic Lagoon	0	0	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Anaerobic Lagoon	0.8	0.288	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Facultative Lagoon	0.2	0.072	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Other / Unspecified Lagoon	0.2	0.072[a]	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Secondary Anaerobic	0.8	0.288	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Secondary Activated Sludge	0.01	0.0036	IPCC (2019) Guideline Refinement
Trickling Filter	0.01	0.0036	IPCC (2019) Guideline Refinement
Trickling Filter – High Rate	0.01	0.0036	IPCC (2019) Guideline Refinement
Rotating Biological Contactor	0.01	0.0036	IPCC (2019) Guideline Refinement
Sequencing Batch Reactor	0.05	0.018	Taseli (2018). Point source pollution and climate change impact from Sequential Batch Reactor wastewater treatment plant
Secondary Biofiltration	0.018	0.0036	IPCC (2019) Guideline Refinement
Secondary with Biological Nutrient Removal	0.018	0.0036	IPCC (2019) Guideline Refinement
Septic	0.5	0.18	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Septic with Marine Outfall	0.5	0.18[b]	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Wetland	0.17	0.0612[d]	IPCC Supplement to 2006 Guidelines for Wetlands (2014). Chapter 6. Mean value of MCF's for three wetland types provided in document.
Other / Unknown	0.2	0.072[c]	Modeling as facultative lagoon

Notes:

a. Unspecified Lagoon types were assumed to be facultative.
b. Discharge to sea, river or lake.
c. Assuming facilities of unknown or other treatment type are either facultative lagoon or untreated discharge to sea. The median value of the MCF and EF of these technologies used.
d. Mean value of three possible wetland treatment types used.

A6.7.2. Waste Incineration

The emission factors for CO_2, CH_4, and N_2O for waste incineration are shown in Table A6.7–3.

A6.7.2.1. Sewage Sludge Incinerators

Emissions from sewage sludge incinerators are estimated from an emission factor obtained from the IPCC 2006 Guidelines (IPCC, 2006).

A6.7.2.2. Municipal Solid Waste Incinerators

The emission estimates from municipal solid waste incineration are calculated based on bach or continuous operations, and based on stoker or fluidized bed combustion technology. The emission factors used are from the IPCC 2006 Guidelines (IPCC, 2006). For CO_2 emissions, only the non-biogenic (fossil) portion of the waste is included when calculating emissions.

A6.7.2.3. Hazardous Waste Incinerators

The emission factors for hazardous waste incineration are taken from the IPCC 2006 Guidelines (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 50% and fossil carbon content of 90% of the carbon content.

A6.7.2.4. Clinical Waste Incinerators

The emission factors for clinical waste incineration are taken from the IPCC 2006 Guidelines (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 45%.

A6.7.3. Biological Treatment of Solid Waste

The emission factors for CO_2, CH_4, and N_2O for the biological treatment of solid waste are shown in Table A6.7–4.

Table A6.7–3 **Emission Factors for Waste Incineration**

Category	Emission Factors			Units
	CO_2	CH_4	N_2O	
Municipal Solid Waste Incineration – Continuous – Fluidized Bed	3666.67*	0.0002	0.00005	kg / tonne waste (for CH_4, N_2), *kg CO_2 / tonne fossil C in waste
Municipal Solid Waste Incineration – Continuous – Stoker		0	0.00005	
Municipal Solid Waste Incineration – Semi-Continuous – Fluidize Bed		0.006	0.00005	
Municipal Solid Waste Incineration – Semi-Continuous – Stoker		0.188	0.00005	
Municipal Solid Waste Incineration – Batch – Fluidized Bed		0.06	0.00006	
Municipal Solid Waste Incineration – Batch – Stoker		0.237	0.00006	
Sewage Sludge Incineration	1650.00	9.70	0.99	kg / tonne sewage sludge
Hazardous Waste Incineration	1650.00	0.20	0.10	kg / tonne waste
Clinical Waste Incineration – Continuous	1738.00	0.0002	0.05	kg / tonne wase
Clinical Waste Incineration – Batch	1738.00	0.06	0.06	kg / tonne waste

Note: Source – IPCC (2006)

Table A6.7–4 **Emission Factors for the Biological Treatment of Solid Waste**

Category	Waste of Facility Type	Emission Factors			Units	Source
		CO_2	CH_4	N_2O		
Anaerobic Digestion	Off-farm facilities	NA	2.10	NA	% of methane produced in biogas	ECCC (2020b)
Composting	Yard Waste	NA	1.72	0.25	g/kg Wet Waste	ECCC (2020c)
	Biosolids or Manure	NA	3.54	0.18	g/kg Wet Waste	ECCC (2020c)
	Mixture of Wastes	NA	1.09	0.11	g/kg Wet Waste	ECCC (2020c)
	Municipal Solid Waste	NA	1.51	0.18	g/kg Wet Waste	ECCC (2020c)

Note:
NA = Not applicable

OZONE AND AEROSOL PRECURSORS

The Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/CP/2013/10/Add.3 – UNFCCC 2014) recommends that Parties provide information on indirect greenhouse gases (GHGs) such as carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x) in the National Inventory Report.

While these gases do not have a direct global warming effect, they either influence the creation and destruction of tropospheric and stratospheric ozone or affect terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHG and quickly react to form GHGs, as in the case of CO reacting with a hydroxyl radical to form carbon dioxide (CO_2) in the atmosphere—hence the label “indirect greenhouse gases.” Emissions from these precursors are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

Information on ozone and aerosol precursor emissions in Canada, including CO, NO_x, NMVOC and SO_x is available in Canada’s Air Pollutant Emissions Inventory Report.[1]

Canada also reports “indirect CO_2 emissions” that result from the atmospheric oxidation of CO emitted from biomass burned on site after forest harvest and from forest conversion activities. These emissions are reported in the Land Use, Land-use Change, and Forestry (LULUCF) sector within Table 6 of the Common Reporting Format[2] (CRF). National totals are presented in CRF Tables 10 and Summary 2 with and without these “indirect CO_2 emissions” in accordance with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines (UNFCCC, 2014). Details on the source of these emissions can be found in Chapter 6 and Annex 3.5 of this report.

1 *Canada’s Air Pollutant Emissions Inventory Report* can be found at www.canada.ca/APEI.

2 Canada’s 2021 Common Reporting Format Tables can be found at https://unfccc.int/ghg-inventories-annex-i-parties/2021

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NATIONAL INVENTORY REPORT 1990–2019: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

CANADA'S SUBMISSION TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

PART 3

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Cat. No.: En81-4E-PDF
ISSN: 1910-7064
EC8369

The Executive Summary of this report is available at: canada.ca/ghg-inventory

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Environment and Climate Change Canada's **50th anniversary**
50e anniversaire d'Environnement et Changement climatique Canada
Meteorological Service of Canada's **150th anniversary**
150e anniversaire du Service météorologique du Canada

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC .... criteria air contaminant

CANSIM .... Statistics Canada's key socioeconomic database

CEPA 1999 ...... *Canadian Environmental Protection Act, 1999*

CESI .... Canadian Environmental Sustainability Indicators

CFC................. chlorofluorocarbon

CFS................. Canadian Forest Service

ECCC............. Environment and Climate Change Canada

EF .... emission factor

GDP .... gross domestic product

GHG................ greenhouse gas

GHGRP .... Greenhouse Gas Reporting Program

HFC................. hydrofluorocarbon

HWP................ harvested wood products

IPCC .... Intergovernmental Panel on Climate Change

IPPU .... Industrial Proccesses and Product Use

LTO .... landing and takeoff

LULUCF .... Land Use, Land-Use Change and Forestry

MSW .... municipal solid waste

N/A.................. not available

NIR.................. National Inventory Report

NMVOC........... non-methane volatile organic compound

NPRI .... National Pollutant Release Inventory

ODS .... ozone-depleting substance

OECD............. Organisation for Economic Co-operation and Development

PFC................. perfluorocarbon

POP .... persistent organic pollutant

QA................... quality assurance

QC .... quality control

RESD .... *Report on Energy Supply and Demand in Canada*

UNECE........... United Nations Economic Commission for Europe

UNFCCC .... United Nations Framework Convention on Climate Change

Chemical Formulas

Al .... aluminium

Al_2O_3 .... alumina

CaC_2 .... calcium carbide

$CaCO_3$............ calcium carbonate; limestone

$CaMg(CO_3)_2$ .... dolomite (also $CaCO_3 \cdot MgCO_3$)

CaO .... lime; quicklime; calcined limestone

CF_4.................. carbon tetrafluoride

C_2F_6................. carbon hexafluoride

CH_3OH .... methanol

CH_4 .... methane

C_2H_6 .... ethane

C_3H_8 .... propane

C_4H_{10} .... butane

C_2H_4 .... ethylene

C_6H_6 .... benzene

$CHCl_3$ .... chloroform

CO .... carbon monoxide

CO_2 .... carbon dioxide

CO_2 eq .... carbon dioxide equivalent

H_2.................... hydrogen

H_2O .... water

H_2S.................. hydrogen sulphide

HCFC .... hydrochlorofluorocarbon

HCl.................. hydrochloric acid

HF .... hydrogen fluoride

HNO_3.............. nitric acid

K_2CO_3............. potassium carbonate

Mg................... magnesium

$MgCO_3$ .... magnesite; magnesium carbonate

MgO .... magnesia; dolomitic lime

N ....nitrogen

N_2...................nitrogen gas

Na_2CO_3...........sodium carbonate; soda ash

Na_3AlF_6 ....cryolite

NF_3.................nitrogen trifluoride

NH_3 ....ammonia

NH_4+ ....ammonium

NH_4NO_3 ....ammonium nitrate

N_2O ....nitrous oxide

N_2O-N ....nitrous oxide emissions represented in terms of nitrogen

NO ....nitric oxide

NO_2 ....nitrogen dioxide

NO_3- ....nitrate

NO_x ....nitrogen oxides

O_2...................oxygen

SF_6.................sulphur hexafluoride

SiC ....silicon carbide

SO_2 ....sulphur dioxide

SO_x ....sulphur oxides

Notation Keys

IE ....included elsewhere

NA..................not applicable

NE..................not estimated

NO ....not occurring

Units

g.....................gram

Gg ....gigagram

Gt...................gigatonne

ha...................hectare

kg...................kilogram

kha ....kilohectare

km ....kilometre

kt....................kilotonne

kWh................kilowatt-hour

m....................metre

Mg..................megagram

Mha................million hectares

mm ....millimetre

ML..................megalitre

Mt...................megatonne

MW.................megawatt

PJ...................petajoule

t......................tonne

TWh ....terrawatt-hour

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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE SECTOR ROUNDING PROTOCOL

A rounding protocol has been developed for the emission and removal estimates presented by activity sectors defined by the Intergovernmental Panel on Climate Change (IPCC) (Annexes 9 and 11) in order to reflect their uncertainty levels. The accuracy of a value is reflected by presenting the emission and removal estimates rounded to an appropriate number of significant figures based on the uncertainty of the category in question. The number of significant figures to which each source and sink category has been rounded, using the rounding rules provided in this protocol, can be found in Table A8–1.

A large number of the uncertainty ranges that are used for the various categories were developed using Monte Carlo analysis, as performed by ICF Consulting (ICF Consulting, 2004, 2005), using the 2001 inventory estimates submitted in the NIR 2003. Default uncertainty values published by the IPCC (IPCC/OECD/IEA, 1997; IPCC, 2001; IPCC, 2006) and those resulting from expert elicitation were also utilized for some ranges. Since 2004–2005, many methodological changes, refinements and updates, including updates to the uncertainty parameters themselves, have been made. The uncertainty ranges have been calculated around the mean values established by these analyses.

For a more complete description of the analysis of uncertainty in Canada's emission estimates, please refer to Annex 2, which includes tables of current uncertainty values. Recent updates to uncertainty estimates are provided in the respective sectoral chapters.

The following uncertainty values have been used to establish the number of significant figures (up to a maximum of 2 decimal places) to which the estimates have been rounded:

- uncertainty greater than 50%: one significant figure
- uncertainty between 10% and 50%: two significant figures
- uncertainty less than 10%: three significant figures

Note that for Land Use, Land-Use Change and Forestry, the rounding rules mentioned above are generally followed, except in some cases where there is a requirement to explain specific details of estimates or trends that may be masked by rounding. In those cases, 2 significant figures are used in spite of some high uncertainty ranges that suggest to use only one significant figures (Refer to Chapter 6 for more details).

This rounding protocol does not apply to estimates presented by Canadian Economic Sectors (Annexes 10 and 12) which have been rounded to the nearest 1 Mt and 0.1 Mt for National-level estimates (Annex 10) and provincial/territorial-level estimates (Annex 12), respectively.

All calculations, including the summing of emission totals, were made using unrounded data. The rounding protocol was applied only after the calculations had been completed. The reader should also note that formatting this report limits the maximum number of decimal places and, therefore, even though a zero entry is recorded, some emissions may exist in that category (zero emissions are identified with a dash "-"). As a result of these procedures, individual values in the emission tables may not add up to the subtotals and/or overall totals.

Table A8–1 **Number of Significant Figures Applied to IPCC Sector GHG Summary Tables**

Greenhouse Gas Categories	Number of Significant Figures							
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	TOTAL
TOTAL	**3**	**2**	**2**	**2**	**2**	**2**	**1**	**3**
ENERGY	**3**	**2**	**1**					**3**
a. Stationary Combustion Sources	**3**	**1**	**1**					**3**
Public Electricity and Heat Production	3	2	1					3
Petroleum Refining Industries	3	1	1					3
Oil and Gas Extraction	3	1	1					3
Mining	3	1	1					3
Manufacturing Industries	3	2	2					3
Iron and Steel	3	1	1					3
Non-Ferrous Metals	3	2	1					3
Chemical	3	2	1					3
Pulp and Paper	3	1	1					3
Cement	3	1	1					3
Other Manufacturing	3	1	1					3
Construction	3	2	2					3
Commercial and Institutional	3	2	1					3
Residential	3	1	1					3
Agriculture and Forestry	3	1	1					3
b. Transport	**3**	**2**	**2**					**3**
Aviation	3	1	2					3
Domestic Aviation (Civil)	3	1	1					3
Military	3	1	2					3
Road Transportation	3	1	2					3
Light-Duty Gasoline Vehicles	3	1	2					3
Light-Duty Gasoline Trucks	3	1	2					3
Heavy-Duty Gasoline Vehicles	3	1	2					3
Motorcycles	3	1	2					3
Light-Duty Diesel Vehicles	3	1	2					3
Light-Duty Diesel Trucks	3	1	2					3
Heavy-Duty Diesel Vehicles	3	1	2					3
Propane and Natural Gas Vehicles	3	1	2					3
Railways	3	1	1					3
Marine	3	2	1					3
Domestic Navigation	3	2	1					3
Fishing	3	1	1					3
Military Water-Borne Navigation	3	2	1					3
Other Transportation	3	2	1					3
Off-Road Agriculture and Forestry	3	2	1					3
Off-Road Commercial and Institutional	3	2	1					3
Off-Road Manufacturing, Mining and Construction	3	2	1					3
Off-Road Residential	3	2	1					3
Off-Road Other Transportation	3	2	1					3
Pipeline Transport	3	2	1					3
c. Fugitive Sources	**2**	**2**	**2**					**2**
Coal Mining		1						1
Oil and Natural Gas	2	2	1					2
Oil	2	2	1					2
Natural Gas	2	2	1					2
Venting	3	3	1					3
Flaring	3	3	1					3
d. CO_2 Transport and Storage	**1**							**1**
INDUSTRIAL PROCESSES AND PRODUCT USE	**3**	**2**	**3**	**2**	**3**	**2**	**1**	**3**
a. Mineral Products	**2**							**2**
Cement Production	3							3
Lime Production	3							3
Mineral Product Use	2							2
b. Chemical Industry	**3**	**2**	**3**					**3**
Ammonia Production	3							3
Nitric Acid Production			3					3
Adipic Acid Production			2					2
Petrochemical and Carbon Black Production	3	2	3					3
c. Metal Production	**3**	**1**			**3**	**3**		**3**
Iron and Steel Production	3	1						3
Aluminium Production	3				3	3		3
SF_6 Used in Magnesium Smelters and Casters						3		3
d. Production and Consumption of Halocarbons, SF_6 and NF_3				**2**	**2**	**2**	**1**	**2**
e. Non-Energy Products from Fuels and Solvent Use	**2**							**2**
f. Other Product Manufacture and Use	**2**		**2**		**1**	**2**		**2**
AGRICULTURE	**2**	**2**	**2**		**2**	**2**		**2**
a. Enteric Fermentation		**2**						**2**
b. Manure Management		**2**	**1**					**2**
c. Agricultural Soils			**2**					**2**
Direct Sources			2					2
Indirect Sources			1					1
d. Field Burning of Agricultural Residues		**1**	**1**					**1**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**2**							**2**
WASTE	**1**	**2**	**1**					**2**
a. Solid Waste Disposal (Landfills)		**2**						**2**
b. Biological Treatment of Solid Waste		**1**	**1**					**1**
c. Wastewater Treatment and Discharge		**2**	**1**					**2**
d. Incineration and Open Burning of Waste	**2**	**1**	**1**					**2**
e. Industrial Wood Waste Landfills	**1**	**1**	**1**					**1**
LAND USE, LAND-USE CHANGE AND FORESTRY	**2**	**2**	**2**					**2**
a. Forest Land	**2**	**1**	**1**					**2**
b. Cropland	**2**	**2**	**2**					**2**
c. Grassland		**1**	**1**					**1**
d. Wetlands	**2**	**2**	**2**					**2**
e. Settlements	**2**	**2**	**2**					**2**
f. Harvested Wood Products	**2**							**2**

CANADA'S GREENHOUSE GAS EMISSION TABLES BY IPCC SECTOR, 1990–2019

In this National Inventory Report, emission estimates are primarily presented for each of the activity sectors defined by the Intergovernmental Panel on Climate Change (IPCC): Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land-Use Change and Forestry, and Waste. This is consistent with the categorization outlined in the *UNFCCC Reporting Guidelines on annual inventories* for Parties included in Annex I to the Convention (Decision 24/CP.19).[1]

This annex contains category descriptions and summary tables (Table A9–1 to Table A9–3) illustrating national GHG emissions by year, by gas and by IPCC sector. National GHG emissions allocated to Canadian economic sectors are provided in Annex 10 of this report.

Canada's greenhouse gas emission tables are also available in electronic file format online at https://open.canada.ca.

1 Available online at http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf.

Table A9–1 GHG Source/Sink Category Descriptions

GHG Source/Sink Categories		
ENERGY		
a.	**Stationary Combustion Sources**	
	Public Electricity and Heat Production	Emissions from fuel consumed by utility electricity generation and steam production (for sale)
	Petroleum Refining Industries	Emissions from fuel consumed by petroleum refining industries
	Oil and Gas Extraction	Emissions from fuel consumed by oil and gas extraction industries
	Mining	Emissions from fuel consumed by:
		– Metal and non-metal mines, coal mines, stone quarries, and gravel pits
		– Mineral exploration and contract drilling operations
	Manufacturing Industries	Emissions from fuel consumed by the following industries:
		– Iron and Steel (steel foundries, casting and rolling mills)
		– Non-ferrous metals (aluminium, magnesium and other production)
		– Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
		– Pulp and Paper (primarily pulp, paper, and paper product manufacturers)
		– Cement and other non-metallic mineral production
		– Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
	Construction	Emissions from fuels consumed by the construction industry—buildings, highways etc.
	Commercial and Institutional	Emissions from fuel consumed by:
		– Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.)
		– Federal, provincial and municipal establishments
		– National Defence and Canadian Coast Guard
		– Train stations, airports and warehouses
	Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums and farm houses)
	Agriculture and Forestry	Emissions from fuel consumed by:
		– Forestry and logging service industry
		– Agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)
b.	**Transport**	Emissions resulting from the:
	Aviation	– Consumption of fossil fuels by civilian aircrafts flying domestically and all military aircraft operations with Canadian purchased fuel
	Domestic Aviation (Civil)	– Consumption of fossil fuels by civilian aircraft flying domestically with Canadian purchased fuel
	Military	– Consumption of fossil fuels by military aircraft operations with Canadian purchased fuel
	Road Transportation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by vehicles licensed to operate on roads
	Railways	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by Canadian railways
	Marine	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by marine vessels navigating between Canadian ports (inclusive of all fishing and military operations)
	Domestic Navigation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by marine vessels navigating between Canadian ports
	Fishing	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by fishing vessels operating in Canadian waters
	Military Water-Borne Navigation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by military vessels operating in Canadian waters
	Others – Off-Road	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads
	Others – Pipeline Transport	– Transportation and distribution of crude oil, natural gas and other products
c.	**Fugitive Sources**	Intentional and unintentional releases of greenhouse gases from the following activities:
	Coal Mining	– Underground and surface mining, abandoned underground coal mines
	Oil and Natural Gas	– Conventional and unconventional oil and gas exploration, production, transportation and distribution
d.	**CO_2 Transport and Storage**	Intentional and unintentional releases of greenhouse gases from the transport and storage of carbon dioxide
INDUSTRIAL PROCESSES AND PRODUCT USE		Emissions resulting from the following process activities:
a.	**Mineral Products**	– Cement production, lime production, and mineral product use (which includes glass production, other uses of soda ash, magnesite use, and other limestone and dolomite use)
b.	**Chemical Industry**	– Production of ammonia, nitric acid, adipic acid, carbide and petrochemicals. Petrochemical production includes production of carbon black, ethylene, ethylene dichloride, ethylene oxide, methanol, styrene and other uses of urea.
c.	**Metal Production**	– Aluminum production, iron and steel production, and magnesium production and casting
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	– By-product production of HFC-23; use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry, and use of SF_6 and NF_3 in semiconductor manufacturing
e.	**Non-Energy Products from Fuels and Solvent Use**	– Non-energy use of fossil fuels (including solvents and lubricants) that are not accounted for elsewhere under the Industrial Processes and Product Use Sector
f.	**Other Product Manufacture and Use**	– Use of N_2O as an anaesthetic and propellant; use of urea in selective catalytic reduction (SCR) equipped vehicles; use of SF_6 in electrical equipment; and PFCs in electronics industry
AGRICULTURE		Emissions resulting from:
a.	**Enteric Fermentation**	– Eructation of CH_4 during the digestion of plant material by (mainly) ruminants
b.	**Manure Management**	– Release of CH_4 and N_2O due to microbial activity during the storage of feces, urine and bedding materials from the cleaning of barns and pens
		– Indirect N_2O emissions from volatilization and leaching of nitrogen from animal manure during storage
c.	**Agricultural Soils**	
	Direct sources	– Direct N_2O emissions from inorganic nitrogen fertilizers, manure and biosolids applied on cropland, pasture range and paddock, crop residue, tillage, summerfallow, irrigation and cultivation of organic soils
	Indirect Sources	– Indirect N_2O emissions from volatilization and leaching of animal manure and biosolid nitrogen, inorganic nitrogen fertilizer and crop residue nitrogen
d.	**Field Burning of Agricultural Residues**	– CH_4 and N_2O emissions from crop residue burning
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	– Direct emissions of CO_2 from the application of lime, urea and other fertilizers containing carbon
WASTE		Emissions resulting from:
a.	**Solid Waste Disposal (Landfills)**	– Municipal solid waste management sites (landfills)
b.	**Biological Treatment of Solid Waste**	– Composting and anaerobic digestion of municipal solid waste
c.	**Wastewater Treatment and Discharge**	– Municipal and industrial wastewater treatment
d.	**Incineration and Open Burning of Waste**	– Municipal solid, hazardous and clinical waste, and sewage sludge incineration
e.	**Industrial Wood Waste Landfills**	– Private, dedicated wood waste landfills
LAND USE, LAND-USE CHANGE AND FORESTRY		Emissions and removals resulting from:
a.	**Forest Land**	– Managed forests and lands converted to forests; reports emissions and removals from forest growth and anthropogenic disturbances related to forest management but tracks separately emissions and removals from fire and most insect disturbances
b.	**Cropland**	– Management practices on lands in annual crops, summerfallow and perennial crops (forage, specialty crops, orchards); immediate and residual emissions from lands converted to cropland
c.	**Grassland**	– Managed agricultural grassland
d.	**Wetlands**	– Peatlands disturbed for peat extraction, or land flooded from hydro reservoir development
e.	**Settlements**	– Forest and grassland converted to built-up land (settlements, transport infrastructure, oil & gas infrastructure, mining, etc); urban tree growth
f.	**Harvested Wood Products**	– Use and disposal of harvested wood products manufactured from wood coming from forest harvest and forest conversion activities in Canada

Table A9–2 **Canada's 1990–2019 GHG Emissions by IPCC Sector**

Greenhouse Gas Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	kt CO_2 eq																													
TOTAL[a]	**602 000**	**596 000**	**614 000**	**617 000**	**638 000**	**656 000**	**679 000**	**691 000**	**697 000**	**710 000**	**734 000**	**723 000**	**727 000**	**745 000**	**746 000**	**739 000**	**730 000**	**752 000**	**736 000**	**694 000**	**703 000**	**714 000**	**717 000**	**725 000**	**723 000**	**723 000**	**707 000**	**716 000**	**728 000**	**730 000**
ENERGY	**472 000**	**463 000**	**481 000**	**482 000**	**498 000**	**513 000**	**531 000**	**547 000**	**555 000**	**569 000**	**592 000**	**584 000**	**585 000**	**600 000**	**595 000**	**591 000**	**584 000**	**608 000**	**593 000**	**562 000**	**569 000**	**577 000**	**575 000**	**583 000**	**584 000**	**585 000**	**566 000**	**578 000**	**588 000**	**589 000**
a. Stationary Combustion Sources	**278 000**	**273 000**	**283 000**	**278 000**	**283 000**	**291 000**	**300 000**	**308 000**	**310 000**	**322 000**	**345 000**	**341 000**	**343 000**	**355 000**	**347 000**	**341 000**	**333 000**	**354 000**	**342 000**	**320 000**	**321 000**	**327 000**	**321 000**	**322 000**	**323 000**	**324 000**	**311 000**	**316 000**	**318 000**	**319 000**
Public Electricity and Heat Production	94 500	95 900	102 000	93 200	95 400	98 800	98 400	110 000	123 000	120 000	132 000	133 000	128 000	133 000	126 000	125 000	119 000	124 000	116 000	100 000	102 000	94 500	91 300	87 500	83 800	87 000	80 500	78 400	69 800	68 600
Petroleum Refining Industries	17 000	16 000	17 000	17 000	16 000	16 000	19 000	19 000	18 000	17 000	17 000	18 000	19 000	20 000	22 000	20 000	20 000	21 000	19 000	19 000	19 000	18 000	18 000	17 000	16 000	16 000	16 000	14 000	15 000	15 000
Oil and Gas Extraction	30 800	29 300	31 200	34 400	35 100	36 400	36 700	35 100	37 700	48 700	52 700	55 600	58 700	63 000	61 200	63 300	67 900	75 800	75 300	77 700	78 100	84 500	88 100	91 100	94 900	97 500	94 000	97 500	104 000	105 000
Mining	4 650	4 320	3 730	4 020	4 580	4 970	5 070	5 230	4 670	4 470	4 890	4 890	4 520	4 910	4 790	4 330	5 140	5 710	6 060	5 650	5 740	5 780	6 270	5 460	5 080	4 580	4 340	4 910	6 310	6 420
Manufacturing Industries	56 200	53 900	53 000	50 800	54 200	56 000	57 600	57 700	54 700	55 800	55 900	51 600	51 300	49 200	50 900	48 000	46 200	47 200	44 600	39 900	41 200	44 200	43 700	44 800	45 000	43 400	41 900	42 100	42 000	42 400
Iron and Steel	4 950	4 960	5 290	5 390	6 020	5 780	6 150	6 160	6 230	6 330	6 210	5 010	5 860	5 530	5 830	5 550	5 550	6 000	5 770	4 290	4 980	5 290	5 500	5 580	6 030	5 700	5 560	5 940	6 300	5 970
Non-Ferrous Metals	3 310	2 700	2 940	2 830	3 430	3 220	4 010	3 890	3 880	3 690	3 580	3 780	3 520	3 530	3 540	3 660	3 490	3 850	3 830	2 930	3 070	3 420	2 970	3 100	2 920	3 110	3 190	3 220	2 790	2 830
Chemical	8 260	8 650	8 600	8 530	10 000	10 300	9 920	10 200	10 800	11 200	10 700	9 470	9 030	8 150	8 970	8 330	8 890	8 720	8 800	8 880	9 920	11 100	11 000	11 600	12 400	12 000	10 700	9 640	9 280	9 420
Pulp and Paper	14 500	14 000	13 000	13 000	12 900	12 800	13 400	13 200	12 100	12 500	12 600	11 600	10 900	10 400	10 200	8 650	7 490	7 740	6 270	6 390	5 970	6 220	5 990	6 230	6 090	5 950	5 950	6 320	6 970	7 310
Cement	3 970	3 440	3 400	3 470	4 070	4 160	4 130	4 040	4 190	4 460	4 640	4 600	4 970	4 990	5 460	5 410	5 720	5 030	4 910	4 490	4 080	4 310	4 030	3 850	4 000	3 910	3 920	4 150	4 160	4 220
Other Manufacturing	21 200	20 200	19 800	17 600	17 800	19 700	20 000	20 200	17 500	17 600	18 200	17 200	17 000	16 700	16 900	16 400	15 100	15 800	15 000	12 900	13 200	13 800	14 200	14 400	13 500	12 800	12 600	12 800	12 500	12 600
Construction	1 880	1 630	1 760	1 390	1 400	1 180	1 270	1 260	1 120	1 170	1 080	1 030	1 270	1 350	1 420	1 450	1 410	1 410	1 390	1 230	1 520	1 370	1 390	1 290	1 300	1 300	1 280	1 290	1 360	1 360
Commercial and Institutional	26 200	26 900	27 500	28 500	27 800	29 400	30 000	30 400	27 800	29 400	33 400	32 700	34 200	35 400	34 100	32 600	29 700	30 800	30 400	30 200	28 700	30 700	28 700	29 700	31 300	30 100	30 100	32 500	33 200	34 400
Residential	43 800	42 300	43 600	45 500	46 200	44 900	49 700	46 300	40 700	42 400	44 700	41 700	43 700	45 900	44 400	43 700	41 600	46 100	45 400	43 600	40 800	43 800	40 200	41 800	41 400	40 500	38 900	40 900	42 500	42 200
Agriculture and Forestry	2 410	2 740	3 250	3 050	2 550	2 770	2 930	2 920	2 600	2 680	2 570	2 240	2 160	2 300	2 210	2 190	2 110	2 690	2 750	2 760	3 110	3 680	3 780	3 790	3 840	3 630	3 810	3 700	3 760	3 690
b. Transport[b]	**145 000**	**140 000**	**143 000**	**147 000**	**154 000**	**159 000**	**163 000**	**169 000**	**172 000**	**176 000**	**177 000**	**175 000**	**177 000**	**181 000**	**185 000**	**190 000**	**189 000**	**193 000**	**192 000**	**186 000**	**194 000**	**195 000**	**195 000**	**200 000**	**199 000**	**201 000**	**201 000**	**207 000**	**215 000**	**217 000**
Aviation	7 510	6 500	6 390	6 020	6 380	6 700	7 080	7 240	7 500	7 890	7 800	7 150	7 020	7 140	7 630	7 720	7 740	7 820	7 460	6 640	6 690	6 590	7 600	7 880	7 590	7 590	7 520	7 940	8 660	8 540
Domestic Aviation (Civil)	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Military	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Road Transportation	83 800	79 900	80 400	81 900	85 600	86 600	90 400	96 400	103 000	108 000	111 000	116 000	118 000	122 000	125 000	130 000	130 000	133 000	133 000	132 000	137 000	139 000	140 000	144 000	142 000	143 000	145 000	148 000	152 000	153 000
Light-Duty Gasoline Vehicles	41 600	39 900	40 200	40 700	41 100	40 400	40 000	40 100	40 400	40 500	40 400	41 500	41 900	41 800	41 200	41 400	40 400	39 700	38 500	38 100	37 800	36 500	35 400	35 600	34 200	34 500	34 600	33 700	33 000	32 400
Light-Duty Gasoline Trucks	20 300	19 700	20 100	20 600	22 500	23 900	25 300	27 100	28 900	30 800	31 800	33 400	34 700	36 000	37 100	38 100	38 600	39 300	39 000	39 900	41 300	41 400	41 900	43 300	43 400	45 300	48 100	49 200	51 100	53 100
Heavy-Duty Gasoline Vehicles	6 320	6 360	6 680	7 170	7 350	7 170	7 940	8 810	9 850	10 300	10 500	11 600	11 700	12 000	12 600	11 700	11 900	12 000	12 100	12 200	12 500	12 100	12 800	13 400	12 400	12 300	13 000	13 300	13 400	13 500
Motorcycles	90	87	85	83	81	78	75	74	72	110	123	144	161	176	189	203	216	225	231	239	248	251	260	262	260	271	287	296	296	298
Light-Duty Diesel Vehicles	467	403	383	379	397	400	408	455	500	537	600	603	642	710	762	605	658	669	619	574	663	793	798	855	857	901	842	842	811	779
Light-Duty Diesel Trucks	153	138	134	138	150	156	182	222	259	294	338	363	370	408	442	344	329	347	366	368	421	482	473	531	641	812	903	1 080	1 180	1 210
Heavy-Duty Diesel Vehicles	13 600	12 200	11 800	12 100	13 100	13 600	15 700	18 900	21 900	24 700	26 500	27 900	27 800	30 300	32 100	36 800	38 000	40 400	42 000	40 300	44 200	47 600	48 700	50 000	49 800	48 500	46 900	49 300	51 900	51 800
Propane and Natural Gas Vehicles	1 160	1 140	1 070	724	913	903	797	762	795	643	522	574	465	429	430	381	293	199	126	62	38	40	30	18	9	8	9	10	10	10
Railways	6 920	6 410	6 700	6 680	6 910	6 260	6 120	6 210	5 980	6 330	6 530	6 470	5 950	6 010	6 180	6 580	6 890	7 380	7 800	6 670	6 540	7 390	7 560	7 290	7 470	7 120	6 540	7 490	7 650	7 700
Marine	3 070	3 130	3 180	3 230	3 280	3 330	3 380	3 440	3 490	3 540	3 600	3 670	3 750	3 820	3 900	3 980	3 920	3 860	3 800	3 740	3 680	3 630	3 580	3 530	3 480	3 430	3 510	3 650	3 830	4 360
Domestic Navigation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fishing	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	-	-	-	-	-	-	-
Military Water-Borne Navigation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	-	100	100	-	100
Other Transportation	43 600	43 500	46 600	49 300	52 100	55 600	55 600	55 400	52 100	50 900	48 800	42 200	42 500	42 300	42 900	41 900	40 500	40 600	39 800	37 600	39 500	38 400	36 100	37 700	39 000	40 500	38 900	40 400	43 300	43 100
Off-Road Agriculture and Forestry	9 040	9 090	9 180	10 200	11 400	12 400	12 600	12 900	12 400	11 700	11 600	10 500	10 300	11 200	11 400	11 400	10 700	11 000	10 600	10 200	11 100	11 000	10 400	10 500	10 400	10 400	9 650	10 400	11 200	11 200
Off-Road Commercial and Institutional	1 520	1 490	1 570	1 690	1 830	1 990	2 010	2 090	2 070	2 020	2 080	2 130	2 060	2 290	2 420	2 400	2 390	2 540	2 550	2 460	2 680	2 730	2 520	2 720	2 760	2 720	2 550	2 820	2 900	2 960
Off-Road Manufacturing, Mining and Construction	9 160	9 100	9 720	10 400	11 300	12 400	12 500	12 600	10 800	10 700	11 300	9 910	10 100	11 000	11 200	10 400	10 200	11 100	11 700	11 200	12 600	13 200	12 000	12 300	12 200	13 100	12 200	13 500	14 500	14 300
Off-Road Residential	241	238	248	284	327	380	451	531	615	705	775	913	1 030	1 150	1 250	1 250	1 230	1 240	1 200	1 160	1 170	1 300	1 220	1 180	1 210	1 220	1 170	1 190	1 230	1 240
Off-Road Other Transportation	16 700	16 000	16 000	16 300	16 400	16 300	15 600	14 700	13 700	13 300	11 700	8 440	8 110	7 600	7 990	6 390	6 260	6 320	6 220	6 150	6 300	4 450	4 310	4 300	4 540	4 830	4 920	5 120	5 260	5 050
Pipeline Transport	6 900	7 650	9 890	10 400	10 800	12 000	12 500	12 600	12 500	12 600	11 300	10 300	10 900	9 120	8 550	10 200	9 690	8 440	7 520	6 360	5 710	5 650	5 730	6 720	7 890	8 160	8 420	7 420	8 190	8 290
c. Fugitive Sources	**49 000**	**51 000**	**55 000**	**57 000**	**61 000**	**64 000**	**68 000**	**70 000**	**73 000**	**70 000**	**69 000**	**67 000**	**65 000**	**63 000**	**63 000**	**61 000**	**61 000**	**61 000**	**59 000**	**55 000**	**55 000**	**56 000**	**59 000**	**61 000**	**63 000**	**59 000**	**54 000**	**55 000**	**55 000**	**54 000**
Coal Mining	3 000	3 000	2 000	3 000	3 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	2 000	1 000	1 000	1 000	1 000	1 000	1 000
Oil and Natural Gas	46 000	48 000	52 000	55 000	58 000	62 000	66 000	68 000	71 000	68 000	68 000	66 000	63 000	62 000	61 000	60 000	60 000	59 000	58 000	54 000	54 000	54 000	57 000	59 000	61 000	58 000	53 000	54 000	53 000	52 000
Oil	5 000	5 200	5 600	5 600	5 700	6 200	6 400	6 700	6 500	6 500	6 600	6 900	6 600	6 400	6 300	5 900	5 800	5 700	5 400	5 100	5 100	4 900	5 700	5 700	5 600	5 400	5 200	5 200	5 500	5 600
Natural Gas	13 000	14 000	15 000	15 000	16 000	17 000	19 000	18 000	20 000	19 000	18 000	16 000	14 000	14 000	14 000	14 000	14 000	13 000	13 000	13 000	12 000	12 000	12 000	13 000	13 000	12 000	12 000	12 000	12 000	12 000
Venting	23 000	24 000	27 000	29 000	31 000	33 000	35 000	37 000	37 000	37 000	38 000	38 000	37 000	37 000	36 000	35 000	35 000	35 000	35 000	32 000	31 000	32 000	34 000	33 000	36 000	34 000	29 000	29 000	29 000	28 000
Flaring	4 700	5 000	5 200	5 000	5 400	5 400	5 700	5 700	7 500	5 700	5 800	5 200	5 800	5 000	5 200	5 300	5 700	5 400	4 900	4 300	4 700	5 000	5 800	7 000	7 300	6 900	5 900	6 600	6 600	6 300
d. CO_2 Transport and Storage	-	-	-	-	-	-	-	-	-	-	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.10**	**0.20**	**0.30**	**0.30**	**0.30**	**0.30**
INDUSTRIAL PROCESSES AND PRODUCT USE	**57 000**	**58 400**	**56 200**	**55 900**	**57 800**	**58 400**	**60 700**	**60 200**	**57 100**	**54 600**	**54 100**	**52 100**	**54 000**	**56 100**	**60 200**	**56 600**	**57 000**	**55 600**	**54 800**	**47 500**	**50 700**	**54 300**	**58 500**	**56 200**	**53 900**	**53 500**	**54 500**	**53 000**	**54 300**	**54 300**
a. Mineral Products	**8 500**	**7 600**	**7 300**	**7 400**	**8 500**	**9 200**	**8 900**	**9 600**	**9 700**	**9 900**	**10 000**	**9 400**	**9 700**	**9 700**	**10 000**	**10 000**	**10 000**	**10 000**	**9 300**	**7 200**	**7 800**	**8 000**	**8 500**	**7 800**	**7 800**	**8 000**	**7 900**	**8 600**	**8 700**	**8 800**
Cement Production	5 800	4 800	4 800	4 900	5 800	6 500	6 200	6 700	6 800	7 100	7 200	7 000	7 100	7 200	7 500	7 600	7 700	7 700	7 000	5 400	6 000	6 000	6 500	6 000	5 900	6 200	6 200	6 900	7 000	7 200
Lime Production	1 800	1 800	1 900	1 900	1 900	1 900	1 900	1 900	1 900	2 000	1 900	1 700	1 700	1 700	1 800	1 800	1 700	1 600	1 600	1 200	1 400	1 500	1 500	1 400	1 500	1 400	1 400	1 400	1 400	1 300
Mineral Product Use	860	980	670	660	820	750	890	990	940	790	910	770	820	790	880	910	880	810	750	610	410	450	440	380	380	410	390	330	320	320
b. Chemical Industry	**17 600**	**17 000**	**16 800**	**16 900**	**19 100**	**18 500**	**19 500**	**17 600**	**13 500**	**10 000**	**8 810**	**8 740**	**8 990**	**9 270**	**11 500**	**10 400**	**9 000**	**8 280**	**9 090**	**5 930**	**5 850**	**6 490**	**6 780**	**6 680**	**6 430**	**6 740**	**6 960**	**6 350**	**6 850**	**6 810**
Ammonia Production	2 800	2 780	2 550	2 950	3 060	2 960	2 830	2 830	3 130	3 030	2 990	2 630	2 660	2 660	2 960	2 740	2 810	2 600	2 830	2 430	2 520	2 910	3 030	2 980	2 560	2 880	2 820	2 580	2 460	2 550
Nitric Acid Production	973	1 020	1 040	1 010	919	965	1 060	1 020	995	1 120	1 180	1 230	1 210	1 220	1 180	1 200	1 190	1 090	780	456	479	476	358	310	213	225	261	245	272	258
Adipic Acid Production	10 000	9 600	9 600	8 700	11 000	10 000	11 000	9 500	4 900	1 700	870	770	1 200	1 000	3 000	2 500	1 200	1 400	2 300	640	-	-	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production	3 520	3 570	3 600	4 180	4 530	4 310	4 560	4 230	4 470	4 170	3 780	4 100	3 920	4 360	4 370	3 960	3 840	3 160	3 170	2 420	2 850	3 110	3 390	3 400	3 650	3 630	3 880	3 520	4 110	4 000
c. Metal Production	**23 800**	**26 800**	**25 600**	**25 400**	**23 900**	**23 500**	**23 200**	**23 000**	**24 000**	**23 200**	**23 400**	**21 400**	**21 300**	**21 000**	**20 500**	**20 200**	**20 700**	**19 300**	**19 000**	**15 900**	**16 000**	**16 900**	**16 700**	**14 800**	**15 000**	**14 400**	**15 300**	**14 600**	**14 500**	**13 800**
Iron and Steel Production	10 500	12 100	12 400	11 900	11 000	11 500	11 300	11 100	11 400	11 600	11 800	10 800	10 600	10 500	10 600	10 300	11 300	11 100	10 800	8 140	8 980	9 880	9 980	8 050	8 890	8 470	9 220	8 450	8 870	8 260
Aluminium Production	10 300	11 200	10 900	11 400	10 700	10 000	10 400	10 300	10 500	9 340	8 890	8 260	7 930	8 130	7 770	8 680	8 080	7 630	7 760	7 540	6 870	6 810	6 470	6 530	5 830	5 720	5 990	6 010	5 510	5 290
SF_6 Used in Magnesium Smelters and Casters	2 960	3 420	2 290	2 110	2 180	2 010	1 560	1 600	2 100	2 160	2 660	2 250	2 800	2 370	2 090	1 230	1 340	489	435	184	186	184	248	214	249	238	141	140	146	290
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**980**	**1 100**	**830**	**5**	**5**	**500**	**840**	**1 100**	**1 600**	**2 200**	**2 800**	**3 200**	**3 600**	**4 000**	**4 600**	**5 100**	**5 400**	**6 100**	**6 100**	**6 900**	**7 700**	**8 600**	**9 100**	**10 000**	**11 000**	**11 000**	**11 000**	**12 000**	**13 000**	**12 000**
e. Non-Energy Products from Fuels and Solvent Use	**5 800**	**5 600**	**5 300**	**5 900**	**6 000**	**6 300**	**7 900**	**8 500**	**7 800**	**8 800**	**8 500**	**8 700**	**9 900**	**12 000**	**13 000**	**10 000**	**11 000**	**11 000**	**11 000**	**11 000**	**13 000**	**14 000**	**17 000**	**16 000**	**13 000**	**13 000**	**12 000**	**11 000**	**11 000**	**12 000**
f. Other Product Manufacture and Use	**370**	**370**	**350**	**350**	**360**	**390**	**350**	**390**	**500**	**580**	**610**	**680**	**520**	**610**	**630**	**540**	**520**	**540**	**530**	**470**	**430**	**390**	**500**	**560**	**480**	**570**	**620**	**660**	**730**	**750**
AGRICULTURE	**47 000**	**47 000**	**48 000**	**50 000**	**52 000**	**54 000**	**55 000**	**55 000**	**56 000**	**56 000**	**57 000**	**56 000**	**56 000**	**58 000**	**59 000**	**60 000**	**59 000**	**58 000**	**59 000**	**56 000**	**55 000**	**55 000**	**57 000**	**59 000**	**58 000**	**58 000**	**59 000**	**58 000**	**59 000**	**59 000**
a. Enteric Fermentation	**22 000**	**23 000**	**24 000**	**24 000**	**25 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**28 000**	**29 000**	**29 000**	**29 000**	**30 000**	**31 000**	**30 000**	**29 000**	**28 000**	**26 000**	**25 000**	**25 000**	**25 000**	**25 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**
b. Manure Management	**6 100**	**6 200**	**6 500**	**6 600**	**6 900**	**7 200**	**7 400**	**7 400**	**7 600**	**7 800**	**8 000**	**8 300**	**8 400**	**8 500**	**8 700**	**8 800**	**8 700**	**8 400**	**8 100**	**7 900**	**7 700**	**7 700**	**7 700**	**7 800**	**7 700**	**7 800**	**7 900**	**7 900**	**7 900**	**7 900**
c. Agricultural Soils	**17 000**	**16 000**	**17 000**	**17 000**	**18 000**	**18 000**	**19 000**	**19 000**	**19 000**	**19 000**	**19 000**	**18 000**	**17 000**	**19 000**	**19 000**	**19 000**	**19 000**	**19 000**	**21 000**	**20 000**	**20 000**	**21 000**	**22 000**	**24 000**	**23 000**	**24 000**	**25 000**	**24 000**	**25 000**	**24 000**
Direct Sources	14 000	14 000	14 000	14 000	15 000	15 000	16 000	16 000	16 000	16 000	16 000	15 000	14 000	15 000	16 000	15 000	15 000	16 000	17 000	17 000	17 000	17 000	18 000	20 000	19 000	20 000	20 000	20 000	20 000	20 000
Indirect Sources	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000
d. Field Burning of Agricultural Residues	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**100**	**100**	**100**	**100**	**100**	**30**	**100**	**50**	**40**	**50**	**50**	**30**	**30**	**40**	**50**	**50**	**60**	**50**	**50**	**50**	**50**
e. Liming, Urea Application and Other Carbon-containing Fertilizers	**1 200**	**1 100**	**1 200**	**1 200**	**1 400**	**1 500**	**1 500**	**1 600**	**1 700**	**1 500**	**1 600**	**1 400**	**1 500**	**1 600**	**1 500**	**1 400**	**1 500**	**1 700**	**1 700**	**1 800**	**1 800**	**2 000**	**2 300**	**2 700**	**2 500**	**2 600**	**2 500**	**2 400**	**2 600**	**2 600**
WASTE	**26 000**	**27 000**	**28 000**	**29 000**	**30 000**	**31 000**	**31 000**	**29 000**	**29 000**	**30 000**	**31 000**	**31 000**	**31 000**	**31 000**	**31 000**	**31 000**	**30 000**	**30 000**	**30 000**	**28 000**	**28 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**28 000**
a. Solid Waste Disposal (Landfills)	**21 000**	**22 000**	**22 000**	**23 000**	**24 000**	**25 000**	**26 000**	**23 000**	**23 000**	**24 000**	**25 000**	**25 000**	**25 000**	**25 000**	**25 000**	**25 000**	**25 000**	**24 000**	**24 000**	**23 000**	**22 000**	**22 000**	**22 000**	**22 000**	**22 000**	**22 000**	**22 000**	**22 000**	**23 000**	**23 000**
b. Biological Treatment of Solid Waste	**70**	**100**	**100**	**100**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**	**400**	**400**
c. Wastewater Treatment and Discharge	**830**	**820**	**830**	**830**	**840**	**850**	**860**	**870**	**880**	**880**	**890**	**920**	**910**	**920**	**930**	**940**	**950**	**960**	**960**	**960**	**990**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**	**1 000**
d. Incineration and Open Burning of Waste	**300**	**300**	**300**	**300**	**300**	**400**	**300**	**300**	**300**	**400**	**400**	**400**	**400**	**400**	**400**	**300**	**300**	**300**	**300**	**300**	**300**	**300**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**
e. Industrial Wood Waste Landfills	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**5 000**	**5 000**	**5 000**	**5 000**	**5 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**4 000**	**3 000**	**3 000**	**3 000**	**3 000**	**3 000**	**3 000**
LAND USE, LAND-USE CHANGE AND FORESTRY	**-57 000**	**-61 000**	**-51 000**	**-45 000**	**-45 000**	**-30 000**	**-37 000**	**-38 000**	**-50 000**	**-35 000**	**-22 000**	**-38 000**	**-20 000**	**-24 000**	**3 500**	**8 200**	**-3 900**	**-7 900**	**-13 000**	**-24 000**	**-7 300**	**-6 500**	**-9 400**	**-4 200**	**-3 500**	**4 000**	**95**	**700**	**8 400**	**9 900**
a. Forest Land	**-200 000**	**-210 000**	**-210 000**	**-200 000**	**-200 000**	**-190 000**	**-190 000**	**-190 000**	**-190 000**	**-180 000**	**-170 000**	**-170 000**	**-160 000**	**-150 000**	**-140 000**	**-130 000**	**-130 000**	**-130 000**	**-140 000**	**-140 000**	**-140 000**	**-140 000**	**-140 000**	**-140 000**	**-140 000**	**-130 000**	**-140 000**	**-140 000**	**-130 000**	**-130 000**
b. Cropland	**7 600**	**6 400**	**5 000**	**3 600**	**2 400**	**1 000**	**- 68**	**-1 300**	**-2 600**	**-3 900**	**-5 200**	**-5 400**	**-6 700**	**-8 000**	**-9 300**	**-10 000**	**-12 000**	**-12 000**	**-12 000**	**-12 000**	**-12 000**	**-11 000**	**-10 000**	**-9 300**	**-8 100**	**-7 000**	**-6 300**	**-5 700**	**-4 800**	**-4 200**
c. Grassland	**0.60**	**0.80**	**1**	**0.40**	**1**	**0.30**	**0.50**	**0.60**	**0.70**	**0.80**	**1**	**1**	**1**	**1**	**0.90**	**0.90**	**1**	**0.40**	**0.50**	**0.40**	**0.30**	**0.60**	**2**	**2**	**0.80**	**1**	**1**	**1**	**1**	**1**
d. Wetlands	**5 300**	**5 200**	**5 100**	**5 400**	**3 200**	**3 100**	**3 000**	**3 100**	**3 400**	**3 700**	**3 200**	**3 100**	**3 200**	**3 000**	**3 200**	**3 100**	**3 200**	**3 200**	**3 200**	**3 100**	**3 100**	**3 000**	**3 000**	**3 000**	**3 100**	**2 900**	**2 900**	**3 000**	**2 700**	**2 600**
e. Settlements	**1 800**	**1 800**	**1 700**	**1 500**	**1 300**	**1 200**	**1 200**	**1 200**	**1 200**	**1 300**	**1 300**	**1 300**	**1 600**	**1 600**	**1 600**	**1 700**	**2 000**	**2 100**	**2 000**	**1 700**	**1 700**	**1 800**	**1 800**	**2 200**	**2 300**	**2 600**	**2 400**	**2 200**	**2 400**	**2 200**
f. Harvested Wood Products	**130 000**	**130 000**	**140 000**	**150 000**	**150 000**	**150 000**	**150 000**	**150 000**	**140 000**	**150 000**	**150 000**	**130 000**	**140 000**	**130 000**	**150 000**	**150 000**	**140 000**	**130 000**	**130 000**	**130 000**	**140 000**	**140 000**	**140 000**	**150 000**	**140 000**	**140 000**	**140 000**	**140 000**	**140 000**	**140 000**

Notes: Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

National GHG emissions allocated to Canadian economic sectors are provided in Annex 10 of this report.

a. National totals exclude all GHGs from the Land-Use, Land-Use Change and Forestry Sector.

b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990–1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

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Table A9–3 **2019 GHG Emission Summary for Canada**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[d]	PFCs[d]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL[a, b]	**582 000**	**3 900**	**98 000**	**120**	**37 000**	**12 000**	**600**	**480**	**0.60**	**730 000**
ENERGY	**540 000**	**1 700**	**43 000**	**20**	**7 000**	**-**	**-**	**-**	**-**	**589 000**
a. Stationary Combustion Sources	**312 000**	**200**	**4 000**	**8**	**2 000**	**-**	**-**	**-**	**-**	**319 000**
Public Electricity and Heat Production	68 000	6	160	1	400	-	-	-	-	68 600
Petroleum Refining Industries	15 000	0.30	8	0.10	30	-	-	-	-	15 000
Oil and Gas Extraction	102 000	100	3 000	2	600	-	-	-	-	105 000
Mining	6 380	0.10	3	0.10	40	-	-	-	-	6 420
Manufacturing Industries	41 800	3	64	2	480	-	-	-	-	42 400
Iron and Steel	5 930	0.10	3	0.10	40	-	-	-	-	5 970
Non-Ferrous Metals	2 820	0.06	1	0.05	10	-	-	-	-	2 830
Chemical	9 370	0.18	5	0.20	50	-	-	-	-	9 420
Pulp and Paper	7 080	1	30	0.70	200	-	-	-	-	7 310
Cement	4 200	0.20	5	0.05	20	-	-	-	-	4 220
Other Manufacturing	12 400	0.70	20	0.60	200	-	-	-	-	12 600
Construction	1 350	0.03	0.62	0.04	11	-	-	-	-	1 360
Commercial and Institutional	34 100	0.83	21	0.80	200	-	-	-	-	34 400
Residential	40 300	60	1 000	2	500	-	-	-	-	42 200
Agriculture and Forestry	3 660	0.07	2	0.10	30	-	-	-	-	3 690
b. Transport[b]	**212 000**	**39**	**980**	**14**	**4 100**	**-**	**-**	**-**	**-**	**217 000**
Aviation	8 460	0.20	5	0.20	70	-	-	-	-	8 540
Domestic Aviation (Civil)	10 000	-	10	-	100	-	-	-	-	10 000
Military	-	-	0.10	0.01	-	-	-	-	-	-
Road Transportation	150 000	10	200	9	2 600	-	-	-	-	153 000
Light-Duty Gasoline Vehicles	31 800	3	70	2	520	-	-	-	-	32 400
Light-Duty Gasoline Trucks	52 100	4	100	3	840	-	-	-	-	53 100
Heavy-Duty Gasoline Vehicles	13 200	0.50	10	1	350	-	-	-	-	13 500
Motorcycles	294	0.10	3	0.01	2	-	-	-	-	298
Light-Duty Diesel Vehicles	759	0.01	0.40	0.06	19	-	-	-	-	779
Light-Duty Diesel Trucks	1 170	0.03	0.80	0.10	29	-	-	-	-	1 210
Heavy-Duty Diesel Vehicles	50 900	2	50	3	860	-	-	-	-	51 800
Propane and Natural Gas Vehicles	9	0.00	0.10	0.00	0.05	-	-	-	-	10
Railways	6 890	0.40	10	3	800	-	-	-	-	7 700
Marine	4 310	0.41	10	0.10	30	-	-	-	-	4 360
Domestic Navigation	-	-	10	-	-	-	-	-	-	-
Fishing	-	-	1	0.01	-	-	-	-	-	-
Military Water-Borne Navigation	100	0.01	-	-	1	-	-	-	-	100
Other Transportation	41 800	28	710	2	500	-	-	-	-	43 100
Off-Road Agriculture and Forestry	11 100	0.51	13	0.50	100	-	-	-	-	11 200
Off-Road Commercial and Institutional	**2 830**	**4**	**100**	**0.09**	**30**	**-**	**-**	**-**	**-**	**2 960**
Off-Road Manufacturing, Mining and Construction	14 000	2	43	0.80	300	-	-	-	-	14 300
Off-Road Residential	1 170	3	64	0.03	10	-	-	-	-	1 240
Off-Road Other Transportation	4 730	11	290	0.10	40	-	-	-	-	5 050
Pipeline Transport	8 030	8	200	0.20	60	-	-	-	-	8 290
c. Fugitive Sources	16 000	1 500	38 000	0.38	110	-	-	-	-	54 000
Coal Mining	-	60	1 000	-	-	-	-	-	-	1 000
Oil and Natural Gas	**16 000**	**1 500**	**36 000**	**0.40**	**100**	**-**	**-**	**-**	**-**	**52 000**
Oil	560	200	4 900	0.30	100	-	-	-	-	5 600
Natural Gas	**110**	**480**	**12 000**	-	-	-	-	-	-	**12 000**
Venting	9 500	760	19 000	-	-	-	-	-	-	28 000
Flaring	5 800	22	560	0.03	8	-	-	-	-	6 300
d. CO_2 Transport and Storage	0.30	-	-	-	-	-	-	-	-	0.30
INDUSTRIAL PROCESSES AND PRODUCT USE	**39 900**	**6**	**140**	**3**	**789**	**12 000**	**597**	**480**	**0.60**	**54 300**
a. Mineral Products	8 800	-	-	-	-	-	-	-	-	8 800
Cement Production	7 200	-	-	-	-	-	-	-	-	7 200
Lime Production	1 300	-	-	-	-	-	-	-	-	1 300
Mineral Product Use	320	-	-	-	-	-	-	-	-	320
b. Chemical Industry	**6 410**	**5**	**140**	**0.91**	**271**	**-**	**-**	**-**	**-**	**6 810**
Ammonia Production	2 550	-	-	-	-	-	-	-	-	2 550
Nitric Acid Production	-	-	-	0.87	258	-	-	-	-	258
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production	3 860	5	140	0.04	13	-	-	-	-	4 000
c. Metal Production	13 000	0.08	2	-	-	-	556	291	-	13 800
Iron and Steel Production	8 260	0.08	2	-	-	-	-	-	-	8 260
Aluminium Production	4 740	-	-	-	-	-	556	0.84	-	5 290
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	290	-	290
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	-	-	-	-	-	12 000	11	20	0.60	12 000
e. Non-Energy Products from Fuels and Solvent Use	12 000	-	-	-	-	-	-	-	-	12 000
f. Other Product Manufacture and Use	32	-	-	2	520	-	30	170	-	750
AGRICULTURE	**2 600**	**1 100**	**28 000**	**96**	**29 000**	**-**	**-**	**-**	**-**	**59 000**
a. Enteric Fermentation	**-**	**960**	**24 000**	**-**	**-**	**-**	**-**	**-**	**-**	**24 000**
b. Manure Management	**-**	**160**	**3 900**	**10**	**4 000**	**-**	**-**	**-**	**-**	**7 900**
c. Agricultural Soils	-	-	-	82	24 000	-	-	-	-	24 000
Direct Sources	**-**	**-**	**-**	**68**	**20 000**	**-**	**-**	**-**	**-**	**20 000**
Indirect Sources	**-**	**-**	**-**	**10**	**4 000**	**-**	**-**	**-**	**-**	**4 000**
d. Field Burning of Agricultural Residues	**-**	**1**	**40**	**0.04**	**10**	**-**	**-**	**-**	**-**	**50**
e. Liming, Urea Application and Other Carbon-containing Fertilizers	2 600	-	-	-	-	-	-	-	-	2 600
WASTE	**100**	**1 100**	**27 000**	**3**	**800**	**-**	**-**	**-**	**-**	**28 000**
a. Solid Waste Disposal (Landfills)	**-**	**920**	**23 000**	**-**	**-**	**-**	**-**	**-**	**-**	**23 000**
b. Biological Treatment of Solid Waste	**-**	**7**	**200**	**0.70**	**200**	**-**	**-**	**-**	**-**	**400**
c. Wastewater Treatment and Discharge	-	21	530	2	500	-	-	-	-	1 000
d. Incineration and Open Burning of Waste	**100**	**0.05**	**1**	**0.30**	**80**	**-**	**-**	**-**	**-**	**200**
e. Industrial Wood Waste Landfills	**-**	**100**	**3 000**	**-**	**-**	**-**	**-**	**-**	**-**	**3 000**
LAND USE, LAND-USE CHANGE AND FORESTRY	**8 900**	**25**	**620**	**1**	**370**	**-**	**-**	**-**	**-**	**9 900**
a. Forest Land	**-130 000**	**20**	**400**	**0.80**	**200**	**-**	**-**	**-**	**-**	**-130 000**
b. Cropland	**-4 400**	**5**	**110**	**0.26**	**79**	**-**	**-**	**-**	**-**	**-4 200**
c. Grassland	-	0.04	0.90	0.00	0.30	-	-	-	-	1
d. Wetlands	**2 600**	**0.61**	**15**	**0.01**	**4**	**-**	**-**	**-**	**-**	**2 600**
e. Settlements	**2 000**	**5**	**120**	**0.18**	**55**	**-**	**-**	**-**	**-**	**2 200**
f. Harvested Wood Products	**140 000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**140 000**

Notes: Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

National GHG emissions allocated to Canadian economic sectors are provided in Annex 10 of this report.

a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.

b. National totals exclude all GHGs from the Land-Use, Land-Use Change and Forestry Sector.

c. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990–1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

A 9

CANADA'S GREENHOUSE GAS EMISSION TABLES BY CANADIAN ECONOMIC SECTOR, 1990–2019

This annex contains summary tables illustrating national GHG emissions for the period 1990–2019 by Canadian economic sector (Table A10–2), as well as the relationship (crosswalk) between the economic sectors and the Intergovernmental Panel on Climate Change (IPCC) sectors presented in Annex 9 of this report (Table A10–3). In addition, Table A10–1 provides a brief description of each economic sector.

Although not a mandatory reporting requirement, reallocating emissions from IPCC sectors to Canadian economic sectors is useful for the purpose of analyzing trends and policies, as most people associate GHG emissions with a particular economic activity (e.g. producing electricity, farming or driving a car). This re-allocation simply re-categorizes emissions under different headings, but does not change the overall magnitude of Canadian emission estimates. Estimates for each economic sector includes emissions from energy-related and non-energy-related processes.

Reallocation of Emissions from IPCC Sector to Canadian Economic Sector

In general, the reallocation of emissions from IPCC sector to economic sector involves aggregating emissions from stationary combustion, fugitive sources, transportation, industrial processes, agriculture and waste into the appropriate economic sector. In many cases, the stationary combustion emissions for a specific IPCC sector are the same as that for the corresponding economic sector with some notable exceptions.

First, unlike allocation for the IPCC sectors, all utility-owned cogeneration facilities that produce steam or electricity for on-site use are reallocated from Electricity to the relevant economic sector. The relevant economic sectors include Natural Gas Production and Processing, Oil Sands, Mining, Pulp and Paper, Chemicals and Fertilizers, Service Industry, and Light Manufacturing. This is generally accomplished by analyzing and reallocating data by sector from the *Electric Power Thermal Generating Station Fuel Consumption Survey* (Statistics Canada 2020).

Second, Lime and Gypsum is split out from the IPCC category Other Manufacturing and reported as an economic sector on its own, while all other industries included in the IPCC category are allocated to the economic sector Light Manufacturing. Constituent sectors include all other manufacturing industries not already accounted for in identified IPCC manufacturing categories (e.g. Iron and Steel, Chemicals, etc.). Examples include automobile manufacturing, textiles, food and beverage industries, etc.

Third, emissions resulting from the combustion of fuel used to transport oil and natural gas in pipelines accounted for in the IPCC category Pipeline Transport, is divided into the Oil and Natural Gas Transmission and Natural Gas Distribution economic sectors. This division is based on sector-specific fuel combustion data from an upstream oil and gas (UOG) study (Environment Canada 2014).

Fourth, combustion emissions from the Mining and Upstream Oil and Gas Production IPCC category are reallocated to many economic sectors including: Coal Production, Mining, Natural Gas Production and Processing, Conventional Light Oil Production, Conventional Heavy Oil Production, Frontier Oil Production and Oil Sands (Mining, In-situ, Upgrading). A variety of external data sources are used to estimate emissions for the appropriate sectors which are then re-proportioned to align with Canada's energy balance. These external data sources include:

- **Mining** – Metal and non-metal mining fuel consumption data from the Canadian Industrial Energy End-Use Data and Analysis Centre (CEEDC) database on Energy, Production and Intensity Indicators for Canadian Industry (CEEDC, n.d.).
- **Coal Production** – Fuel consumption estimates for the coal mining industry are based on the *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry* (Cheminfo/Clearstone 2014) and annual coal production data provided by Statistics Canada (see Annex 3.2 for further discussion on this activity data).

- **UOG sectors** – Fuel consumption data for the various UOG sectors, except Oil Sands, is estimated from the UOG study (Environment Canada 2014).
- **Oil Sands** – Fuel consumption data for the Oil Sands industry (including mining and extraction, in-situ and upgrading) is modelled by ECCC and adjusted so that the resultant emissions align with the facility level emissions data that is reported to ECCC through the Greenhouse Gas Emissions Reporting Program (GHGRP) (see Chapter 1 for more information on the GHGRP).

Fifth, emissions from road, rail, marine and air transport are separated into passenger and freight components. Emissions for Other Transportation (Off-Road) are reallocated to their relevant economic sectors and to the Transportation category Other: Recreational, Commercial, and Residential.

Sixth, CO_2 captured from waste streams at large industrial facilities (e.g. electric utilities, oil sands upgraders) is presented separately in the economic sectors. It is displayed as a negative number to represent the removal of CO_2 from the specific sector while the source of the CO_2 emissions (e.g. stationary combustion) for the sector is displayed as a gross amount.

In terms of process and product use-related emissions, emissions from mineral products, chemical industry and metal production are reallocated to Heavy Industry and Light Manufacturing. Emissions from consumption of halocarbons, SF_6 and NF_3, which mainly consist of HFC emissions from refrigeration and air conditioning, are reallocated to Transport and Buildings, where the majority of HFCs are used and emitted. Emissions from non-energy products from fuels and solvent use are reallocated to multiple relevant economic categories. Finally, emissions from other product manufacture and use are mainly distributed to Electricity and Service Industry.

Once all of these sector specific fuel consumption estimates are compiled the data are reconciled by province and by fuel with the fuel consumption data from the *Report on Energy Supply and Demand* (Statistics Canada, 2003–). This ensures that the economic sector estimates match the IPCC sector estimates.

Canada’s greenhouse gas emission tables are also available in electronic file format online at http://open.canada.ca.

Table A10–1 **Canadian Economic Sector Descriptions**

Economic Sector	Description
OIL AND GAS	
Upstream Oil and Gas	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Natural Gas Production and Processing	– natural gas production and processing
Conventional Oil Production	Emissions resulting from:
Conventional Light Oil Production	– conventional light crude oil production
Conventional Heavy Oil Production	– conventinoal heavy crude oil production
Frontier Oil Production	– offshore and arctic production of crude oil
Oil Sands (Mining, In-situ, Upgrading)	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Mining and Extraction	– crude bitumen mining and extraction
In-situ	– in-situ extraction of crude bitumen including primary extraction, cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD) and other experimental techniques.
Upgrading	– crude bitumen and heavy oil upgrading to synthetic crude oil
Oil, Natural Gas and CO_2 Transmission	Combustion and fugitive emissions from the transport and storage of crude oil and natural gas.
Downstream Oil and Gas	Emissions resulting from:
Petroleum Refining	– stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from petroleum refining industries
Natural Gas Distribution	– combustion and fugitive emissions from local distribution of natural gas
ELECTRICITY	Combustion and process emissions from utility electricity generation, steam production (for sale) and transmission. Excludes utility owned cogeneration at industrial sites.
TRANSPORT	Mobile related emissions including all fossil fuels and non-CO_2 emission from biofuels.
Passenger Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily move people around.
Cars, Light Trucks and Motorcycles	Light duty cars and trucks up to 8500 lb. GVWR and motorcycles.
Bus, Rail and Aviation	All buses and the passenger component of rail and aviation.
Freight Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily move cargo or freight around.
Heavy Duty Trucks, Rail	Vehicles above 8500 lb. GVWR and the freight component of rail.
Aviation and Marine	Cargo component of aviation and all domestic navigation (inclusive of all fishing and military operations).
Other: Recreational, Commercial and Residential	Combustion emissions from the non-industrial use of off-road engines (e.g., ATVs, snowmobiles, personal watercraft), including portable engines (e.g., generators, lawn mowers, chain saws).
HEAVY INDUSTRY	Stationary combustion, onsite transportation, electricty and steam production, and process emissions from:
Mining	– metal and non-metal mines, stone quarries, and gravel pits
Smelting and Refining (Non-Ferrous Metals)	– non-ferrous metals (aluminium, magnesium and other production)
Pulp and Paper	– pulp and paper (primarily pulp, paper, and paper product manufacturers)
Iron and Steel	– iron and steel (steel foundries, casting, rolling mills and iron making)
Cement	– cement and other non-metallic mineral production
Lime and Gypsum	– lime and gypsum product manufacturing
Chemicals and Fertilizers	– chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
BUILDINGS	Stationary combustion and process (i.e. air conditioning) emissions from:
Service Industry	– service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.; offices, health, arts, accommodation, food, information & cultural; Federal, provincial and municipal establishments; National Defence and Canadian Coast Guard; Train stations, airports and warehouses
Residential	– personal residences (homes, apartment hotels, condominiums and farm houses)
AGRICULTURE	Emissions resulting from:
On Farm Fuel Use	– stationary combustion, onsite transportation and process emissions from the agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing, and repair)
Crop Production	– application of biosolids and inorganic nitrogen fertilizers, decomposition of crop residues, loss of soil organic carbon, cultivation of organic soils, indirect emissions from leaching and volatilization, field burning of agricultural residues, liming, and urea application
Animal Production	– animal housing, manure storage, manure deposited by grazing animals, and application of manure to managed soils
WASTE	Non-CO_2 Emissions from biomass resulting from:
Solid Waste	– municipal solid waste management sites (landfills), dedicated wood waste landfills, and other treatment of municipal solid waste
Wastewater	– municipal and industrial wastewater treatment
Waste Incineration	– municipal solid, hazardous and clinical waste, and sewage sludge incineration
Coal Production	Stationary combustion, onsite transportation and fugitive emissions from underground and surface coal mines
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	Stationary combustion, onsite transportation, electricty and steam production, and process emissions from (excluding LULUCF):
Light Manufacturing	– all other manufacturing industries not included in the Heavy Industry category above
Construction	– construction of buildings, highways etc.
Forest Resources	– forestry and logging service industry

Table A10–2 **Canada's GHG Emissions by Canadian Economic Sector, 1990–2019**

Greenhouse Gas Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq																													
NATIONAL GHG TOTAL	**602**	**596**	**614**	**617**	**638**	**656**	**679**	**691**	**697**	**710**	**734**	**723**	**727**	**745**	**746**	**739**	**730**	**752**	**736**	**694**	**703**	**714**	**717**	**725**	**723**	**723**	**707**	**716**	**728**	**730**
OIL AND GAS	**102**	**102**	**111**	**118**	**122**	**128**	**136**	**137**	**141**	**149**	**153**	**153**	**156**	**159**	**159**	**160**	**165**	**171**	**167**	**165**	**166**	**172**	**178**	**184**	**190**	**190**	**181**	**183**	**191**	**191**
Upstream Oil and Gas	**82**	**83**	**92**	**98**	**103**	**109**	**114**	**115**	**120**	**129**	**133**	**133**	**134**	**136**	**135**	**137**	**142**	**147**	**145**	**142**	**143**	**150**	**157**	**163**	**170**	**169**	**160**	**163**	**172**	**172**
Natural Gas Production and Processing	34	33	36	38	41	43	45	43	45	53	58	58	60	63	59	61	62	64	63	60	56	60	58	58	58	55	52	50	53	53
Conventional Oil Production	21	22	24	25	26	28	30	31	31	32	34	33	32	30	29	29	28	29	28	25	25	27	28	30	32	31	27	27	27	25
Conventional Light Oil Production	11	11	11	12	12	12	12	12	11	11	12	12	12	12	12	13	13	13	13	12	12	14	16	18	19	18	16	17	17	17
Conventional Heavy Oil Production	10	11	13	14	14	16	17	19	18	19	21	20	18	16	15	14	13	13	12	11	11	11	11	11	12	12	9	9	8	7
Frontier Oil Production	0	0	0	0	0	0	0	0	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	15	17	18	19	20	20	22	24	25	25	28	29	32	36	35	41	44	45	49	54	56	62	65	70	72	69	76	81	83
Mining and Extraction	2	2	2	2	3	3	3	3	3	3	3	4	4	5	6	6	6	7	7	8	8	8	9	10	10	11	11	13	15	15
In-situ	4	4	4	4	4	4	5	7	9	8	9	9	9	10	11	12	14	16	18	20	23	24	29	31	35	38	37	41	43	43
Upgrading	8	9	11	12	13	12	13	12	13	13	14	15	16	17	19	17	20	22	20	22	23	23	24	25	24	24	21	23	24	25
Oil, Natural Gas and CO_2 Transmission	12	13	16	16	17	18	19	19	19	19	15	14	13	11	10	12	11	10	9	8	7	7	8	9	10	10	11	10	10	11
Downstream Oil and Gas	**20**	**19**	**19**	**20**	**19**	**19**	**22**	**22**	**21**	**20**	**20**	**21**	**22**	**23**	**24**	**23**	**23**	**24**	**22**	**22**	**23**	**22**	**22**	**22**	**21**	**21**	**21**	**19**	**19**	**20**
Petroleum Refining	18	17	17	18	17	17	20	20	19	18	19	19	21	22	23	22	22	22	21	21	22	20	21	21	20	19	20	18	18	19
Natural Gas Distribution	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ELECTRICITY	**95**	**96**	**103**	**93**	**95**	**98**	**98**	**109**	**122**	**119**	**129**	**129**	**124**	**127**	**119**	**118**	**112**	**118**	**109**	**94**	**95**	**87**	**83**	**80**	**76**	**79**	**74**	**72**	**62**	**61**
TRANSPORT	**120**	**114**	**115**	**117**	**121**	**122**	**126**	**131**	**137**	**143**	**145**	**147**	**148**	**152**	**156**	**160**	**161**	**165**	**165**	**161**	**167**	**168**	**170**	**174**	**171**	**172**	**174**	**179**	**184**	**186**
Passenger Transport	**71**	**68**	**68**	**69**	**71**	**72**	**74**	**76**	**79**	**81**	**82**	**85**	**86**	**88**	**89**	**90**	**90**	**90**	**89**	**88**	**90**	**89**	**89**	**91**	**89**	**92**	**94**	**95**	**97**	**99**
Cars, Light Trucks and Motorcycles	64	62	62	63	65	66	67	69	72	74	75	77	79	81	81	82	82	82	80	81	82	81	80	82	81	83	86	86	88	89
Bus, Rail and Aviation	7	6	6	6	6	6	7	7	7	8	8	7	7	7	8	8	8	9	8	8	8	8	9	9	9	9	9	9	10	10
Freight Transport	**31**	**29**	**29**	**30**	**31**	**31**	**34**	**38**	**42**	**46**	**48**	**50**	**50**	**53**	**56**	**60**	**61**	**64**	**66**	**63**	**67**	**71**	**73**	**75**	**74**	**72**	**70**	**74**	**78**	**78**
Heavy Duty Trucks, Rail	26	24	25	25	27	26	29	33	37	41	43	45	45	48	50	54	56	59	61	59	63	66	69	70	69	67	66	69	72	72
Aviation and Marine	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	6
Other: Recreational, Commercial and Residential	**18**	**18**	**18**	**18**	**19**	**19**	**18**	**17**	**16**	**16**	**15**	**11**	**11**	**11**	**12**	**10**	10	10	10	10	10	8	8	8	8	9	9	9	9	9
HEAVY INDUSTRY	**97**	**97**	**95**	**94**	**100**	**100**	**103**	**103**	**98**	**95**	**94**	**88**	**89**	**88**	**92**	**87**	**87**	**86**	**85**	**72**	**75**	**81**	**80**	**78**	**79**	**77**	**76**	**75**	**77**	**77**
Mining	**7**	**6**	**6**	**7**	**8**	**8**	**8**	**9**	**8**	**7**	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**7**	**8**	**9**	**9**
Smelting and Refining (Non-Ferrous Metals)	**17**	**18**	**17**	**17**	**17**	**16**	**17**	**17**	**17**	**16**	**16**	**15**	**15**	**15**	**14**	**14**	**14**	**13**	**13**	**12**	**11**	**12**	**10**	**11**	**10**	**10**	**11**	**11**	**10**	**10**
Pulp and Paper	**15**	**15**	**14**	**14**	**13**	**13**	**14**	**14**	**13**	**13**	**13**	**12**	**11**	**11**	**11**	**9**	**8**	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**6**	**7**	**7**	**8**	**8**
Iron and Steel	**16**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**19**	**19**	**17**	**17**	**17**	**17**	**16**	**17**	**18**	**17**	**13**	**14**	**17**	**16**	**15**	**16**	**14**	**15**	**15**	**16**	**15**
Cement	**10**	**8**	**8**	**9**	**10**	**11**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**13**	**13**	**14**	**13**	**12**	**10**	**10**	**10**	**11**	**10**	**10**	**10**	**10**	**11**	**11**	**11**
Lime and Gypsum	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**3**	**3**	**3**	**2**	**3**	**2**	**2**	**3**	**3**	**2**
Chemicals and Fertilizers	**29**	**29**	**28**	**28**	**31**	**31**	**33**	**32**	**28**	**25**	**23**	**23**	**24**	**23**	**27**	**25**	**24**	**24**	**24**	**20**	**22**	**24**	**25**	**25**	**26**	**26**	**24**	**21**	**21**	**21**
BUILDINGS	**71**	**71**	**72**	**76**	**76**	**77**	**83**	**81**	**72**	**76**	**83**	**80**	**84**	**89**	**88**	**84**	**79**	**85**	**85**	**83**	**80**	**85**	**83**	**84**	**85**	**83**	**81**	**86**	**90**	**91**
Service Industry	**28**	**28**	**29**	**30**	**30**	**32**	**34**	**34**	**32**	**34**	**38**	**38**	**40**	**43**	**43**	**40**	**37**	**39**	**39**	**39**	**38**	**41**	**42**	**42**	**42**	**41**	**41**	**44**	**45**	**47**
Residential	**44**	**42**	**44**	**46**	**46**	**45**	**50**	**46**	**41**	**43**	**45**	**42**	**44**	**46**	**45**	**44**	**42**	**46**	**46**	**44**	**41**	**45**	**41**	**42**	**42**	**42**	**40**	**42**	**44**	**44**
AGRICULTURE	**57**	**58**	**60**	**62**	**65**	**68**	**70**	**70**	**70**	**70**	**70**	**68**	**67**	**70**	**72**	**72**	**70**	**71**	**71**	**68**	**68**	**68**	**70**	**73**	**71**	**71**	**72**	**71**	**73**	**73**
On Farm Fuel Use	**11**	**11**	**11**	**12**	**13**	**14**	**14**	**15**	**14**	**13**	**13**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**13**	**14**	**13**	**13**	**13**	**13**	**13**	**13**	**14**	**14**
Crop Production	**15**	**14**	**15**	**15**	**16**	**16**	**17**	**17**	**17**	**17**	**17**	**15**	**15**	**16**	**17**	**16**	**16**	**17**	**19**	**18**	**18**	**19**	**21**	**23**	**22**	**23**	**24**	**23**	**24**	**24**
Animal Production	**32**	**32**	**34**	**34**	**36**	**38**	**38**	**38**	**39**	**39**	**40**	**41**	**41**	**42**	**43**	**44**	**43**	**41**	**40**	**38**	**37**	**36**	**36**	**36**	**36**	**35**	**36**	**36**	**36**	**36**
WASTE	**26**	**27**	**28**	**29**	**30**	**31**	**31**	**29**	**29**	**30**	**31**	**31**	**31**	**31**	**31**	**31**	**30**	**30**	**30**	**28**	**28**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**28**
Solid Waste	**25**	**26**	**27**	**28**	**29**	**30**	**30**	**28**	**28**	**29**	**29**	**29**	**30**	**30**	**30**	**30**	**29**	**29**	**28**	**27**	**26**	**26**	**26**	**26**	**25**	**26**	**25**	**26**	**26**	**26**
Wastewater	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Waste Incineration	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
COAL PRODUCTION	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**3**	**3**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**28**	**27**	**26**	**24**	**25**	**27**	**27**	**28**	**24**	**25**	**26**	**24**	**24**	**24**	**25**	**24**	**23**	**24**	**23**	**20**	**22**	**23**	**22**	**22**	**21**	**21**	**21**	**21**	**22**	**21**
Light Manufacturing	**21**	**20**	**20**	**18**	**18**	**20**	**20**	**21**	**18**	**18**	**19**	**17**	**17**	**17**	**17**	**17**	**16**	**17**	**16**	**14**	**15**	**16**	**16**	**16**	**15**	**15**	**14**	**14**	**14**	**14**
Construction	**6**	**5**	**5**	**5**	**6**	**6**	**6**	**5**	**5**	**5**	**5**	**5**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**5**	**6**	**6**	**5**	**5**	**5**	**5**	**5**	**6**	**6**	**6**
Forest Resources	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0 Indicates emissions of less than 0.5 Mt CO_2 eq were truncated due to rounding.

\- Indicates no emissions

Table A10–3 Relationship between Canadian Economic Sectors and IPCC Sectors, 2019

Economic Category	Economic Category Total	Energy: Fuel Combustion – Stationary Combustion – Stationary	Energy: Fuel Combustion – Stationary Combustion – Industrial Cogeneration – Electricity[c]	Energy: Fuel Combustion – Stationary Combustion – Industrial Cogeneration – Steam for Sale	Energy: Fuel Combustion – Transport	Energy: Fugitive – Fugitive (Unintentional)	Energy: Fugitive – Flaring	Energy: Fugitive – Venting	Energy – Total	IPPU – Mineral Products[d]	IPPU – Chemical Industry[e]	IPPU – Metal Production[f]	IPPU – Consumption of Halocarbons, SF_6 and NF_3	IPPU – Non-Energy Products from Fuels and Solvent Use	IPPU – Other Product Manufacture and Use	IPPU – Total	Agriculture – Manure Management	Agriculture – Enteric Fermentation	Agriculture – Agriculture Soils	Agriculture – Total	Waste – Solid Waste Disposal	Waste – Biological Treatment of Solid Waste	Waste – Wastewater Treatment and Discharge	Waste – Incineration and Open Burning of Waste	Waste – Industrial Wood Waste Landfills	Waste – Total	CO_2 Captured[j]	LULUCF[b]
	Mt CO_2 equivalent																											
National Inventory Total[a,b]	730	295	23.2	0.9	217	19.1	6.3	29.6	591	8.8	6.8	13.8	12.4	11.6	0.8	54.3	7.9	24.0	27.1	59.1	23.0	0.4	1.0	0.2	3.0	27.6	-1.7	
OIL AND GAS	191	109.2	14.9	0.0	12.9	17.7	6.3	29.6	190.7					1.8		1.8											-1.1	
Upstream Oil and Gas	172	95.0	14.0		12.9	16.6	5.9	28.4	172.7					0.1		0.1											-1.1	
Natural Gas Production and Processing	53	30.0	1.5		0.2	9.6	1.3	10.2	52.7					0.0		0.0												
Conventional Oil Production	25	8.2	0.3		0.2	2.9	3.2	10.6	25.3					0.0		0.0												
Conventional Light Oil Production	17	4.1			0.1	2.1	2.0	8.1	16.5					0.0		0.0												
Conventional Heavy Oil Production	7	3.1			0.1	0.7	0.6	2.5	6.9																			
Frontier Oil Production	2	0.9	0.3		0.0	0.0	0.6	0.0	1.9																			
Oil Sands (Mining, In-situ, Upgrading)[c]	83	56.8	12.2		4.3	2.6	1.4	6.8	84.1					0.1		0.1											-1.1	
Mining and Extraction	15	7.0	2.0		4.2	2.0	0.2	0.0	15.4					0.1		0.1												
In-situ	43	33.9	7.0		0.1	0.6	0.2	1.0	42.7																			
Upgrading	25	15.9	3.3		0.0	0.1	1.1	5.7	26.0					0.0		0.0											-1.1	
Oil, Natural Gas and CO_2 Transmission	11				8.2	1.4	0.0	0.9	10.5																			
Downstream Oil and Gas	20	14.2	1.0	0.0	0.1	1.1	0.4	1.2	18.0					1.7		1.7												
Petroleum Refining	19	14.2	1.0	0.0	0.0	0.1	0.4	1.1	16.8					1.7		1.7												
Natural Gas Distribution	1				0.1	1.0	0.0	0.1	1.1																			
ELECTRICITY	61	61.1		0.5					61.5						0.2	0.2											-0.6	
TRANSPORT[g]	186				183.0				183.0				2.6	0.2	0.0	2.8												
Passenger Transport	99				97.2				97.2				1.3	0.1	0.0	1.4												
Cars, Light Trucks and Motorcycles	89				87.7				87.7				1.2	0.1	0.0	1.3												
Bus, Rail and Aviation	10				9.5				9.5				0.1	0.0	0.0	0.1												
Freight Transport	78				76.6				76.6				1.3	0.1	0.0	1.4												
Heavy Duty Trucks, Rail	72				71.1				71.1				1.2	0.1	0.0	1.3												
Aviation and Marine	6				5.5				5.5				0.2	0.0		0.2												
Other: Recreational, Commercial and Residential	9				9.2				9.2																			
HEAVY INDUSTRY	77	32.4	7.1	0.3	3.1				42.9	8.7	6.8	13.8	0.3	4.6		34.2												
Mining	9	5.1	1.2		2.4				8.6				0.0	0.2		0.2												
Smelting and Refining (Non-Ferrous Metals)	10	2.8		0.0	0.2				3.0			5.6		1.5		7.1												
Pulp and Paper	8	5.4	2.5	0.1	0.3				8.2	0.0				0.0		0.1												
Iron and Steel	15	5.8	0.1	0.0	0.2				6.2			8.3		0.2		8.4												
Cement	11	4.2			0.1				4.3	7.2				0.0		7.2												
Lime and Gypsum	2	1.0			0.0				1.0	1.3				0.0		1.4												
Chemicals and Fertilizers	21	8.1	3.3	0.2	0.1				11.6	0.1	6.8		0.2	2.6		9.8												
BUILDINGS	91	76.0	0.6						76.6				9.1	4.5	0.5	14.1												
Service Industry	47	33.8	0.6						34.4				7.2	4.5	0.5	12.2												
Residential	44	42.2							42.2				1.9			1.9												
AGRICULTURE	73	3.6	0.0		10.0				13.6					0.1		0.1	7.9	24.0	27.1	59.1								
On Farm Fuel Use[h]	14	3.6	0.0		10.0				13.6					0.1		0.1												
Crop Production	24																		23.5	23.5								
Animal Production	36																7.9	24.0	3.6	35.6								
WASTE	28												0.0			0.0					23.0	0.4	1.0	0.2	3.0	27.6		
Solid Waste[i]	26												0.0			0.0					23.0	0.4			3.0	26.4		
Wastewater	1																						1.0			1.0		
Waste Incineration	0																							0.2		0.2		
COAL PRODUCTION	3	0.5			0.7	1.4			2.6																			
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	21	12.4	0.5	0.1	7.1				20.1	0.2			0.5	0.5	0.0	1.1												
Light Manufacturing	14	10.9	0.5	0.1	1.3				12.9	0.2			0.5	0.4	0.0	1.1												
Construction	6	1.4	0.0		4.6				5.9					0.0		0.0												
Forest Resources	1	0.1			1.2				1.3					0.0		0.0												
																												9.9

Notes:

Totals may not add up due to rounding. Economic category totals rounded to nearest megatonne (Mt). The estimates for the economic categories may not add up to the National Inventory Totals due to rounding and statistical differences in the RESD for the IP category of Other & Undifferentiated Production.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

a. Categorization of emissions is consistent with the IPCC's sectors following the reporting requirement of the UNFCCC.

b. National totals exclude all GHGs from the Land Use, Land Use Change and Forestry Sector.

c. Industrial cogeneration includes emissions associated with the simultaneous production of heat and power. At some facilities, a portion of this power is generated by onsite utility-owned generators. As such, the cogeneration emissions for these specific facilities are included under the Public Electricity and Heat Generation category in the National Inventory (UNFCCC) format.

d. Mineral products includes cement production, lime production and mineral product use.

e. Chemical industry includes the production of ammonia, nitric acid, adipic acid, carbide and petrochemicals. ammonia production, nitric acid production, petrochemical production, and adipic acid production.

f. Metal production includes iron and steel production, aluminum production, and SF_6 used in magnesium smelters and casters.

g. Emissions from the consumption of propane and natural gas in Transport are allocated to Cars, Light Trucks and Buses

h. On Farm Fuel Use includes emissions associated with the use of lube oils and greases.

i. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

j. Some facilities capture CO_2 emissions. This is displayed as a negative quantity, as it is computed as an emission reduction at the source. Though the CO_2 has been captured, this does not imply permanent storage; some portion may be subsequently re-emitted (for instance, as fugitive releases) in another activity—in such cases, the re-emissions are reported in the economic sectors where they occur.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

A 10

PROVINCIAL/ TERRITORIAL GREENHOUSE GAS EMISSION TABLES BY IPCC SECTOR, 1990–2019

This annex contains summary tables (Table A11–1 to Table A11–28) illustrating GHG emissions by province/territory and year for each IPCC sector.

To account for the creation of Nunavut in 1999, separate time-series are provided from 1999 onwards for both the Northwest Territories and Nunavut (Table A11–24 and Table A11–26); emissions for the years 1990–1998 are presented as a combined region in Table A11–28.

Provincial/territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

Although the UNFCCC Reporting Guidelines only require reporting national-level information, provincial and territorial information is important, owing to differences in regional emission levels and trends. Note that provincial and territorial emission estimates may not necessarily sum to the national totals due to rounding.

Several Canadian provinces develop independent inventories of provincial GHG emissions, in some cases making use of alternate methodologies, data inputs and/or inclusions/omissions of GHG source categories. While Canada is developing a national emission inventory consistent with IPCC guidelines and international obligations, provincial governments may elect to develop an inventory structure in accordance with specific provincial needs. Environment and Climate Change Canada encourages collaboration with provinces and territories for quality assurance and continuous improvement of this annual National Inventory Report.

Provincial/territorial greenhouse gas emission tables are also available in electronic file format online at https://open.canada.ca.

Table A11–1 **GHG Source/Sink Category Descriptions**

GHG Source/Sink Categories	
ENERGY	
a. Stationary Combustion Sources	
Public Electricity and Heat Production	Emissions from fuel consumed by utility electricity generation and steam production (for sale)
Petroleum Refining Industries	Emissions from fuel consumed by petroleum refining industries
Oil and Gas Extraction	Emissions from fuel consumed by oil and gas extraction industries
Mining	Emissions from fuel consumed by:
	– Metal and non-metal mines, coal mines, stone quarries, and gravel pits
	– Mineral exploration and contract drilling operations
Manufacturing Industries	Emissions from fuel consumed by the following industries:
	– Iron and Steel (steel foundries, casting and rolling mills)
	– Non-ferrous metals (aluminium, magnesium and other production)
	– Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
	– Pulp and Paper (primarily pulp, paper, and paper product manufacturers)
	– Cement and other non-metallic mineral production
	– Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
Construction	Emissions from fuels consumed by the construction industry—buildings, highways etc.
Commercial and Institutional	Emissions from fuel consumed by:
	– Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.)
	– Federal, provincial and municipal establishments
	– National Defence and Canadian Coast Guard
	– Train stations, airports and warehouses
Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums and farm houses)
Agriculture and Forestry	Emissions from fuel consumed by:
	– Forestry and logging service industry
	– Agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)
b. Transport	Emissions resulting from the:
Aviation	– Consumption of fossil fuels by civilian aircrafts flying domestically and all military aircraft operations with Canadian purchased fuel
Domestic Aviation (Civil)	– Consumption of fossil fuels by civilian aircraft flying domestically with Canadian purchased fuel
Military	– Consumption of fossil fuels by military aircraft operations with Canadian purchased fuel
Road Transportation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by vehicles licensed to operate on roads
Railways	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by Canadian railways
Marine	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by marine vessels navigating between Canadian ports (inclusive of all fishing and military operations)
Domestic Navigation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by marine vessels navigating between Canadian ports
Fishing	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by fishing vessels operating in Canadian waters
Military Water-Borne Navigation	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by military vessels operating in Canadian waters
Others – Off-Road	– Consumption of fuels (excluding the biogenic CO_2 emissions from Ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads
Others – Pipeline Transport	– Transportation and distribution of crude oil, natural gas and other products
c. Fugitive Sources	Intentional and unintentional releases of greenhouse gases from the following activities:
Coal Mining	– Underground and surface mining, abandoned underground coal mines
Oil and Natural Gas	– Conventional and unconventional oil and gas exploration, production, transportation and distribution
d. CO_2 Transport and Storage	Intentional and unintentional releases of greenhouse gases from the transport and storage of carbon dioxide
INDUSTRIAL PROCESSES AND PRODUCT USE	Emissions resulting from the following process activities:
a. Mineral Products	– Cement production, lime production, and mineral product use (which includes glass production, other uses of soda ash, magnesite use, and other limestone and dolomite use)
b. Chemical Industry	– Production of ammonia, nitric acid, adipic acid, carbide and petrochemicals. Petrochemical production includes production of carbon black, ethylene, ethylene dichloride, ethylene oxide, methanol, styrene and other uses of urea.
c. Metal Production	– Aluminum production, iron and steel production, and magnesium production and casting
d. Production and Consumption of Halocarbons, SF_6 and NF_3	– By-product production of HFC-23; use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry, and use of SF_6 and NF_3 in semiconductor manufacturing
e. Non-Energy Products from Fuels and Solvent Use	– Non-energy use of fossil fuels (including solvents and lubricants) that are not accounted for elsewhere under the Industrial Processes and Product Use Sector
f. Other Product Manufacture and Use	– Use of N_2O as an anaesthetic and propellant; use of urea in selective catalytic reduction (SCR) equipped vehicles; use of SF_6 in electrical equipment; and PFCs in electronics industry
AGRICULTURE	Emissions resulting from:
a. Enteric Fermentation	– Eructation of CH_4 during the digestion of plant material by (mainly) ruminants
b. Manure Management	– Release of CH_4 and N_2O due to microbial activity during the storage of feces, urine and bedding materials from the cleaning of barns and pens
	– Indirect N_2O emissions from volatilization and leaching of nitrogen from animal manure during storage
c. Agricultural Soils	
Direct sources	– Direct N_2O emissions from inorganic nitrogen fertilizers, manure and biosolids applied on cropland, pasture range and paddock, crop residue, tillage, summerfallow, irrigation and cultivation of organic soils
Indirect Sources	– Indirect N_2O emissions from volatilization and leaching of animal manure and biosolid nitrogen, inorganic nitrogen fertilizer and crop residue nitrogen
d. Field Burning of Agricultural Residues	– CH_4 and N_2O emissions from crop residue burning
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	– Direct emissions of CO_2 from the application of lime, urea and other fertilizers containing carbon
WASTE	Emissions resulting from:
a. Solid Waste Disposal (Landfills)	– Municipal solid waste management sites (landfills)
b. Biological Treatment of Solid Waste	– Composting and anaerobic digestion of municipal solid waste
c. Wastewater Treatment and Discharge	– Municipal and industrial wastewater treatment
d. Incineration and Open Burning of Waste	– Municipal solid, hazardous and clinical waste, and sewage sludge incineration
e. Industrial Wood Waste Landfills	– Private, dedicated wood waste landfills
LAND USE, LAND-USE CHANGE AND FORESTRY	Emissions and removals resulting from:
a. Forest Land	– Managed forests and lands converted to forests; reports emissions and removals from forest growth and anthropogenic disturbances related to forest management but tracks separately emissions and removals from fire and most insect disturbances
b. Cropland	– Management practices on lands in annual crops, summerfallow and perennial crops (forage, specialty crops, orchards); immediate and residual emissions from lands converted to cropland
c. Grassland	– Managed agricultural grassland
d. Wetlands	– Peatlands disturbed for peat extraction, or land flooded from hydro reservoir development
e. Settlements	– Forest and grassland converted to built-up land (settlements, transport infrastructure, oil & gas infrastructure, mining, etc); urban tree growth
f. Harvested Wood Products	– Use and disposal of harvested wood products manufactured from wood coming from forest harvest and forest conversion activities in Canada

Table A11–2 GHG Emission Summary for Newfoundland and Labrador, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**9 550**	**10 500**	**10 900**	**11 000**	**11 200**	**11 100**	**10 900**	**11 100**
ENERGY	**8 670**	**9 500**	**9 950**	**10 000**	**10 200**	**10 100**	**9 890**	**10 100**
a. Stationary Combustion Sources	**5 450**	**4 690**	**5 000**	**4 990**	**5 150**	**5 010**	**4 480**	**4 700**
Public Electricity and Heat Production	1 640	819	1 210	1 340	1 520	1 530	1 130	1 140
Petroleum Refining Industries	1 000	950	850	960	1 100	890	860	930
Oil and Gas Extraction	-	764	1 130	1 030	1 170	1 170	1 090	1 160
Mining	1 160	1 130	742	692	373	390	557	612
Manufacturing Industries	506	276	40	35	40	82	81	78
Construction	33	24	7	18	5	6	7	6
Commercial and Institutional	320	358	630	599	572	488	317	349
Residential	728	360	380	306	352	446	434	409
Agriculture and Forestry	25	8	11	12	10	9	7	9
b. Transport[a]	**3 190**	**3 900**	**4 300**	**4 490**	**4 520**	**4 440**	**4 580**	**4 630**
Aviation	238	340	312	307	303	280	289	280
Road Transportation	1 570	2 120	2 940	3 100	3 120	3 030	3 060	3 050
Light-Duty Gasoline Vehicles	678	604	679	684	640	627	589	551
Light-Duty Gasoline Trucks	440	646	1 090	1 160	1 160	1 220	1 210	1 190
Heavy-Duty Gasoline Vehicles	86	102	208	223	232	253	255	245
Motorcycles	3	2	8	9	9	10	10	10
Light-Duty Diesel Vehicles	4	5	7	8	8	6	6	6
Light-Duty Diesel Trucks	2	6	6	8	10	10	11	12
Heavy-Duty Diesel Vehicles	358	756	943	1 020	1 060	903	982	1 030
Propane and Natural Gas Vehicles	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Railways	-	-	-	-	-	-	-	-
Marine	764	929	610	552	570	604	649	726
Other Transportation	614	513	442	530	522	521	576	575
Off-Road Agriculture and Forestry	25	34	21	26	23	22	26	28
Off-Road Commercial and Institutional	31	48	46	50	21	11	12	12
Off-Road Manufacturing, Mining and Construction	223	282	242	307	335	341	394	394
Off-Road Residential	7	25	28	30	29	29	29	30
Off-Road Other Transportation	328	124	105	117	114	117	116	111
Pipeline Transport	-	-	-	-	-	-	-	-
c. Fugitive Sources	**41**	**910**	**660**	**560**	**560**	**660**	**840**	**740**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	41	910	660	560	560	660	840	740
Oil	6	49	35	30	35	37	38	42
Natural Gas	0.00	1	2	2	2	2	2	2
Venting	25	52	39	46	45	59	55	61
Flaring	11	810	580	490	480	560	740	640
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**99**	**148**	**192**	**189**	**201**	**241**	**256**	**228**
a. Mineral Products	**65**	**2**	**0.59**	**0.63**	**0.54**	**0.53**	**0.48**	**0.44**
Cement Production	61	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	4	2	0.59	0.63	0.54	0.53	0.48	0.44
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**71**	**160**	**160**	**160**	**170**	**190**	**190**
e. Non-Energy Products from Fuels and Solvent Use	**29**	**68**	**28**	**19**	**26**	**57**	**55**	**28**
f. Other Product Manufacture and Use	**5**	**7**	**6**	**9**	**10**	**9**	**10**	**10**
AGRICULTURE	**54**	**66**	**96**	**89**	**90**	**85**	**87**	**89**
a. Enteric Fermentation	**23**	**31**	**32**	**31**	**31**	**31**	**33**	**34**
b. Manure Management	**16**	**20**	**25**	**25**	**25**	**25**	**25**	**25**
c. Agricultural Soils	**12**	**15**	**18**	**19**	**18**	**18**	**19**	**19**
Direct Sources	10	12	14	15	15	14	15	15
Indirect Sources	2	3	3	3	3	3	3	3
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**3**	**-**	**21**	**14**	**17**	**12**	**11**	**11**
WASTE	**720**	**810**	**700**	**690**	**710**	**710**	**710**	**700**
a. Solid Waste Disposal (Landfills)	**620**	**710**	**630**	**630**	**640**	**650**	**640**	**640**
b. Biological Treatment of Solid Waste	**-**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.10**	**0.10**
c. Wastewater Treatment and Discharge	**23**	**21**	**20**	**20**	**21**	**22**	**22**	**22**
d. Incineration and Open Burning of Waste	**30**	**10**	**0.20**	**0.20**	**0.10**	**0.10**	**0.09**	**0.09**
e. Industrial Wood Waste Landfills	**60**	**60**	**50**	**40**	**40**	**40**	**40**	**40**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–3 2019 GHG Emission Summary for Newfoundland and Labrador

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**9 800**	**39**	**960**	**0.45**	**130**	**190**	**0.05**	**2**	**-**	**11 100**
ENERGY	**9 760**	**9**	**220**	**0.30**	**90**	**-**	**-**	**-**	**-**	**10 100**
a. Stationary Combustion Sources	**4 560**	**4**	**100**	**0.10**	**30**	**-**	**-**	**-**	**-**	**4 700**
Public Electricity and Heat Production	1 130	0.02	0.39	0.02	7	-	-	-	-	1 140
Petroleum Refining Industries	930	0.02	0.60	0.01	2	-	-	-	-	930
Oil and Gas Extraction	1 090	3	70	0.03	7	-	-	-	-	1 160
Mining	610	0.01	0.40	0.01	3	-	-	-	-	612
Manufacturing Industries	77	0.00	0.05	0.00	0.55	-	-	-	-	78
Construction	6	0.00	0.00	0.00	0.02	-	-	-	-	6
Commercial and Institutional	347	0.00	0.10	0.01	2	-	-	-	-	349
Residential	363	1	40	0.03	9	-	-	-	-	409
Agriculture and Forestry	9	0.00	0.00	0.00	0.03	-	-	-	-	9
b. Transport[b]	**4 560**	**0.59**	**15**	**0.19**	**55**	**-**	**-**	**-**	**-**	**4 630**
Aviation	278	0.00	0.07	0.01	2	-	-	-	-	280
Road Transportation	3 010	0.20	5	0.13	40	-	-	-	-	3 050
Light-Duty Gasoline Vehicles	544	0.04	1	0.02	5	-	-	-	-	551
Light-Duty Gasoline Trucks	1 180	0.09	2	0.04	11	-	-	-	-	1 190
Heavy-Duty Gasoline Vehicles	239	0.01	0.20	0.02	6	-	-	-	-	245
Motorcycles	10	0.00	0.09	0.00	0.05	-	-	-	-	10
Light-Duty Diesel Vehicles	6	0.00	0.00	0.00	0.15	-	-	-	-	6
Light-Duty Diesel Trucks	12	0.00	0.01	0.00	0.29	-	-	-	-	12
Heavy-Duty Diesel Vehicles	1 010	0.04	1	0.06	17	-	-	-	-	1 030
Propane and Natural Gas Vehicles	0.00	0.00	0.00	0.00	0.00	-	-	-	-	0.00
Railways	-	-	-	-	-	-	-	-	-	-
Marine	719	0.07	2	0.02	6	-	-	-	-	726
Other Transportation	559	0.33	8	0.03	8	-	-	-	-	575
Off-Road Agriculture and Forestry	27	0.00	0.04	0.00	0.50	-	-	-	-	28
Off-Road Commercial and Institutional	12	0.01	0.36	0.00	0.10	-	-	-	-	12
Off-Road Manufacturing, Mining and Construction	387	0.03	0.67	0.02	6	-	-	-	-	394
Off-Road Residential	28	0.05	1	0.00	0.20	-	-	-	-	30
Off-Road Other Transportation	105	0.23	6	0.00	0.90	-	-	-	-	111
Pipeline Transport	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**640**	**4**	**100**	**0.01**	**2**	**-**	**-**	**-**	**-**	**740**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	640	4	100	0.01	2	-	-	-	-	740
Oil	0.18	2	40	0.01	2	-	-	-	-	42
Natural Gas	0.02	0.08	2	-	-	-	-	-	-	2
Venting	61	0.02	0.49	-	-	-	-	-	-	61
Flaring	580	2	57	0.00	0.30	-	-	-	-	640
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**29**	**-**	**-**	**0.02**	**7**	**190**	**0.05**	**2**	**-**	**228**
a. Mineral Products	**0.44**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.44**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	0.44	-	-	-	-	-	-	-	-	0.44
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**190**	**0.03**	**-**	**-**	**190**
e. Non-Energy Products from Fuels and Solvent Use	**28**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**28**
f. Other Product Manufacture and Use	**0.60**	**-**	**-**	**0.02**	**7**	**-**	**0.02**	**2**	**-**	**10**
AGRICULTURE	**11**	**2**	**46**	**0.11**	**32**	**-**	**-**	**-**	**-**	**89**
a. Enteric Fermentation	**-**	**1**	**34**	**-**	**-**	**-**	**-**	**-**	**-**	**34**
b. Manure Management	**-**	**0.50**	**12**	**0.04**	**10**	**-**	**-**	**-**	**-**	**25**
c. Agricultural Soils	**-**	**-**	**-**	**0.06**	**19**	**-**	**-**	**-**	**-**	**19**
Direct Sources	-	-	-	0.05	15	-	-	-	-	15
Indirect Sources	-	-	-	0.01	3	-	-	-	-	3
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**11**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**11**
WASTE	**0.09**	**28**	**700**	**0.02**	**7**	**-**	**-**	**-**	**-**	**700**
a. Solid Waste Disposal (Landfills)	**-**	**26**	**640**	**-**	**-**	**-**	**-**	**-**	**-**	**640**
b. Biological Treatment of Solid Waste	**-**	**0.00**	**0.05**	**0.00**	**0.08**	**-**	**-**	**-**	**-**	**0.10**
c. Wastewater Treatment and Discharge	**-**	**0.59**	**15**	**0.02**	**7**	**-**	**-**	**-**	**-**	**22**
d. Incineration and Open Burning of Waste	**0.09**	**0.00**	**0.00**	**0.00**	**0.01**	**-**	**-**	**-**	**-**	**0.09**
e. Industrial Wood Waste Landfills	**-**	**2**	**40**	**-**	**-**	**-**	**-**	**-**	**-**	**40**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–4 GHG Emission Summary for Prince Edward Island, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**1 870**	**2 040**	**1 710**	**1 660**	**1 720**	**1 740**	**1 730**	**1 760**
ENERGY	**1 400**	**1 430**	**1 190**	**1 180**	**1 190**	**1 210**	**1 170**	**1 200**
a. Stationary Combustion Sources	**756**	**642**	**444**	**393**	**366**	**373**	**345**	**369**
Public Electricity and Heat Production	104	5	4	14	4	9	3	1
Petroleum Refining Industries	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-
Mining	0.89	x	x	x	x	x	x	x
Manufacturing Industries	55	145	75	63	67	74	60	75
Construction	11	x	x	x	x	x	x	x
Commercial and Institutional	202	152	93	96	67	57	61	61
Residential	364	306	258	208	213	220	208	218
Agriculture and Forestry	19	24	12	10	11	11	12	13
b. Transport[a]	**642**	**791**	**749**	**783**	**820**	**840**	**825**	**828**
Aviation	17	13	20	20	21	22	24	25
Road Transportation	467	624	590	612	648	657	633	634
Light-Duty Gasoline Vehicles	234	243	195	196	206	207	187	185
Light-Duty Gasoline Trucks	127	228	218	222	247	263	254	265
Heavy-Duty Gasoline Vehicles	41	47	40	40	44	47	44	44
Motorcycles	0.58	0.98	1	1	2	2	2	2
Light-Duty Diesel Vehicles	1	2	2	3	3	2	2	2
Light-Duty Diesel Trucks	0.45	0.90	0.67	1	1	1	2	2
Heavy-Duty Diesel Vehicles	62	102	133	149	146	133	142	136
Propane and Natural Gas Vehicles	-	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-
Marine	32	46	55	55	53	58	62	66
Other Transportation	126	107	85	96	99	103	106	102
Off-Road Agriculture and Forestry	47	48	36	42	37	31	34	33
Off-Road Commercial and Institutional	5	9	9	9	8	8	7	7
Off-Road Manufacturing, Mining and Construction	15	15	14	17	26	35	38	36
Off-Road Residential	0.86	7	5	5	6	6	6	6
Off-Road Other Transportation	60	28	21	22	23	24	21	20
Pipeline Transport	-	-	-	-	-	-	-	-
c. Fugitive Sources	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	-	-	-	-	-	-	-	-
Venting	-	-	-	-	-	-	-	-
Flaring	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**6**	**30**	**54**	**53**	**54**	**57**	**62**	**61**
a. Mineral Products	**0.34**	**0.91**	**0.59**	**0.69**	**0.62**	**0.36**	**0.44**	**0.44**
Cement Production	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	0.34	0.91	0.59	0.69	0.62	0.36	0.44	0.44
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**25**	**51**	**50**	**51**	**54**	**59**	**58**
e. Non-Energy Products from Fuels and Solvent Use	**5**	**2**	**1**	**0.87**	**0.90**	**0.73**	**0.61**	**0.62**
f. Other Product Manufacture and Use	**0.83**	**2**	**1**	**2**	**2**	**2**	**2**	**2**
AGRICULTURE	**370**	**440**	**350**	**320**	**380**	**370**	**400**	**400**
a. Enteric Fermentation	**140**	**130**	**110**	**110**	**110**	**110**	**110**	**110**
b. Manure Management	**47**	**51**	**40**	**39**	**37**	**38**	**38**	**39**
c. Agricultural Soils	**180**	**250**	**200**	**170**	**230**	**220**	**240**	**240**
Direct Sources	150	210	170	140	200	190	210	200
Indirect Sources	30	40	30	30	40	40	40	40
d. Field Burning of Agricultural Residues	**0.10**	**0.20**	**0.10**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**5**	**5**	**2**	**3**	**3**	**2**	**2**	**4**
WASTE	**89**	**140**	**110**	**110**	**100**	**100**	**100**	**99**
a. Solid Waste Disposal (Landfills)	**82**	**130**	**96**	**93**	**92**	**90**	**89**	**88**
b. Biological Treatment of Solid Waste	**-**	**3**	**3**	**3**	**3**	**3**	**2**	**2**
c. Wastewater Treatment and Discharge	**6**	**8**	**8**	**9**	**8**	**8**	**8**	**8**
d. Incineration and Open Burning of Waste	**0.02**	**0.09**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
e. Industrial Wood Waste Landfills	**0.80**	**0.70**	**0.60**	**0.60**	**0.50**	**0.50**	**0.50**	**0.50**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

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Table A11–5 **2019 GHG Emission Summary for Prince Edward Island**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**1 170**	**10**	**240**	**0.95**	**280**	**58**	**0.06**	**-**	**-**	**1 760**
ENERGY	**1 170**	**0.64**	**16**	**0.05**	**10**	**-**	**-**	**-**	**-**	**1 200**
a. Stationary Combustion Sources	**353**	**0.50**	**10**	**0.01**	**4**	**-**	**-**	**-**	**-**	**369**
Public Electricity and Heat Production	1	0.00	0.00	0.00	0.00	-	-	-	-	1
Petroleum Refining Industries	-	-	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	x	x	x	x	x	x	x	x	x	x
Manufacturing Industries	75	0.00	0.03	0.00	0.40	-	-	-	-	75
Construction	x	x	x	x	x	x	x	x	x	x
Commercial and Institutional	60	0.01	0.22	0.00	0.70	-	-	-	-	61
Residential	203	0.50	10	0.01	3	-	-	-	-	218
Agriculture and Forestry	13	0.00	0.00	0.00	0.05	-	-	-	-	13
b. Transport[b]	**814**	**0.13**	**3**	**0.04**	**10**	**-**	**-**	**-**	**-**	**828**
Aviation	25	0.00	0.01	0.00	0.20	-	-	-	-	25
Road Transportation	625	0.05	1	0.03	9	-	-	-	-	634
Light-Duty Gasoline Vehicles	182	0.02	0.40	0.01	2	-	-	-	-	185
Light-Duty Gasoline Trucks	261	0.02	0.60	0.01	3	-	-	-	-	265
Heavy-Duty Gasoline Vehicles	43	0.00	0.04	0.00	1	-	-	-	-	44
Motorcycles	2	0.00	0.01	0.00	0.01	-	-	-	-	2
Light-Duty Diesel Vehicles	2	0.00	0.00	0.00	0.05	-	-	-	-	2
Light-Duty Diesel Trucks	1	0.00	0.00	0.00	0.04	-	-	-	-	2
Heavy-Duty Diesel Vehicles	134	0.01	0.10	0.01	2	-	-	-	-	136
Propane and Natural Gas Vehicles	-	-	-	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-	-	-
Marine	65	0.01	0.15	0.00	0.50	-	-	-	-	66
Other Transportation	99	0.08	2	0.00	1	-	-	-	-	102
Off-Road Agriculture and Forestry	33	0.00	0.03	0.00	0.40	-	-	-	-	33
Off-Road Commercial and Institutional	7	0.01	0.23	0.00	0.06	-	-	-	-	7
Off-Road Manufacturing, Mining and Construction	35	0.01	0.14	0.00	0.50	-	-	-	-	36
Off-Road Residential	5	0.01	0.27	0.00	0.04	-	-	-	-	6
Off-Road Other Transportation	19	0.05	1	0.00	0.10	-	-	-	-	20
Pipeline Transport	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**-**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**-**	**-**	**0.00**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	0.00	0.00	-	-	-	-	-	-	0.00
Oil	-	0.00	0.00	-	-	-	-	-	-	0.00
Natural Gas	-	-	-	-	-	-	-	-	-	-
Venting	-	-	-	-	-	-	-	-	-	-
Flaring	-	-	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**1**	**-**	**-**	**0.01**	**2**	**58**	**0.06**	**-**	**-**	**61**
a. Mineral Products	**0.44**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.44**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	0.44	-	-	-	-	-	-	-	-	0.44
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**58**	**0.01**	**-**	**-**	**58**
e. Non-Energy Products from Fuels and Solvent Use	**0.62**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.62**
f. Other Product Manufacture and Use	**0.08**	**-**	**-**	**0.01**	**2**	**-**	**0.05**	**-**	**-**	**2**
AGRICULTURE	**4**	**5**	**130**	**0.88**	**260**	**-**	**-**	**-**	**-**	**400**
a. Enteric Fermentation	**-**	**5**	**110**	**-**	**-**	**-**	**-**	**-**	**-**	**110**
b. Manure Management	**-**	**0.73**	**18**	**0.07**	**20**	**-**	**-**	**-**	**-**	**39**
c. Agricultural Soils	**-**	**-**	**-**	**0.81**	**240**	**-**	**-**	**-**	**-**	**240**
Direct Sources	-	-	-	0.68	200	-	-	-	-	200
Indirect Sources	-	-	-	0.10	40	-	-	-	-	40
d. Field Burning of Agricultural Residues	**-**	**0.01**	**0.20**	**0.00**	**0.05**	**-**	**-**	**-**	**-**	**0.20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**4**
WASTE	**0.10**	**4**	**96**	**0.01**	**3**	**-**	**-**	**-**	**-**	**99**
a. Solid Waste Disposal (Landfills)	**-**	**4**	**88**	**-**	**-**	**-**	**-**	**-**	**-**	**88**
b. Biological Treatment of Solid Waste	**-**	**0.03**	**0.80**	**0.00**	**1**	**-**	**-**	**-**	**-**	**2**
c. Wastewater Treatment and Discharge	**-**	**0.25**	**6**	**0.01**	**2**	**-**	**-**	**-**	**-**	**8**
d. Incineration and Open Burning of Waste	**0.10**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.10**
e. Industrial Wood Waste Landfills	**-**	**0.02**	**0.50**	**-**	**-**	**-**	**-**	**-**	**-**	**0.50**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.

b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–6 GHG Emission Summary for Nova Scotia, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**19 600**	**23 200**	**16 600**	**16 700**	**15 600**	**16 200**	**16 800**	**16 200**
ENERGY	**17 900**	**21 400**	**15 000**	**15 300**	**14 100**	**14 700**	**15 300**	**14 700**
a. Stationary Combustion Sources	**11 500**	**15 400**	**10 300**	**10 000**	**8 880**	**9 110**	**9 420**	**8 940**
Public Electricity and Heat Production	6 900	10 700	7 210	6 990	6 390	6 680	6 990	6 690
Petroleum Refining Industries	620	1 100	x	x	x	x	x	x
Oil and Gas Extraction	46	302	727	565	415	284	184	-
Mining	39	39	5	4	4	4	3	3
Manufacturing Industries	775	556	416	397	366	369	455	443
Construction	50	x	x	x	x	x	x	x
Commercial and Institutional	816	x	538	651	539	571	486	502
Residential	2 130	1 330	1 360	1 380	1 140	1 170	1 270	1 270
Agriculture and Forestry	104	96	33	28	24	32	31	24
b. Transport[a]	**4 780**	**5 740**	**4 650**	**5 170**	**5 140**	**5 500**	**5 750**	**5 630**
Aviation	299	277	265	269	266	278	302	294
Road Transportation	3 100	4 100	3 410	3 910	3 930	4 080	4 180	4 090
Light-Duty Gasoline Vehicles	1 490	1 350	971	1 190	1 200	1 190	1 170	1 120
Light-Duty Gasoline Trucks	735	1 190	1 030	1 310	1 390	1 470	1 530	1 560
Heavy-Duty Gasoline Vehicles	165	237	224	272	288	302	310	309
Motorcycles	6	5	7	9	10	11	11	12
Light-Duty Diesel Vehicles	29	42	44	44	38	37	27	24
Light-Duty Diesel Trucks	6	9	8	12	12	15	16	16
Heavy-Duty Diesel Vehicles	664	1 260	1 120	1 070	990	1 050	1 110	1 050
Propane and Natural Gas Vehicles	4	2	0.00	0.00	0.00	0.00	0.00	0.00
Railways	66	115	x	x	x	151	163	158
Marine	504	605	380	326	291	375	434	474
Other Transportation	815	638	x	x	x	621	666	619
Off-Road Agriculture and Forestry	86	90	60	63	51	57	62	57
Off-Road Commercial and Institutional	43	66	68	74	65	68	72	71
Off-Road Manufacturing, Mining and Construction	225	235	188	208	211	273	294	266
Off-Road Residential	9	38	32	38	x	x	x	x
Off-Road Other Transportation	452	175	129	161	164	177	190	176
Pipeline Transport	-	35	x	x	x	x	x	x
c. Fugitive Sources	**1 700**	**230**	**79**	**53**	**49**	**110**	**130**	**170**
Coal Mining	2 000	100	0.70	0.60	0.70	70	100	200
Oil and Natural Gas	51	130	79	52	48	38	29	15
Oil	7	5	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	-	13	14	14	14	13	15	14
Venting	30	80	33	20	18	13	7	0.09
Flaring	13	32	32	19	17	12	7	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**333**	**498**	**525**	**528**	**528**	**466**	**489**	**487**
a. Mineral Products	**190**	**250**	**190**	**200**	**190**	**110**	**120**	**98**
Cement Production	180	250	190	200	190	x	x	x
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	4	3	1	1	1	x	x	x
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**140**	**260**	**260**	**270**	**280**	**310**	**310**
e. Non-Energy Products from Fuels and Solvent Use	**120**	**71**	**35**	**24**	**30**	**23**	**23**	**43**
f. Other Product Manufacture and Use	**29**	**40**	**42**	**42**	**39**	**53**	**39**	**40**
AGRICULTURE	**470**	**440**	**410**	**390**	**390**	**380**	**380**	**380**
a. Enteric Fermentation	**230**	**210**	**170**	**170**	**170**	**170**	**170**	**170**
b. Manure Management	**80**	**100**	**100**	**99**	**91**	**92**	**89**	**89**
c. Agricultural Soils	**120**	**120**	**110**	**110**	**110**	**110**	**120**	**110**
Direct Sources	95	98	93	88	95	94	96	93
Indirect Sources	20	20	20	20	20	20	20	20
d. Field Burning of Agricultural Residues	**0.06**	**0.10**	**0.05**	**0.05**	**0.07**	**0.08**	**0.06**	**0.06**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**38**	**13**	**20**	**15**	**17**	**12**	**12**	**14**
WASTE	**890**	**810**	**610**	**560**	**600**	**610**	**610**	**610**
a. Solid Waste Disposal (Landfills)	**790**	**680**	**490**	**440**	**480**	**490**	**490**	**490**
b. Biological Treatment of Solid Waste	**0.70**	**20**	**30**	**30**	**30**	**30**	**30**	**30**
c. Wastewater Treatment and Discharge	**41**	**43**	**38**	**41**	**39**	**37**	**37**	**38**
d. Incineration and Open Burning of Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**60**	**60**	**50**	**50**	**50**	**50**	**40**	**40**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–7 **2019 GHG Emission Summary for Nova Scotia**

	Greenhouse Gases									
Greenhouse Gas Categories	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**14 500**	**43**	**1 100**	**1**	**340**	**310**	**0.55**	**25**	**-**	**16 200**
ENERGY	**14 300**	**12**	**290**	**0.50**	**100**	**-**	**-**	**-**	**-**	**14 700**
a. Stationary Combustion Sources	**8 790**	**4**	**100**	**0.20**	**60**	**-**	**-**	**-**	**-**	**8 940**
Public Electricity and Heat Production	6 660	0.27	7	0.09	30	-	-	-	-	6 690
Petroleum Refining Industries	x	x	x	x	x	x	x	x	x	x
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	3	0.00	0.00	0.00	0.01	-	-	-	-	3
Manufacturing Industries	432	0.04	1	0.03	10	-	-	-	-	443
Construction	x	x	x	x	x	x	x	x	x	x
Commercial and Institutional	499	0.01	0.21	0.01	3	-	-	-	-	502
Residential	1 160	4	90	0.06	20	-	-	-	-	1 270
Agriculture and Forestry	24	0.00	0.01	0.00	0.09	-	-	-	-	24
b. Transport[b]	**5 520**	**1**	**26**	**0.27**	**82**	**-**	**-**	**-**	**-**	**5 630**
Aviation	291	0.00	0.07	0.01	2	-	-	-	-	294
Road Transportation	4 030	0.30	7	0.18	52	-	-	-	-	4 090
Light-Duty Gasoline Vehicles	1 110	0.09	2	0.04	11	-	-	-	-	1 120
Light-Duty Gasoline Trucks	1 540	0.10	3	0.05	16	-	-	-	-	1 560
Heavy-Duty Gasoline Vehicles	301	0.01	0.20	0.03	8	-	-	-	-	309
Motorcycles	11	0.00	0.10	0.00	0.06	-	-	-	-	12
Light-Duty Diesel Vehicles	24	0.00	0.01	0.00	0.58	-	-	-	-	24
Light-Duty Diesel Trucks	15	0.00	0.01	0.00	0.37	-	-	-	-	16
Heavy-Duty Diesel Vehicles	1 030	0.04	1	0.06	17	-	-	-	-	1 050
Propane and Natural Gas Vehicles	0.00	0.00	0.00	0.00	0.00	-	-	-	-	0.00
Railways	142	0.01	0.20	0.05	20	-	-	-	-	158
Marine	469	0.04	1	0.01	4	-	-	-	-	474
Other Transportation	595	0.70	17	0.02	7	-	-	-	-	619
Off-Road Agriculture and Forestry	56	0.00	0.09	0.00	0.90	-	-	-	-	57
Off-Road Commercial and Institutional	67	0.14	4	0.00	0.60	-	-	-	-	71
Off-Road Manufacturing, Mining and Construction	261	0.04	0.90	0.01	4	-	-	-	-	266
Off-Road Residential	x	x	x	x	x	x	x	x	x	x
Off-Road Other Transportation	164	0.42	11	0.00	1	-	-	-	-	176
Pipeline Transport	x	x	x	x	x	x	x	x	x	x
c. Fugitive Sources	**0.00**	**7**	**170**	**-**	**-**	**-**	**-**	**-**	**-**	**170**
Coal Mining	-	6	200	-	-	-	-	-	-	200
Oil and Natural Gas	0.00	0.58	15	-	-	-	-	-	-	15
Oil	-	0.00	0.00	-	-	-	-	-	-	0.00
Natural Gas	0.00	0.58	14	-	-	-	-	-	-	14
Venting	0.00	0.00	0.09	-	-	-	-	-	-	0.09
Flaring	-	-	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**141**	**-**	**-**	**0.04**	**13**	**310**	**0.55**	**25**	**-**	**487**
a. Mineral Products	**98**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**98**
Cement Production	x	-	-	-	-	-	-	-	-	x
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	x	-	-	-	-	-	-	-	-	x
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**310**	**0.06**	**-**	**-**	**310**
e. Non-Energy Products from Fuels and Solvent Use	**43**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**43**
f. Other Product Manufacture and Use	**0.62**	**-**	**-**	**0.05**	**13**	**-**	**0.49**	**25**	**-**	**40**
AGRICULTURE	**14**	**9**	**210**	**0.53**	**160**	**-**	**-**	**-**	**-**	**380**
a. Enteric Fermentation	**-**	**7**	**170**	**-**	**-**	**-**	**-**	**-**	**-**	**170**
b. Manure Management	**-**	**2**	**43**	**0.20**	**50**	**-**	**-**	**-**	**-**	**89**
c. Agricultural Soils	**-**	**-**	**-**	**0.38**	**110**	**-**	**-**	**-**	**-**	**110**
Direct Sources	-	-	-	0.31	93	-	-	-	-	93
Indirect Sources	-	-	-	0.06	20	-	-	-	-	20
d. Field Burning of Agricultural Residues	**-**	**0.00**	**0.04**	**0.00**	**0.01**	**-**	**-**	**-**	**-**	**0.06**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**14**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**14**
WASTE	**-**	**23**	**580**	**0.10**	**30**	**-**	**-**	**-**	**-**	**610**
a. Solid Waste Disposal (Landfills)	**-**	**20**	**490**	**-**	**-**	**-**	**-**	**-**	**-**	**490**
b. Biological Treatment of Solid Waste	**-**	**0.70**	**20**	**0.05**	**20**	**-**	**-**	**-**	**-**	**30**
c. Wastewater Treatment and Discharge	**-**	**1**	**25**	**0.04**	**10**	**-**	**-**	**-**	**-**	**38**
d. Incineration and Open Burning of Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**-**	**2**	**40**	**-**	**-**	**-**	**-**	**-**	**-**	**40**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

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Table A11–8 GHG Emission Summary for New Brunswick, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**16 300**	**20 000**	**13 500**	**13 700**	**14 400**	**13 300**	**13 100**	**12 400**
ENERGY	**14 700**	**18 300**	**12 000**	**12 300**	**12 800**	**11 800**	**11 500**	**11 000**
a. Stationary Combustion Sources	**10 700**	**13 000**	**8 080**	**8 070**	**8 270**	**7 590**	**7 420**	**7 030**
Public Electricity and Heat Production	6 020	8 060	3 760	3 780	4 000	3 340	3 670	3 300
Petroleum Refining Industries	1 200	2 300	x	x	x	x	x	x
Oil and Gas Extraction	-	-	35	29	26	26	34	24
Mining	126	161	x	x	x	x	x	x
Manufacturing Industries	1 630	1 170	680	673	615	621	678	653
Construction	69	6	10	28	17	10	10	7
Commercial and Institutional	580	602	403	428	380	271	305	331
Residential	1 060	750	676	816	691	628	619	557
Agriculture and Forestry	53	33	60	25	31	36	34	32
b. Transport[a]	**3 990**	**5 050**	**3 720**	**4 010**	**4 380**	**3 950**	**3 900**	**3 790**
Aviation	137	127	114	111	109	108	116	118
Road Transportation	2 260	3 590	2 790	3 090	3 420	3 010	2 980	2 880
Light-Duty Gasoline Vehicles	931	1 030	716	851	943	810	770	729
Light-Duty Gasoline Trucks	533	985	894	1 100	1 290	1 170	1 190	1 190
Heavy-Duty Gasoline Vehicles	125	197	182	216	251	226	222	219
Motorcycles	3	6	7	9	10	9	9	9
Light-Duty Diesel Vehicles	15	22	16	16	15	12	9	8
Light-Duty Diesel Trucks	6	10	4	6	7	7	7	7
Heavy-Duty Diesel Vehicles	649	1 340	975	891	902	768	776	715
Propane and Natural Gas Vehicles	0.67	0.15	-	0.00	0.00	0.00	0.00	0.00
Railways	129	284	x	x	x	157	160	151
Marine	182	217	140	121	126	145	133	162
Other Transportation	1 280	829	x	x	x	534	510	476
Off-Road Agriculture and Forestry	123	167	96	98	87	81	78	71
Off-Road Commercial and Institutional	30	55	46	48	48	44	42	41
Off-Road Manufacturing, Mining and Construction	151	194	130	138	155	158	152	137
Off-Road Residential	5	x	x	x	x	30	28	28
Off-Road Other Transportation	971	386	172	205	229	211	200	184
Pipeline Transport	-	x	-	-	13	10	11	15
c. Fugitive Sources	**61**	**220**	**150**	**180**	**190**	**220**	**170**	**200**
Coal Mining	1	0.30	-	-	-	-	-	-
Oil and Natural Gas	60	220	150	180	190	220	170	200
Oil	8	18	15	17	17	16	13	14
Natural Gas	0.02	20	16	16	19	19	19	19
Venting	36	150	100	120	130	150	110	140
Flaring	15	31	21	25	27	31	23	29
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**188**	**269**	**401**	**395**	**477**	**525**	**538**	**371**
a. Mineral Products	**91**	**98**	**3**	**4**	**78**	**60**	**48**	**46**
Cement Production	-	-	-	-	-	-	-	-
Lime Production	81	90	-	-	75	x	x	x
Mineral Products Use	10	8	3	4	4	x	x	x
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**130**	**240**	**240**	**240**	**250**	**270**	**270**
e. Non-Energy Products from Fuels and Solvent Use	**92**	**37**	**150**	**140**	**150**	**200**	**210**	**45**
f. Other Product Manufacture and Use	**5**	**9**	**8**	**9**	**9**	**12**	**13**	**13**
AGRICULTURE	**490**	**540**	**480**	**430**	**480**	**450**	**460**	**460**
a. Enteric Fermentation	**200**	**180**	**150**	**150**	**150**	**150**	**150**	**150**
b. Manure Management	**60**	**74**	**61**	**60**	**58**	**59**	**60**	**59**
c. Agricultural Soils	**160**	**230**	**180**	**160**	**200**	**190**	**200**	**200**
Direct Sources	140	190	150	130	170	160	170	170
Indirect Sources	30	40	30	20	30	30	30	30
d. Field Burning of Agricultural Residues	**0.02**	**0.02**	**0.03**	**0.03**	**0.03**	**0.03**	**0.02**	**0.02**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**68**	**55**	**92**	**62**	**73**	**52**	**49**	**51**
WASTE	**830**	**930**	**640**	**620**	**560**	**570**	**570**	**580**
a. Solid Waste Disposal (Landfills)	**760**	**790**	**520**	**500**	**450**	**460**	**480**	**480**
b. Biological Treatment of Solid Waste	**3**	**50**	**30**	**30**	**30**	**30**	**20**	**20**
c. Wastewater Treatment and Discharge	**36**	**38**	**38**	**38**	**36**	**35**	**35**	**35**
d. Incineration and Open Burning of Waste	**-**	**0.04**	**1**	**1**	**0.20**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**40**	**60**	**50**	**40**	**40**	**40**	**40**	**40**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–9 2019 GHG Emission Summary for New Brunswick

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**10 900**	**35**	**880**	**1**	**400**	**270**	**0.07**	**1**	**-**	**12 400**
ENERGY	**10 700**	**6**	**140**	**0.50**	**100**	**-**	**-**	**-**	**-**	**11 000**
a. Stationary Combustion Sources	**6 870**	**4**	**90**	**0.20**	**70**	**-**	**-**	**-**	**-**	**7 030**
Public Electricity and Heat Production	3 280	0.22	6	0.05	20	-	-	-	-	3 300
Petroleum Refining Industries	x	x	x	x	x	x	x	x	x	x
Oil and Gas Extraction	23	0.00	0.01	0.00	0.50	-	-	-	-	24
Mining	x	x	x	x	x	x	x	x	x	x
Manufacturing Industries	621	0.16	4	0.09	28	-	-	-	-	653
Construction	7	0.00	0.00	0.00	0.02	-	-	-	-	7
Commercial and Institutional	328	0.01	0.13	0.01	3	-	-	-	-	331
Residential	455	3	80	0.06	20	-	-	-	-	557
Agriculture and Forestry	32	0.00	0.01	0.00	0.10	-	-	-	-	32
b. Transport[b]	**3 700**	**0.83**	**21**	**0.21**	**64**	**-**	**-**	**-**	**-**	**3 790**
Aviation	117	0.01	0.20	0.00	1	-	-	-	-	118
Road Transportation	2 830	0.20	5	0.14	41	-	-	-	-	2 880
Light-Duty Gasoline Vehicles	719	0.06	2	0.03	9	-	-	-	-	729
Light-Duty Gasoline Trucks	1 180	0.10	3	0.05	14	-	-	-	-	1 190
Heavy-Duty Gasoline Vehicles	213	0.01	0.20	0.02	6	-	-	-	-	219
Motorcycles	9	0.00	0.08	0.00	0.05	-	-	-	-	9
Light-Duty Diesel Vehicles	8	0.00	0.00	0.00	0.20	-	-	-	-	8
Light-Duty Diesel Trucks	7	0.00	0.00	0.00	0.16	-	-	-	-	7
Heavy-Duty Diesel Vehicles	703	0.03	0.70	0.04	12	-	-	-	-	715
Propane and Natural Gas Vehicles	0.00	0.00	0.00	0.00	0.00	-	-	-	-	0.00
Railways	135	0.01	0.20	0.05	20	-	-	-	-	151
Marine	161	0.02	0.38	0.00	1	-	-	-	-	162
Other Transportation	456	0.59	15	0.02	5	-	-	-	-	476
Off-Road Agriculture and Forestry	70	0.01	0.14	0.00	1	-	-	-	-	71
Off-Road Commercial and Institutional	39	0.05	1	0.00	0.40	-	-	-	-	41
Off-Road Manufacturing, Mining and Construction	135	0.02	0.58	0.01	2	-	-	-	-	137
Off-Road Residential	26	0.06	1	0.00	0.20	-	-	-	-	28
Off-Road Other Transportation	172	0.44	11	0.01	1	-	-	-	-	184
Pipeline Transport	14	0.01	0.36	0.00	0.10	-	-	-	-	15
c. Fugitive Sources	**170**	**1**	**30**	**0.01**	**4**	**-**	**-**	**-**	**-**	**200**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	170	1	30	0.01	4	-	-	-	-	200
Oil	0.10	0.42	11	0.01	4	-	-	-	-	14
Natural Gas	0.01	0.77	19	-	-	-	-	-	-	19
Venting	140	0.01	0.17	-	-	-	-	-	-	140
Flaring	29	0.00	0.03	0.00	0.01	-	-	-	-	29
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**92**	**-**	**-**	**0.04**	**11**	**270**	**0.07**	**1**	**-**	**371**
a. Mineral Products	**46**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**46**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	x	-	-	-	-	-	-	-	-	x
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**270**	**0.05**	**-**	**-**	**270**
e. Non-Energy Products from Fuels and Solvent Use	**45**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**45**
f. Other Product Manufacture and Use	**0.42**	**-**	**-**	**0.04**	**11**	**-**	**0.02**	**1**	**-**	**13**
AGRICULTURE	**51**	**7**	**180**	**0.76**	**230**	**-**	**-**	**-**	**-**	**460**
a. Enteric Fermentation	**-**	**6**	**150**	**-**	**-**	**-**	**-**	**-**	**-**	**150**
b. Manure Management	**-**	**1**	**29**	**0.10**	**30**	**-**	**-**	**-**	**-**	**59**
c. Agricultural Soils	**-**	**-**	**-**	**0.66**	**200**	**-**	**-**	**-**	**-**	**200**
Direct Sources	-	-	-	0.56	170	-	-	-	-	170
Indirect Sources	-	-	-	0.10	30	-	-	-	-	30
d. Field Burning of Agricultural Residues	**-**	**0.00**	**0.02**	**0.00**	**0.01**	**-**	**-**	**-**	**-**	**0.02**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**51**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**51**
WASTE	**-**	**22**	**560**	**0.07**	**20**	**-**	**-**	**-**	**-**	**580**
a. Solid Waste Disposal (Landfills)	**-**	**19**	**480**	**-**	**-**	**-**	**-**	**-**	**-**	**480**
b. Biological Treatment of Solid Waste	**-**	**0.50**	**10**	**0.04**	**10**	**-**	**-**	**-**	**-**	**20**
c. Wastewater Treatment and Discharge	**-**	**0.98**	**25**	**0.03**	**10**	**-**	**-**	**-**	**-**	**35**
d. Incineration and Open Burning of Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**-**	**2**	**40**	**-**	**-**	**-**	**-**	**-**	**-**	**40**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–10 GHG Emission Summary for Quebec, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**86 400**	**87 600**	**79 200**	**79 100**	**79 000**	**81 200**	**82 500**	**83 700**
ENERGY	**57 800**	**60 200**	**54 400**	**55 300**	**54 700**	**56 600**	**57 500**	**58 500**
a. Stationary Combustion Sources	**30 300**	**26 500**	**21 100**	**21 300**	**20 300**	**20 400**	**21 300**	**21 600**
Public Electricity and Heat Production	1 490	621	245	205	233	239	242	234
Petroleum Refining Industries	3 500	3 600	1 800	2 000	1 800	1 500	2 000	1 800
Oil and Gas Extraction	-	-	-	-	-	-	-	-
Mining	824	319	722	570	648	826	1 470	1 480
Manufacturing Industries	12 300	10 000	9 240	9 440	8 540	8 760	8 710	8 800
Construction	458	314	374	351	345	363	395	405
Commercial and Institutional	4 410	5 450	4 610	4 800	4 770	5 140	4 830	5 060
Residential	7 070	5 810	3 560	3 470	3 530	3 140	3 210	3 390
Agriculture and Forestry	291	367	469	484	496	451	461	473
b. Transport[a]	**27 100**	**33 300**	**33 000**	**33 600**	**34 100**	**35 800**	**35 900**	**36 500**
Aviation	952	764	718	718	742	806	904	896
Road Transportation	18 100	26 300	26 400	26 800	27 400	28 600	28 500	29 000
Light-Duty Gasoline Vehicles	10 600	10 800	9 110	9 170	9 120	9 210	8 920	8 810
Light-Duty Gasoline Trucks	3 580	6 900	7 270	7 530	7 880	8 390	8 620	9 130
Heavy-Duty Gasoline Vehicles	785	1 620	1 790	1 800	1 880	2 010	1 990	2 030
Motorcycles	17	71	65	68	70	74	72	72
Light-Duty Diesel Vehicles	210	151	196	204	194	191	176	172
Light-Duty Diesel Trucks	57	69	121	156	184	225	231	241
Heavy-Duty Diesel Vehicles	2 820	6 680	7 880	7 890	8 040	8 470	8 460	8 550
Propane and Natural Gas Vehicles	2	0.99	0.22	0.20	0.17	0.11	0.11	0.11
Railways	567	706	776	682	673	621	696	639
Marine	699	947	810	794	818	863	916	1 100
Other Transportation	6 800	4 570	4 300	4 620	4 490	4 970	4 890	4 880
Off-Road Agriculture and Forestry	999	780	691	739	677	713	680	686
Off-Road Commercial and Institutional	359	456	575	585	687	876	859	891
Off-Road Manufacturing, Mining and Construction	2 030	1 620	1 660	1 890	1 870	2 130	2 040	2 020
Off-Road Residential	61	264	244	251	216	225	234	239
Off-Road Other Transportation	3 330	1 120	765	829	854	939	976	948
Pipeline Transport	26	338	359	326	189	80	96	100
c. Fugitive Sources	**430**	**380**	**270**	**290**	**310**	**330**	**300**	**330**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	430	380	270	290	310	330	300	330
Oil	22	28	21	22	22	20	20	20
Natural Gas	260	74	48	49	52	53	51	51
Venting	99	240	170	190	200	220	200	220
Flaring	40	47	29	32	35	39	35	40
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**14 800**	**12 700**	**11 500**	**10 200**	**9 910**	**10 600**	**10 300**	**10 600**
a. Mineral Products	**1 900**	**2 100**	**1 800**	**1 700**	**1 600**	**2 200**	**2 100**	**2 500**
Cement Production	1 400	1 300	1 200	1 300	1 200	1 700	1 600	2 100
Lime Production	290	490	470	350	330	x	x	x
Mineral Products Use	200	260	69	68	64	x	x	x
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**10 900**	**7 560**	**5 320**	**5 280**	**5 160**	**5 250**	**4 750**	**4 560**
Iron and Steel Production	-	-	27	29	29	18	7	7
Aluminium Production	8 660	7 460	5 280	5 240	5 130	5 220	4 740	4 540
SF_6 Used in Magnesium Smelters and Casters	2 280	103	11	11	8	11	11	11
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**2**	**1 100**	**2 200**	**2 200**	**2 300**	**2 300**	**2 500**	**2 500**
e. Non-Energy Products from Fuels and Solvent Use	**1 900**	**1 900**	**2 200**	**830**	**690**	**760**	**790**	**850**
f. Other Product Manufacture and Use	**80**	**120**	**97**	**160**	**180**	**140**	**190**	**190**
AGRICULTURE	**7 000**	**7 600**	**7 700**	**7 900**	**8 000**	**7 600**	**8 200**	**7 900**
a. Enteric Fermentation	**3 100**	**3 100**	**2 700**	**2 600**	**2 600**	**2 600**	**2 700**	**2 700**
b. Manure Management	**1 100**	**1 600**	**1 600**	**1 600**	**1 700**	**1 700**	**1 700**	**1 700**
c. Agricultural Soils	**2 500**	**2 700**	**3 200**	**3 400**	**3 500**	**3 100**	**3 600**	**3 400**
Direct Sources	2 100	2 300	2 700	2 900	3 000	2 700	3 100	2 900
Indirect Sources	400	400	500	500	500	500	500	500
d. Field Burning of Agricultural Residues	**0.30**	**0.30**	**0.20**	**0.20**	**0.20**	**0.10**	**0.20**	**0.20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**220**	**160**	**270**	**220**	**260**	**190**	**240**	**220**
WASTE	**6 700**	**7 100**	**5 500**	**5 800**	**6 300**	**6 400**	**6 500**	**6 700**
a. Solid Waste Disposal (Landfills)	**5 800**	**6 000**	**4 700**	**5 000**	**5 500**	**5 700**	**5 700**	**5 900**
b. Biological Treatment of Solid Waste	**40**	**30**	**30**	**30**	**30**	**30**	**70**	**80**
c. Wastewater Treatment and Discharge	**180**	**180**	**220**	**220**	**210**	**210**	**220**	**220**
d. Incineration and Open Burning of Waste	**200**	**200**	**40**	**40**	**40**	**40**	**40**	**40**
e. Industrial Wood Waste Landfills	**500**	**700**	**500**	**500**	**500**	**500**	**500**	**400**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–11 2019 GHG Emission Summary for Quebec

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**64 300**	**450**	**11 000**	**17**	**5 000**	**2 500**	**510**	**79**	**0.60**	**83 700**
ENERGY	**56 700**	**38**	**950**	**3**	**900**	**-**	**-**	**-**	**-**	**58 500**
a. Stationary Combustion Sources	**20 600**	**30**	**700**	**1**	**300**	**-**	**-**	**-**	**-**	**21 600**
Public Electricity and Heat Production	228	0.04	0.87	0.02	5	-	-	-	-	234
Petroleum Refining Industries	1 800	0.04	1	0.02	7	-	-	-	-	1 800
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	1 480	0.04	0.90	0.02	6	-	-	-	-	1 480
Manufacturing Industries	8 680	0.58	15	0.35	100	-	-	-	-	8 800
Construction	403	0.01	0.19	0.01	3	-	-	-	-	405
Commercial and Institutional	5 010	0.18	5	0.10	40	-	-	-	-	5 060
Residential	2 560	30	700	0.50	100	-	-	-	-	3 390
Agriculture and Forestry	465	0.01	0.20	0.03	7	-	-	-	-	473
b. Transport[b]	**35 800**	**6**	**160**	**2**	**540**	**-**	**-**	**-**	**-**	**36 500**
Aviation	887	0.03	0.80	0.03	8	-	-	-	-	896
Road Transportation	28 600	2	50	1	400	-	-	-	-	29 000
Light-Duty Gasoline Vehicles	8 690	0.70	20	0.33	97	-	-	-	-	8 810
Light-Duty Gasoline Trucks	9 010	0.80	20	0.33	100	-	-	-	-	9 130
Heavy-Duty Gasoline Vehicles	1 980	0.07	2	0.17	52	-	-	-	-	2 030
Motorcycles	71	0.03	0.70	0.00	0.39	-	-	-	-	72
Light-Duty Diesel Vehicles	167	0.00	0.08	0.01	4	-	-	-	-	172
Light-Duty Diesel Trucks	235	0.01	0.20	0.02	6	-	-	-	-	241
Heavy-Duty Diesel Vehicles	8 400	0.40	9	0.47	140	-	-	-	-	8 550
Propane and Natural Gas Vehicles	0.11	0.00	0.00	0.00	0.00	-	-	-	-	0.11
Railways	571	0.03	0.80	0.20	70	-	-	-	-	639
Marine	1 090	0.10	3	0.03	9	-	-	-	-	1 100
Other Transportation	4 720	4	100	0.20	60	-	-	-	-	4 880
Off-Road Agriculture and Forestry	676	0.03	0.86	0.03	10	-	-	-	-	686
Off-Road Commercial and Institutional	854	1	29	0.03	8	-	-	-	-	891
Off-Road Manufacturing, Mining and Construction	1 980	0.32	8	0.10	30	-	-	-	-	2 020
Off-Road Residential	225	0.49	12	0.01	2	-	-	-	-	239
Off-Road Other Transportation	890	2	50	0.03	8	-	-	-	-	948
Pipeline Transport	97	0.10	2	0.00	0.80	-	-	-	-	100
c. Fugitive Sources	**230**	**4**	**91**	**0.02**	**5**	**-**	**-**	**-**	**-**	**330**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	230	4	91	0.02	5	-	-	-	-	330
Oil	0.14	0.58	15	0.02	5	-	-	-	-	20
Natural Gas	0.04	2	51	-	-	-	-	-	-	51
Venting	190	1	26	-	-	-	-	-	-	220
Flaring	40	0.00	0.02	0.00	0.01	-	-	-	-	40
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**7 440**	**0.00**	**0.00**	**0.39**	**117**	**2 500**	**508**	**79**	**0.60**	**10 600**
a. Mineral Products	**2 500**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2 500**
Cement Production	2 100	-	-	-	-	-	-	-	-	2 100
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	x	-	-	-	-	-	-	-	-	x
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**4 050**	**0.00**	**0.00**	**-**	**-**	**-**	**496**	**12**	**-**	**4 560**
Iron and Steel Production	7	0.00	0.00	-	-	-	-	-	-	7
Aluminium Production	4 040	-	-	-	-	-	496	0.84	-	4 540
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	11	-	11
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**2 500**	**4**	**10**	**0.60**	**2 500**
e. Non-Energy Products from Fuels and Solvent Use	**850**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**850**
f. Other Product Manufacture and Use	**5**	**-**	**-**	**0.39**	**120**	**-**	**8**	**58**	**-**	**190**
AGRICULTURE	**220**	**160**	**3 900**	**13**	**3 800**	**-**	**-**	**-**	**-**	**7 900**
a. Enteric Fermentation	**-**	**110**	**2 700**	**-**	**-**	**-**	**-**	**-**	**-**	**2 700**
b. Manure Management	**-**	**48**	**1 200**	**2**	**500**	**-**	**-**	**-**	**-**	**1 700**
c. Agricultural Soils	**-**	**-**	**-**	**11**	**3 400**	**-**	**-**	**-**	**-**	**3 400**
Direct Sources	-	-	-	10	2 900	-	-	-	-	2 900
Indirect Sources	-	-	-	2	500	-	-	-	-	500
d. Field Burning of Agricultural Residues	**-**	**0.01**	**0.10**	**0.00**	**0.04**	**-**	**-**	**-**	**-**	**0.20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**220**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**220**
WASTE	**8**	**260**	**6 500**	**0.60**	**200**	**-**	**-**	**-**	**-**	**6 700**
a. Solid Waste Disposal (Landfills)	**-**	**240**	**5 900**	**-**	**-**	**-**	**-**	**-**	**-**	**5 900**
b. Biological Treatment of Solid Waste	**-**	**2**	**40**	**0.10**	**40**	**-**	**-**	**-**	**-**	**80**
c. Wastewater Treatment and Discharge	**-**	**4**	**110**	**0.40**	**100**	**-**	**-**	**-**	**-**	**220**
d. Incineration and Open Burning of Waste	**8**	**0.00**	**0.03**	**0.10**	**30**	**-**	**-**	**-**	**-**	**40**
e. Industrial Wood Waste Landfills	**-**	**20**	**400**	**-**	**-**	**-**	**-**	**-**	**-**	**400**

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Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–12 GHG Emission Summary for Ontario, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**180 000**	**206 000**	**164 000**	**163 000**	**161 000**	**158 000**	**163 000**	**163 000**
ENERGY	**131 000**	**161 000**	**123 000**	**123 000**	**120 000**	**118 000**	**123 000**	**124 000**
a. Stationary Combustion Sources	**82 500**	**96 400**	**63 300**	**61 700**	**59 200**	**56 400**	**59 400**	**59 500**
Public Electricity and Heat Production	25 900	35 400	6 030	6 250	5 540	2 560	4 090	3 880
Petroleum Refining Industries	6 200	6 900	5 300	4 900	4 800	3 400	3 800	3 800
Oil and Gas Extraction	100	169	60	72	76	31	57	95
Mining	493	420	569	436	529	553	489	489
Manufacturing Industries	22 000	18 800	16 600	15 900	15 700	16 300	16 000	16 000
Construction	571	637	380	350	341	305	289	297
Commercial and Institutional	9 180	12 800	13 300	12 700	12 200	12 600	13 000	13 500
Residential	17 300	20 300	19 600	19 600	18 400	19 200	20 200	20 000
Agriculture and Forestry	775	1 040	1 500	1 420	1 510	1 360	1 390	1 480
b. Transport[a]	**47 400**	**63 500**	**58 300**	**59 800**	**59 500**	**60 200**	**62 400**	**62 800**
Aviation	2 370	2 220	2 240	2 270	2 280	2 410	2 590	2 580
Road Transportation	29 300	47 800	45 500	46 300	46 600	46 800	48 300	49 000
Light-Duty Gasoline Vehicles	16 400	16 600	12 800	12 900	12 700	12 100	12 000	11 900
Light-Duty Gasoline Trucks	7 210	15 800	16 400	16 900	17 700	18 000	19 000	19 900
Heavy-Duty Gasoline Vehicles	1 480	3 150	3 310	3 310	3 420	3 410	3 430	3 560
Motorcycles	27	61	86	88	93	95	95	96
Light-Duty Diesel Vehicles	127	217	327	363	337	339	337	314
Light-Duty Diesel Trucks	34	72	241	328	376	467	523	518
Heavy-Duty Diesel Vehicles	3 970	11 800	12 300	12 400	11 900	12 300	13 000	12 700
Propane and Natural Gas Vehicles	68	55	0.91	0.65	0.74	0.53	0.53	0.52
Railways	1 780	1 550	1 410	1 430	1 450	1 450	1 540	1 560
Marine	201	259	259	265	261	272	273	287
Other Transportation	13 700	11 700	8 970	9 500	8 920	9 250	9 660	9 370
Off-Road Agriculture and Forestry	1 340	1 410	1 110	1 170	1 040	1 040	1 120	1 090
Off-Road Commercial and Institutional	561	960	1 020	993	1 040	1 200	1 250	1 270
Off-Road Manufacturing, Mining and Construction	3 130	3 310	3 130	3 540	3 420	3 790	3 930	3 760
Off-Road Residential	89	491	480	475	452	460	471	481
Off-Road Other Transportation	6 340	2 460	1 700	1 770	1 780	1 850	1 890	1 840
Pipeline Transport	2 280	3 070	1 530	1 550	1 200	914	997	931
c. Fugitive Sources	**1 600**	**1 600**	**1 500**	**1 500**	**1 500**	**1 500**	**1 500**	**1 500**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	1 600	1 600	1 500	1 500	1 500	1 500	1 500	1 500
Oil	64	42	35	34	32	27	29	28
Natural Gas	1 000	960	920	920	940	960	960	970
Venting	340	460	440	440	450	450	450	480
Flaring	160	100	65	67	60	61	62	67
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**30 600**	**25 100**	**23 900**	**23 400**	**24 500**	**23 000**	**23 600**	**23 000**
a. Mineral Products	**3 900**	**4 800**	**3 500**	**3 700**	**3 500**	**3 800**	**3 800**	**3 600**
Cement Production	2 400	3 700	2 700	2 800	2 700	3 000	2 900	2 800
Lime Production	1 100	810	730	740	710	x	x	x
Mineral Products Use	380	320	120	130	120	x	x	x
b. Chemical Industry[b]	**10 300**	**2 550**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	10 000	2 500	-	-	-	-	-	-
c. Metal Production	**11 200**	**11 400**	**9 100**	**8 670**	**9 320**	**8 560**	**9 000**	**8 540**
Iron and Steel Production	10 500	10 300	8 870	8 440	9 190	8 430	8 870	8 260
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	687	1 130	238	227	131	129	135	279
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**970**	**2 000**	**4 300**	**4 200**	**4 300**	**4 400**	**4 800**	**4 700**
e. Non-Energy Products from Fuels and Solvent Use	**4 100**	**4 100**	**6 900**	**6 600**	**7 200**	**6 000**	**5 800**	**5 900**
f. Other Product Manufacture and Use	**140**	**200**	**180**	**200**	**220**	**250**	**270**	**280**
AGRICULTURE	**10 000**	**10 000**	**9 700**	**9 500**	**10 000**	**10 000**	**9 900**	**9 600**
a. Enteric Fermentation	**4 300**	**4 100**	**3 300**	**3 300**	**3 300**	**3 300**	**3 300**	**3 300**
b. Manure Management	**1 800**	**2 000**	**1 800**	**1 800**	**1 800**	**1 800**	**1 900**	**1 900**
c. Agricultural Soils	**3 900**	**3 800**	**4 400**	**4 200**	**4 600**	**4 600**	**4 500**	**4 200**
Direct Sources	3 300	3 200	3 800	3 600	4 000	4 000	3 900	3 700
Indirect Sources	600	600	600	600	600	600	600	600
d. Field Burning of Agricultural Residues	**3**	**0.60**	**0.30**	**0.30**	**0.30**	**0.20**	**0.20**	**0.30**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**250**	**160**	**190**	**150**	**200**	**200**	**200**	**160**
WASTE	**7 700**	**9 000**	**7 100**	**7 000**	**6 600**	**6 600**	**6 600**	**6 700**
a. Solid Waste Disposal (Landfills)	**7 000**	**8 200**	**6 300**	**6 100**	**5 700**	**5 700**	**5 800**	**5 900**
b. Biological Treatment of Solid Waste	**30**	**60**	**100**	**100**	**100**	**100**	**100**	**100**
c. Wastewater Treatment and Discharge	**240**	**310**	**340**	**340**	**340**	**340**	**350**	**360**
d. Incineration and Open Burning of Waste	**70**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
e. Industrial Wood Waste Landfills	**300**	**400**	**300**	**300**	**300**	**300**	**300**	**300**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

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Table A11–13 2019 GHG Emission Summary for Ontario

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**138 000**	**510**	**13 000**	**25**	**7 300**	**4 700**	**17**	**340**	**-**	**163 000**
ENERGY	**120 000**	**78**	**1 900**	**6**	**2 000**	**-**	**-**	**-**	**-**	**124 000**
a. Stationary Combustion Sources	**58 600**	**20**	**400**	**2**	**500**	**-**	**-**	**-**	**-**	**59 500**
Public Electricity and Heat Production	3 820	1	25	0.10	30	-	-	-	-	3 880
Petroleum Refining Industries	3 800	0.08	2	0.03	8	-	-	-	-	3 800
Oil and Gas Extraction	93	0.00	0.04	0.01	1	-	-	-	-	95
Mining	482	0.01	0.20	0.02	7	-	-	-	-	489
Manufacturing Industries	15 800	0.53	13	0.39	120	-	-	-	-	16 000
Construction	294	0.01	0.13	0.01	3	-	-	-	-	297
Commercial and Institutional	13 400	0.35	9	0.30	90	-	-	-	-	13 500
Residential	19 400	10	400	0.60	200	-	-	-	-	20 000
Agriculture and Forestry	1 470	0.03	0.70	0.04	10	-	-	-	-	1 480
b. Transport[b]	**61 300**	**12**	**290**	**4**	**1 200**	**-**	**-**	**-**	**-**	**62 800**
Aviation	2 560	0.05	1	0.07	20	-	-	-	-	2 580
Road Transportation	48 000	3	80	3	920	-	-	-	-	49 000
Light-Duty Gasoline Vehicles	11 600	0.90	20	0.78	230	-	-	-	-	11 900
Light-Duty Gasoline Trucks	19 600	1	40	1	360	-	-	-	-	19 900
Heavy-Duty Gasoline Vehicles	3 470	0.10	3	0.31	94	-	-	-	-	3 560
Motorcycles	94	0.04	0.90	0.00	0.54	-	-	-	-	96
Light-Duty Diesel Vehicles	307	0.01	0.20	0.03	8	-	-	-	-	314
Light-Duty Diesel Trucks	504	0.01	0.30	0.04	13	-	-	-	-	518
Heavy-Duty Diesel Vehicles	12 500	0.50	10	0.72	220	-	-	-	-	12 700
Propane and Natural Gas Vehicles	0.51	0.00	0.01	0.00	0.00	-	-	-	-	0.52
Railways	1 390	0.08	2	0.60	200	-	-	-	-	1 560
Marine	285	0.03	0.65	0.01	2	-	-	-	-	287
Other Transportation	9 050	8	210	0.40	100	-	-	-	-	9 370
Off-Road Agriculture and Forestry	1 080	0.05	1	0.05	10	-	-	-	-	1 090
Off-Road Commercial and Institutional	1 220	2	39	0.04	10	-	-	-	-	1 270
Off-Road Manufacturing, Mining and Construction	3 690	0.64	16	0.20	60	-	-	-	-	3 760
Off-Road Residential	452	1	25	0.01	4	-	-	-	-	481
Off-Road Other Transportation	1 720	4	100	0.05	20	-	-	-	-	1 840
Pipeline Transport	902	0.88	22	0.02	7	-	-	-	-	931
c. Fugitive Sources	**290**	**50**	**1 200**	**0.02**	**6**	**-**	**-**	**-**	**-**	**1 500**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	290	50	1 200	0.02	6	-	-	-	-	1 500
Oil	0.17	0.88	22	0.02	6	-	-	-	-	28
Natural Gas	2	39	960	-	-	-	-	-	-	970
Venting	220	10	260	-	-	-	-	-	-	480
Flaring	64	0.11	3	0.00	0.03	-	-	-	-	67
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**17 700**	**2**	**43**	**0.77**	**229**	**4 700**	**17**	**340**	**-**	**23 000**
a. Mineral Products	**3 600**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3 600**
Cement Production	2 800	-	-	-	-	-	-	-	-	2 800
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	x	-	-	-	-	-	-	-	-	x
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**8 250**	**0.08**	**2**	**-**	**-**	**-**	**-**	**279**	**-**	**8 540**
Iron and Steel Production	8 250	0.08	2	-	-	-	-	-	-	8 260
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	279	-	279
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**4 700**	**4**	**8**	**-**	**4 700**
e. Non-Energy Products from Fuels and Solvent Use	**5 800**	**-**	**-**	**0.10**	**-**	**-**	**-**	**-**	**-**	**5 900**
f. Other Product Manufacture and Use	**8**	**-**	**-**	**0.67**	**200**	**-**	**12**	**57**	**-**	**280**
AGRICULTURE	**160**	**170**	**4 300**	**17**	**5 100**	**-**	**-**	**-**	**-**	**9 600**
a. Enteric Fermentation	**-**	**130**	**3 300**	**-**	**-**	**-**	**-**	**-**	**-**	**3 300**
b. Manure Management	**-**	**40**	**1 000**	**3**	**900**	**-**	**-**	**-**	**-**	**1 900**
c. Agricultural Soils	**-**	**-**	**-**	**14**	**4 200**	**-**	**-**	**-**	**-**	**4 200**
Direct Sources	-	-	-	12	3 700	-	-	-	-	3 700
Indirect Sources	-	-	-	2	600	-	-	-	-	600
d. Field Burning of Agricultural Residues	**-**	**0.01**	**0.20**	**0.00**	**0.07**	**-**	**-**	**-**	**-**	**0.30**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**160**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**160**
WASTE	**70**	**250**	**6 400**	**1**	**300**	**-**	**-**	**-**	**-**	**6 700**
a. Solid Waste Disposal (Landfills)	**-**	**240**	**5 900**	**-**	**-**	**-**	**-**	**-**	**-**	**5 900**
b. Biological Treatment of Solid Waste	**-**	**2**	**60**	**0.20**	**70**	**-**	**-**	**-**	**-**	**100**
c. Wastewater Treatment and Discharge	**-**	**7**	**170**	**0.60**	**200**	**-**	**-**	**-**	**-**	**360**
d. Incineration and Open Burning of Waste	**70**	**0.05**	**1**	**0.10**	**40**	**-**	**-**	**-**	**-**	**100**
e. Industrial Wood Waste Landfills	**-**	**10**	**300**	**-**	**-**	**-**	**-**	**-**	**-**	**300**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.

b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–14 **GHG Emission Summary for Manitoba, Selected Years**

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**18 600**	**20 600**	**21 500**	**21 200**	**21 500**	**22 200**	**23 000**	**22 600**
ENERGY	**12 500**	**12 300**	**13 100**	**12 600**	**12 800**	**13 300**	**13 900**	**13 600**
a. Stationary Combustion Sources	**4 910**	**4 540**	**4 210**	**4 030**	**4 030**	**4 270**	**4 210**	**4 130**
Public Electricity and Heat Production	519	358	127	124	69	69	41	40
Petroleum Refining Industries	-	-	-	-	-	-	-	-
Oil and Gas Extraction	1	0.46	0.31	0.00	-	0.00	0.00	-
Mining	79	96	91	78	59	97	120	118
Manufacturing Industries	1 180	1 470	1 190	1 400	1 500	1 490	1 180	1 130
Construction	63	86	111	104	122	113	125	121
Commercial and Institutional	1 400	1 420	1 450	1 300	1 260	1 360	1 510	1 480
Residential	1 620	1 070	1 200	1 000	994	1 100	1 190	1 180
Agriculture and Forestry	43	43	34	32	26	40	49	49
b. Transport[a]	**7 100**	**7 510**	**8 470**	**8 130**	**8 340**	**8 630**	**9 330**	**9 120**
Aviation	472	534	470	438	433	475	515	509
Road Transportation	3 260	4 180	5 560	5 250	5 540	5 660	6 020	5 910
Light-Duty Gasoline Vehicles	1 540	1 210	1 230	1 140	1 130	1 080	1 120	1 070
Light-Duty Gasoline Trucks	915	1 470	2 100	2 080	2 150	2 130	2 340	2 350
Heavy-Duty Gasoline Vehicles	318	443	500	487	497	487	520	513
Motorcycles	4	4	8	9	9	9	10	10
Light-Duty Diesel Vehicles	8	10	16	14	15	17	14	13
Light-Duty Diesel Trucks	6	15	11	11	13	15	15	15
Heavy-Duty Diesel Vehicles	442	1 020	1 690	1 500	1 720	1 930	2 010	1 930
Propane and Natural Gas Vehicles	31	7	0.09	0.07	0.05	0.08	0.08	0.08
Railways	605	299	656	704	660	803	881	893
Marine	2	2	3	1	0.13	1	4	3
Other Transportation	2 750	2 490	1 780	1 740	1 710	1 690	1 910	1 800
Off-Road Agriculture and Forestry	1 060	1 310	971	890	908	919	938	911
Off-Road Commercial and Institutional	41	81	100	92	84	88	96	95
Off-Road Manufacturing, Mining and Construction	193	229	213	215	238	297	307	288
Off-Road Residential	6	45	51	51	51	51	57	56
Off-Road Other Transportation	604	222	177	185	182	182	205	192
Pipeline Transport	848	601	268	311	245	155	304	261
c. Fugitive Sources	**450**	**210**	**440**	**420**	**400**	**370**	**390**	**400**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	450	210	440	420	400	370	390	400
Oil	6	65	120	110	100	91	99	100
Natural Gas	380	72	130	120	120	120	120	120
Venting	41	40	72	67	64	58	63	66
Flaring	29	31	130	120	110	99	110	110
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**488**	**703**	**859**	**918**	**905**	**942**	**1 030**	**992**
a. Mineral Products	**220**	**70**	**57**	**58**	**55**	**85**	**80**	**73**
Cement Production	150	-	-	-	-	-	-	-
Lime Production	61	60	51	52	50	x	x	x
Mineral Products Use	6	10	6	6	5	x	x	x
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**190**	**430**	**430**	**450**	**450**	**480**	**470**
e. Non-Energy Products from Fuels and Solvent Use	**250**	**420**	**360**	**410**	**390**	**390**	**440**	**420**
f. Other Product Manufacture and Use	**11**	**18**	**13**	**14**	**18**	**20**	**23**	**23**
AGRICULTURE	**4 700**	**6 300**	**6 100**	**6 300**	**6 500**	**6 600**	**6 700**	**6 700**
a. Enteric Fermentation	**1 900**	**3 200**	**2 400**	**2 300**	**2 300**	**2 400**	**2 400**	**2 300**
b. Manure Management	**410**	**780**	**690**	**710**	**720**	**740**	**740**	**720**
c. Agricultural Soils	**2 100**	**2 100**	**2 800**	**3 000**	**3 100**	**3 200**	**3 200**	**3 300**
Direct Sources	1 700	1 600	2 300	2 500	2 500	2 600	2 600	2 700
Indirect Sources	400	400	500	600	600	600	600	600
d. Field Burning of Agricultural Residues	**100**	**10**	**20**	**20**	**20**	**20**	**20**	**20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**130**	**190**	**240**	**260**	**280**	**310**	**310**	**330**
WASTE	**960**	**1 400**	**1 400**	**1 400**	**1 300**	**1 300**	**1 300**	**1 400**
a. Solid Waste Disposal (Landfills)	**900**	**1 300**	**1 300**	**1 300**	**1 200**	**1 300**	**1 300**	**1 300**
b. Biological Treatment of Solid Waste	**0.30**	**5**	**9**	**9**	**9**	**9**	**9**	**9**
c. Wastewater Treatment and Discharge	**35**	**38**	**46**	**43**	**43**	**43**	**43**	**43**
d. Incineration and Open Burning of Waste	**0.40**	**0.40**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.06**
e. Industrial Wood Waste Landfills	**30**	**30**	**20**	**20**	**20**	**20**	**20**	**20**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–15 **2019 GHG Emission Summary for Manitoba**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**13 800**	**180**	**4 400**	**13**	**3 900**	**470**	**0.98**	**2**	**-**	**22 600**
ENERGY	**13 000**	**14**	**360**	**0.80**	**200**	**-**	**-**	**-**	**-**	**13 600**
a. Stationary Combustion Sources	**4 070**	**0.90**	**20**	**0.10**	**30**	**-**	**-**	**-**	**-**	**4 130**
Public Electricity and Heat Production	40	0.00	0.10	0.00	0.20	-	-	-	-	40
Petroleum Refining Industries	-	-	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	116	0.00	0.05	0.01	2	-	-	-	-	118
Manufacturing Industries	1 120	0.05	1	0.03	10	-	-	-	-	1 130
Construction	120	0.00	0.06	0.00	0.69	-	-	-	-	121
Commercial and Institutional	1 470	0.03	0.71	0.03	9	-	-	-	-	1 480
Residential	1 150	0.80	20	0.03	10	-	-	-	-	1 180
Agriculture and Forestry	48	0.00	0.02	0.00	1	-	-	-	-	49
b. Transport[b]	**8 870**	**2**	**40**	**0.70**	**210**	**-**	**-**	**-**	**-**	**9 120**
Aviation	504	0.01	0.30	0.01	4	-	-	-	-	509
Road Transportation	5 810	0.40	10	0.30	90	-	-	-	-	5 910
Light-Duty Gasoline Vehicles	1 050	0.10	3	0.05	15	-	-	-	-	1 070
Light-Duty Gasoline Trucks	2 320	0.20	6	0.10	29	-	-	-	-	2 350
Heavy-Duty Gasoline Vehicles	499	0.02	0.50	0.05	13	-	-	-	-	513
Motorcycles	10	0.00	0.10	0.00	0.06	-	-	-	-	10
Light-Duty Diesel Vehicles	13	0.00	0.01	0.00	0.32	-	-	-	-	13
Light-Duty Diesel Trucks	15	0.00	0.01	0.00	0.36	-	-	-	-	15
Heavy-Duty Diesel Vehicles	1 900	0.08	2	0.11	32	-	-	-	-	1 930
Propane and Natural Gas Vehicles	0.08	0.00	0.00	0.00	0.00	-	-	-	-	0.08
Railways	799	0.05	1	0.30	90	-	-	-	-	893
Marine	3	0.00	0.01	0.00	0.03	-	-	-	-	3
Other Transportation	1 760	1	27	0.07	20	-	-	-	-	1 800
Off-Road Agriculture and Forestry	899	0.04	1	0.04	10	-	-	-	-	911
Off-Road Commercial and Institutional	91	0.14	4	0.00	0.90	-	-	-	-	95
Off-Road Manufacturing, Mining and Construction	282	0.06	2	0.01	4	-	-	-	-	288
Off-Road Residential	52	0.13	3	0.00	0.40	-	-	-	-	56
Off-Road Other Transportation	179	0.46	11	0.01	2	-	-	-	-	192
Pipeline Transport	253	0.25	6	0.01	2	-	-	-	-	261
c. Fugitive Sources	**100**	**12**	**300**	**0.00**	**0.10**	**-**	**-**	**-**	**-**	**400**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	100	12	300	0.00	0.10	-	-	-	-	400
Oil	0.25	4	100	-	-	-	-	-	-	100
Natural Gas	6	5	110	-	-	-	-	-	-	120
Venting	0.47	3	65	-	-	-	-	-	-	66
Flaring	98	0.62	15	0.00	0.10	-	-	-	-	110
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**449**	**-**	**-**	**0.23**	**68**	**470**	**0.98**	**2**	**-**	**992**
a. Mineral Products	**73**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**73**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	x	-	-	-	-	-	-	-	-	x
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**470**	**0.09**	**-**	**-**	**470**
e. Non-Energy Products from Fuels and Solvent Use	**380**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**420**
f. Other Product Manufacture and Use	**1**	**-**	**-**	**0.06**	**19**	**-**	**0.90**	**2**	**-**	**23**
AGRICULTURE	**330**	**110**	**2 700**	**12**	**3 600**	**-**	**-**	**-**	**-**	**6 700**
a. Enteric Fermentation	**-**	**91**	**2 300**	**-**	**-**	**-**	**-**	**-**	**-**	**2 300**
b. Manure Management	**-**	**18**	**440**	**0.90**	**300**	**-**	**-**	**-**	**-**	**720**
c. Agricultural Soils	**-**	**-**	**-**	**11**	**3 300**	**-**	**-**	**-**	**-**	**3 300**
Direct Sources	-	-	-	9	2 700	-	-	-	-	2 700
Indirect Sources	-	-	-	2	600	-	-	-	-	600
d. Field Burning of Agricultural Residues	**-**	**0.60**	**10**	**0.02**	**5**	**-**	**-**	**-**	**-**	**20**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**330**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**330**
WASTE	**0.05**	**53**	**1 300**	**0.08**	**20**	**-**	**-**	**-**	**-**	**1 400**
a. Solid Waste Disposal (Landfills)	**-**	**51**	**1 300**	**-**	**-**	**-**	**-**	**-**	**-**	**1 300**
b. Biological Treatment of Solid Waste	**-**	**0.10**	**4**	**0.02**	**6**	**-**	**-**	**-**	**-**	**9**
c. Wastewater Treatment and Discharge	**-**	**1**	**25**	**0.06**	**20**	**-**	**-**	**-**	**-**	**43**
d. Incineration and Open Burning of Waste	**0.05**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.06**
e. Industrial Wood Waste Landfills	**-**	**0.80**	**20**	**-**	**-**	**-**	**-**	**-**	**-**	**20**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–16 GHG Emission Summary for Saskatchewan, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**43 300**	**67 800**	**74 200**	**76 200**	**73 800**	**76 000**	**76 200**	**74 800**
ENERGY	**34 200**	**53 100**	**59 600**	**61 200**	**58 600**	**60 600**	**60 700**	**59 400**
a. Stationary Combustion Sources	**18 300**	**26 400**	**27 900**	**28 800**	**28 300**	**29 200**	**29 400**	**29 100**
Public Electricity and Heat Production	11 100	15 300	15 200	16 100	16 000	16 600	16 100	15 800
Petroleum Refining Industries	630	770	1 100	1 200	1 200	1 200	1 100	1 200
Oil and Gas Extraction	1 400	5 190	4 640	4 980	4 690	4 230	3 780	3 620
Mining	974	1 280	1 930	1 920	1 810	2 210	2 760	2 800
Manufacturing Industries	790	534	970	851	804	864	1 240	1 210
Construction	70	42	39	67	39	45	43	35
Commercial and Institutional	985	1 510	1 130	1 110	1 300	1 470	1 600	1 650
Residential	2 080	1 590	1 850	1 670	1 640	1 800	1 950	2 060
Agriculture and Forestry	296	256	997	870	783	815	785	723
b. Transport[a]	**9 160**	**11 500**	**16 600**	**16 900**	**16 400**	**16 700**	**17 500**	**17 200**
Aviation	259	193	234	234	225	224	235	217
Road Transportation	3 780	5 170	8 650	9 060	9 110	9 380	9 440	9 240
Light-Duty Gasoline Vehicles	1 480	1 370	1 320	1 400	1 380	1 300	1 220	1 160
Light-Duty Gasoline Trucks	1 230	1 720	2 860	3 200	3 350	3 380	3 360	3 370
Heavy-Duty Gasoline Vehicles	628	777	898	971	1 000	1 000	978	967
Motorcycles	2	3	7	7	8	8	8	7
Light-Duty Diesel Vehicles	5	11	25	26	24	25	24	22
Light-Duty Diesel Trucks	8	39	33	37	36	40	40	40
Heavy-Duty Diesel Vehicles	386	1 250	3 510	3 420	3 310	3 630	3 810	3 670
Propane and Natural Gas Vehicles	37	5	0.16	0.14	0.27	0.50	0.51	0.53
Railways	584	410	718	802	781	1 120	1 280	1 360
Marine	0.00	-	-	-	-	-	-	-
Other Transportation	4 540	5 730	6 990	6 790	6 300	6 020	6 520	6 350
Off-Road Agriculture and Forestry	2 130	3 240	3 830	3 870	3 760	4 130	4 480	4 400
Off-Road Commercial and Institutional	32	77	131	128	54	32	32	33
Off-Road Manufacturing, Mining and Construction	166	238	392	438	304	287	310	269
Off-Road Residential	4	35	50	51	59	62	60	60
Off-Road Other Transportation	612	243	268	292	294	301	289	275
Pipeline Transport	1 590	1 900	2 320	2 010	1 830	1 210	1 350	1 300
c. Fugitive Sources	**6 700**	**15 000**	**15 000**	**16 000**	**14 000**	**15 000**	**14 000**	**13 000**
Coal Mining	20	20	20	20	20	20	20	20
Oil and Natural Gas	6 700	15 000	15 000	16 000	14 000	15 000	14 000	13 000
Oil	650	1 300	1 100	1 000	980	1 000	1 000	1 000
Natural Gas	2 100	2 000	2 400	2 300	2 600	2 600	2 600	2 600
Venting	3 500	10 000	9 000	9 500	7 900	8 400	8 000	7 400
Flaring	390	1 500	2 500	2 700	2 400	2 700	2 100	2 000
d. CO_2 Transport and Storage	**-**	**0.09**	**0.10**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**
INDUSTRIAL PROCESSES AND PRODUCT USE	**355**	**850**	**881**	**874**	**856**	**803**	**792**	**826**
a. Mineral Products	**96**	**10**	**8**	**8**	**7**	**6**	**6**	**5**
Cement Production	88	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	8	10	8	8	7	6	6	5
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**180**	**400**	**410**	**410**	**430**	**460**	**460**
e. Non-Energy Products from Fuels and Solvent Use	**250**	**650**	**460**	**450**	**420**	**350**	**300**	**340**
f. Other Product Manufacture and Use	**8**	**13**	**12**	**13**	**15**	**18**	**19**	**19**
AGRICULTURE	**7 700**	**12 000**	**12 000**	**13 000**	**13 000**	**13 000**	**13 000**	**13 000**
a. Enteric Fermentation	**3 300**	**6 100**	**4 600**	**4 600**	**4 600**	**4 700**	**4 600**	**4 600**
b. Manure Management	**710**	**1 300**	**1 000**	**1 000**	**1 100**	**1 100**	**1 000**	**1 000**
c. Agricultural Soils	**3 500**	**4 500**	**5 800**	**6 200**	**6 400**	**6 400**	**6 600**	**6 600**
Direct Sources	3 000	3 700	4 700	5 000	5 200	5 200	5 400	5 400
Indirect Sources	500	900	1 000	1 000	1 000	1 000	1 000	1 000
d. Field Burning of Agricultural Residues	**70**	**30**	**30**	**40**	**30**	**30**	**30**	**30**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**190**	**450**	**850**	**950**	**940**	**1 000**	**1 000**	**1 000**
WASTE	**1 000**	**1 400**	**1 400**	**1 400**	**1 300**	**1 400**	**1 400**	**1 400**
a. Solid Waste Disposal (Landfills)	**870**	**1 200**	**1 200**	**1 200**	**1 200**	**1 200**	**1 300**	**1 300**
b. Biological Treatment of Solid Waste	**0.01**	**1**	**3**	**3**	**3**	**3**	**3**	**3**
c. Wastewater Treatment and Discharge	**44**	**43**	**44**	**36**	**35**	**34**	**35**	**35**
d. Incineration and Open Burning of Waste	**0.00**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
e. Industrial Wood Waste Landfills	**100**	**100**	**90**	**90**	**80**	**80**	**80**	**80**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

A 11

Table A11–17 **2019 GHG Emission Summary for Saskatchewan**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**49 200**	**690**	**17 000**	**27**	**8 000**	**460**	**0.50**	**0.27**	**-**	**74 800**
ENERGY	**47 800**	**440**	**11 000**	**2**	**600**	**-**	**-**	**-**	**-**	**59 400**
a. Stationary Combustion Sources	**28 700**	**8**	**200**	**0.70**	**200**	**-**	**-**	**-**	**-**	**29 100**
Public Electricity and Heat Production	15 700	1	33	0.40	100	-	-	-	-	15 800
Petroleum Refining Industries	1 200	0.03	0.70	0.01	4	-	-	-	-	1 200
Oil and Gas Extraction	3 430	6	200	0.09	30	-	-	-	-	3 620
Mining	2 780	0.06	1	0.05	20	-	-	-	-	2 800
Manufacturing Industries	1 200	0.04	0.88	0.03	9	-	-	-	-	1 210
Construction	35	0.00	0.02	0.00	0.27	-	-	-	-	35
Commercial and Institutional	1 640	0.03	0.82	0.03	10	-	-	-	-	1 650
Residential	2 040	0.50	10	0.05	10	-	-	-	-	2 060
Agriculture and Forestry	719	0.01	0.30	0.01	4	-	-	-	-	723
b. Transport[b]	**16 700**	**3**	**79**	**1**	**350**	**-**	**-**	**-**	**-**	**17 200**
Aviation	215	0.01	0.20	0.01	2	-	-	-	-	217
Road Transportation	9 080	0.60	20	0.48	140	-	-	-	-	9 240
Light-Duty Gasoline Vehicles	1 140	0.10	3	0.06	16	-	-	-	-	1 160
Light-Duty Gasoline Trucks	3 320	0.30	8	0.13	40	-	-	-	-	3 370
Heavy-Duty Gasoline Vehicles	942	0.04	0.90	0.08	25	-	-	-	-	967
Motorcycles	7	0.00	0.07	0.00	0.04	-	-	-	-	7
Light-Duty Diesel Vehicles	21	0.00	0.01	0.00	0.53	-	-	-	-	22
Light-Duty Diesel Trucks	39	0.00	0.02	0.00	0.95	-	-	-	-	40
Heavy-Duty Diesel Vehicles	3 610	0.20	4	0.20	60	-	-	-	-	3 670
Propane and Natural Gas Vehicles	0.52	0.00	0.01	0.00	0.00	-	-	-	-	0.53
Railways	1 210	0.07	2	0.50	100	-	-	-	-	1 360
Marine	-	-	-	-	-	-	-	-	-	-
Other Transportation	6 220	2	60	0.20	70	-	-	-	-	6 350
Off-Road Agriculture and Forestry	4 350	0.18	5	0.20	50	-	-	-	-	4 400
Off-Road Commercial and Institutional	31	0.06	2	0.00	0.30	-	-	-	-	33
Off-Road Manufacturing, Mining and Construction	264	0.04	0.91	0.01	4	-	-	-	-	269
Off-Road Residential	57	0.13	3	0.00	0.50	-	-	-	-	60
Off-Road Other Transportation	256	0.70	18	0.01	2	-	-	-	-	275
Pipeline Transport	1 260	1	33	0.03	10	-	-	-	-	1 300
c. Fugitive Sources	**2 400**	**420**	**11 000**	**0.26**	**77**	**-**	**-**	**-**	**-**	**13 000**
Coal Mining	-	0.60	20	-	-	-	-	-	-	20
Oil and Natural Gas	2 400	420	11 000	0.30	80	-	-	-	-	13 000
Oil	4	38	960	0.30	70	-	-	-	-	1 000
Natural Gas	50	100	2 500	-	-	-	-	-	-	2 600
Venting	440	280	6 900	-	-	-	-	-	-	7 400
Flaring	1 900	7	160	0.01	2	-	-	-	-	2 000
d. CO_2 Transport and Storage	**0.20**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.20**
INDUSTRIAL PROCESSES AND PRODUCT USE	**336**	**-**	**-**	**0.10**	**30**	**460**	**0.50**	**0.27**	**-**	**826**
a. Mineral Products	**5**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**5**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	5	-	-	-	-	-	-	-	-	5
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**460**	**0.08**	**-**	**-**	**460**
e. Non-Energy Products from Fuels and Solvent Use	**330**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**340**
f. Other Product Manufacture and Use	**2**	**-**	**-**	**0.05**	**16**	**-**	**0.42**	**0.27**	**-**	**19**
AGRICULTURE	**1 000**	**200**	**4 900**	**25**	**7 300**	**-**	**-**	**-**	**-**	**13 000**
a. Enteric Fermentation	**-**	**180**	**4 600**	**-**	**-**	**-**	**-**	**-**	**-**	**4 600**
b. Manure Management	**-**	**12**	**300**	**2**	**700**	**-**	**-**	**-**	**-**	**1 000**
c. Agricultural Soils	**-**	**-**	**-**	**22**	**6 600**	**-**	**-**	**-**	**-**	**6 600**
Direct Sources	-	-	-	18	5 400	-	-	-	-	5 400
Indirect Sources	-	-	-	4	1 000	-	-	-	-	1 000
d. Field Burning of Agricultural Residues	**-**	**0.80**	**20**	**0.02**	**6**	**-**	**-**	**-**	**-**	**30**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**1 000**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1 000**
WASTE	**0.02**	**54**	**1 400**	**0.06**	**20**	**-**	**-**	**-**	**-**	**1 400**
a. Solid Waste Disposal (Landfills)	**-**	**50**	**1 300**	**-**	**-**	**-**	**-**	**-**	**-**	**1 300**
b. Biological Treatment of Solid Waste	**-**	**0.05**	**1**	**0.01**	**2**	**-**	**-**	**-**	**-**	**3**
c. Wastewater Treatment and Discharge	**-**	**0.80**	**20**	**0.05**	**20**	**-**	**-**	**-**	**-**	**35**
d. Incineration and Open Burning of Waste	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.02**
e. Industrial Wood Waste Landfills	**-**	**3**	**80**	**-**	**-**	**-**	**-**	**-**	**-**	**80**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.

b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–18 **GHG Emission Summary for Alberta, Selected Years**

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**172 000**	**235 000**	**278 000**	**278 000**	**264 000**	**271 000**	**272 000**	**276 000**
ENERGY	**149 000**	**201 000**	**244 000**	**242 000**	**228 000**	**236 000**	**237 000**	**239 000**
a. Stationary Combustion Sources	**92 800**	**130 000**	**160 000**	**164 000**	**155 000**	**161 000**	**159 000**	**160 000**
Public Electricity and Heat Production	39 800	52 000	49 200	51 500	45 800	46 700	36 500	36 300
Petroleum Refining Industries	3 000	4 000	3 900	4 100	4 300	4 300	4 400	4 400
Oil and Gas Extraction	26 800	51 200	80 100	83 700	80 100	84 100	90 700	91 600
Mining	298	324	207	158	160	148	162	171
Manufacturing Industries	10 500	8 850	11 400	10 200	9 570	8 640	8 650	9 050
Construction	238	171	298	297	307	343	382	381
Commercial and Institutional	5 040	5 660	6 340	5 770	6 300	7 580	8 190	8 490
Residential	6 740	7 550	8 520	8 170	8 100	8 920	9 300	8 990
Agriculture and Forestry	477	240	347	346	358	390	385	313
b. Transport[a]	**22 300**	**34 000**	**44 100**	**41 900**	**40 100**	**42 600**	**44 900**	**46 200**
Aviation	1 140	1 350	1 580	1 570	1 490	1 540	1 700	1 660
Road Transportation	11 900	19 400	28 300	26 400	25 800	27 200	28 200	29 000
Light-Duty Gasoline Vehicles	4 200	3 680	3 370	3 040	3 120	3 090	3 030	3 040
Light-Duty Gasoline Trucks	3 400	5 140	7 020	6 910	7 380	7 610	7 830	8 210
Heavy-Duty Gasoline Vehicles	1 720	3 200	3 390	3 180	3 390	3 490	3 520	3 580
Motorcycles	13	28	44	44	47	48	50	52
Light-Duty Diesel Vehicles	21	51	100	90	77	82	82	83
Light-Duty Diesel Trucks	16	52	107	122	119	144	157	166
Heavy-Duty Diesel Vehicles	2 180	7 200	14 200	13 000	11 600	12 800	13 600	13 900
Propane and Natural Gas Vehicles	395	97	0.97	0.96	1	2	2	2
Railways	1 760	2 780	2 910	2 530	1 890	2 070	1 910	1 950
Marine	0.01	0.04	0.01	0.03	0.02	0.29	-	0.01
Other Transportation	7 460	10 400	11 300	11 300	11 000	11 700	13 000	13 600
Off-Road Agriculture and Forestry	2 520	3 430	3 030	2 870	2 490	2 710	3 010	3 160
Off-Road Commercial and Institutional	165	295	392	363	237	204	214	222
Off-Road Manufacturing, Mining and Construction	1 520	2 610	4 750	4 710	4 010	4 390	4 870	5 060
Off-Road Residential	20	128	126	119	128	136	142	148
Off-Road Other Transportation	1 940	751	611	607	609	636	660	654
Pipeline Transport	1 300	3 210	2 360	2 660	3 500	3 640	4 120	4 330
c. Fugitive Sources	**34 000**	**37 000**	**39 000**	**36 000**	**33 000**	**33 000**	**33 000**	**33 000**
Coal Mining	400	300	200	300	300	200	200	200
Oil and Natural Gas	33 000	37 000	39 000	36 000	33 000	32 000	33 000	33 000
Oil	4 000	4 300	4 300	4 100	3 900	3 900	4 200	4 300
Natural Gas	8 500	9 700	8 600	7 900	7 900	7 900	7 700	7 500
Venting	17 000	21 000	23 000	21 000	19 000	18 000	18 000	18 000
Flaring	3 600	2 000	3 200	2 900	2 300	2 500	2 900	2 900
d. CO_2 Transport and Storage	**-**	**-**	**-**	**0.04**	**0.09**	**0.09**	**0.10**	**0.10**
INDUSTRIAL PROCESSES AND PRODUCT USE	**6 820**	**11 600**	**11 700**	**13 300**	**12 900**	**12 600**	**13 100**	**13 900**
a. Mineral Products	**1 100**	**1 500**	**1 100**	**1 200**	**1 400**	**1 400**	**1 500**	**1 500**
Cement Production	790	1 100	890	930	1 100	x	x	x
Lime Production	110	130	110	110	110	x	x	x
Mineral Products Use	190	250	140	170	160	150	150	150
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**1**	**0.67**	**0.61**	**-**	**-**
Iron and Steel Production	-	-	-	1	0.67	0.61	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**0.27**	**710**	**1 600**	**1 600**	**1 600**	**1 700**	**1 800**	**1 800**
e. Non-Energy Products from Fuels and Solvent Use	**5 700**	**9 400**	**8 900**	**10 000**	**9 800**	**9 400**	**9 700**	**11 000**
f. Other Product Manufacture and Use	**17**	**40**	**47**	**50**	**56**	**65**	**73**	**76**
AGRICULTURE	**14 000**	**19 000**	**18 000**	**18 000**	**18 000**	**17 000**	**18 000**	**18 000**
a. Enteric Fermentation	**7 800**	**12 000**	**9 400**	**9 400**	**9 500**	**9 400**	**9 300**	**9 200**
b. Manure Management	**1 500**	**2 400**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**
c. Agricultural Soils	**4 100**	**4 600**	**6 000**	**6 000**	**5 900**	**5 300**	**5 600**	**5 800**
Direct Sources	3 400	3 600	4 900	4 900	4 800	4 300	4 600	4 800
Indirect Sources	700	900	1 000	1 000	1 000	1 000	1 000	1 000
d. Field Burning of Agricultural Residues	**4**	**0.70**	**1**	**1**	**0.80**	**0.80**	**0.80**	**1**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**260**	**370**	**790**	**870**	**730**	**610**	**720**	**760**
WASTE	**2 400**	**3 800**	**4 600**	**4 600**	**4 800**	**4 900**	**5 000**	**5 200**
a. Solid Waste Disposal (Landfills)	**1 700**	**3 000**	**3 900**	**4 000**	**4 100**	**4 200**	**4 400**	**4 500**
b. Biological Treatment of Solid Waste	**4**	**20**	**20**	**20**	**20**	**20**	**30**	**20**
c. Wastewater Treatment and Discharge	**110**	**120**	**130**	**120**	**120**	**120**	**120**	**120**
d. Incineration and Open Burning of Waste	**7**	**20**	**20**	**30**	**40**	**40**	**30**	**40**
e. Industrial Wood Waste Landfills	**500**	**600**	**500**	**500**	**500**	**500**	**500**	**400**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990–1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

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Table A11–19 **2019 GHG Emission Summary for Alberta**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**225 000**	**1 600**	**40 000**	**31**	**9 300**	**1 800**	**6**	**4**	**-**	**276 000**
ENERGY	**213 000**	**990**	**25 000**	**6**	**2 000**	**-**	**-**	**-**	**-**	**239 000**
a. Stationary Combustion Sources	**157 000**	**80**	**2 000**	**3**	**1 000**	**-**	**-**	**-**	**-**	**160 000**
Public Electricity and Heat Production	36 000	3	79	0.70	200	-	-	-	-	36 300
Petroleum Refining Industries	4 400	0.09	2	0.02	6	-	-	-	-	4 400
Oil and Gas Extraction	89 200	70	2 000	2	500	-	-	-	-	91 600
Mining	170	0.00	0.08	0.00	0.90	-	-	-	-	171
Manufacturing Industries	8 950	0.42	11	0.29	85	-	-	-	-	9 050
Construction	377	0.01	0.17	0.01	4	-	-	-	-	381
Commercial and Institutional	8 430	0.16	4	0.20	60	-	-	-	-	8 490
Residential	8 860	2	60	0.20	60	-	-	-	-	8 990
Agriculture and Forestry	310	0.01	0.10	0.01	3	-	-	-	-	313
b. Transport[b]	**45 100**	**9**	**220**	**3**	**860**	**-**	**-**	**-**	**-**	**46 200**
Aviation	1 650	0.03	0.70	0.05	10	-	-	-	-	1 660
Road Transportation	28 500	2	40	2	460	-	-	-	-	29 000
Light-Duty Gasoline Vehicles	3 000	0.30	7	0.13	38	-	-	-	-	3 040
Light-Duty Gasoline Trucks	8 100	0.70	20	0.31	91	-	-	-	-	8 210
Heavy-Duty Gasoline Vehicles	3 490	0.10	3	0.31	92	-	-	-	-	3 580
Motorcycles	52	0.02	0.50	0.00	0.29	-	-	-	-	52
Light-Duty Diesel Vehicles	81	0.00	0.04	0.01	2	-	-	-	-	83
Light-Duty Diesel Trucks	162	0.00	0.10	0.01	4	-	-	-	-	166
Heavy-Duty Diesel Vehicles	13 600	0.60	10	0.77	230	-	-	-	-	13 900
Propane and Natural Gas Vehicles	2	0.00	0.02	0.00	0.01	-	-	-	-	2
Railways	1 740	0.10	2	0.70	200	-	-	-	-	1 950
Marine	0.01	0.00	0.00	0.00	0.00	-	-	-	-	0.01
Other Transportation	13 200	7	170	0.60	200	-	-	-	-	13 600
Off-Road Agriculture and Forestry	3 110	0.15	4	0.10	40	-	-	-	-	3 160
Off-Road Commercial and Institutional	207	0.52	13	0.01	2	-	-	-	-	222
Off-Road Manufacturing, Mining and Construction	4 940	0.28	7	0.40	100	-	-	-	-	5 060
Off-Road Residential	140	0.29	7	0.00	1	-	-	-	-	148
Off-Road Other Transportation	610	2	39	0.02	5	-	-	-	-	654
Pipeline Transport	4 200	4	100	0.10	30	-	-	-	-	4 330
c. Fugitive Sources	**11 000**	**900**	**22 000**	**0.06**	**17**	**-**	**-**	**-**	**-**	**33 000**
Coal Mining	-	9	200	-	-	-	-	-	-	200
Oil and Natural Gas	11 000	890	22 000	0.06	20	-	-	-	-	33 000
Oil	550	150	3 700	0.04	10	-	-	-	-	4 300
Natural Gas	42	300	7 500	-	-	-	-	-	-	7 500
Venting	7 500	430	11 000	-	-	-	-	-	-	18 000
Flaring	2 600	10	260	0.02	5	-	-	-	-	2 900
d. CO_2 Transport and Storage	**0.10**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.10**
INDUSTRIAL PROCESSES AND PRODUCT USE	**11 800**	**4**	**94**	**0.80**	**240**	**1 800**	**6**	**4**	**-**	**13 900**
a. Mineral Products	**1 500**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1 500**
Cement Production	x	-	-	-	-	-	-	-	-	x
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	150	-	-	-	-	-	-	-	-	150
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**1 800**	**1**	**2**	**-**	**1 800**
e. Non-Energy Products from Fuels and Solvent Use	**10 000**	**-**	**100**	**1**	**-**	**-**	**-**	**-**	**-**	**11 000**
f. Other Product Manufacture and Use	**8**	**-**	**-**	**0.20**	**60**	**-**	**5**	**2**	**-**	**76**
AGRICULTURE	**760**	**390**	**9 800**	**24**	**7 200**	**-**	**-**	**-**	**-**	**18 000**
a. Enteric Fermentation	**-**	**370**	**9 200**	**-**	**-**	**-**	**-**	**-**	**-**	**9 200**
b. Manure Management	**-**	**26**	**650**	**4**	**1 000**	**-**	**-**	**-**	**-**	**2 000**
c. Agricultural Soils	**-**	**-**	**-**	**20**	**5 800**	**-**	**-**	**-**	**-**	**5 800**
Direct Sources	-	-	-	16	4 800	-	-	-	-	4 800
Indirect Sources	-	-	-	4	1 000	-	-	-	-	1 000
d. Field Burning of Agricultural Residues	**-**	**0.03**	**0.80**	**0.00**	**0.30**	**-**	**-**	**-**	**-**	**1**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**760**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**760**
WASTE	**30**	**200**	**5 000**	**0.30**	**80**	**-**	**-**	**-**	**-**	**5 200**
a. Solid Waste Disposal (Landfills)	**-**	**180**	**4 500**	**-**	**-**	**-**	**-**	**-**	**-**	**4 500**
b. Biological Treatment of Solid Waste	**-**	**0.50**	**10**	**0.03**	**10**	**-**	**-**	**-**	**-**	**20**
c. Wastewater Treatment and Discharge	**-**	**2**	**60**	**0.20**	**60**	**-**	**-**	**-**	**-**	**120**
d. Incineration and Open Burning of Waste	**30**	**0.00**	**0.02**	**0.03**	**10**	**-**	**-**	**-**	**-**	**40**
e. Industrial Wood Waste Landfills	**-**	**20**	**400**	**-**	**-**	**-**	**-**	**-**	**-**	**400**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–20 **GHG Emission Summary for British Columbia, Selected Years**

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**51 800**	**63 000**	**60 400**	**59 200**	**61 800**	**63 200**	**65 500**	**65 700**
ENERGY	**41 700**	**50 000**	**49 700**	**48 900**	**51 100**	**52 700**	**54 800**	**55 300**
a. Stationary Combustion Sources	**19 300**	**21 700**	**21 300**	**19 600**	**20 800**	**21 700**	**22 100**	**22 900**
Public Electricity and Heat Production	804	1 340	578	503	677	574	697	971
Petroleum Refining Industries	1 200	490	510	530	630	500	370	420
Oil and Gas Extraction	2 140	5 390	8 230	7 070	7 440	7 620	8 190	8 420
Mining	616	386	562	456	490	471	516	515
Manufacturing Industries	6 490	6 190	4 390	4 410	4 660	4 840	4 900	4 940
Construction	307	114	66	71	95	95	104	99
Commercial and Institutional	2 950	3 170	2 650	2 420	2 450	2 820	2 730	2 870
Residential	4 470	4 520	3 880	3 730	3 770	4 220	4 030	4 110
Agriculture and Forestry	323	75	382	413	563	560	602	575
b. Transport[a]	**18 200**	**23 000**	**23 400**	**24 500**	**25 900**	**26 800**	**28 300**	**28 200**
Aviation	1 340	1 550	1 310	1 320	1 350	1 460	1 600	1 590
Road Transportation	9 600	15 500	16 300	16 800	18 000	18 200	19 200	19 000
Light-Duty Gasoline Vehicles	3 900	4 450	3 680	3 800	4 110	4 030	3 970	3 780
Light-Duty Gasoline Trucks	2 110	3 910	4 380	4 680	5 260	5 370	5 540	5 600
Heavy-Duty Gasoline Vehicles	950	1 860	1 750	1 740	1 960	1 990	2 050	1 970
Motorcycles	15	21	25	27	30	30	30	29
Light-Duty Diesel Vehicles	44	93	121	131	128	127	131	130
Light-Duty Diesel Trucks	17	45	86	107	119	135	157	166
Heavy-Duty Diesel Vehicles	1 940	4 890	6 270	6 300	6 350	6 520	7 270	7 320
Propane and Natural Gas Vehicles	624	214	7	6	6	7	7	7
Railways	1 430	430	664	665	789	1 100	1 000	985
Marine	576	809	1 100	1 190	1 260	1 200	1 240	1 400
Other Transportation	5 240	4 710	3 960	4 500	4 540	4 800	5 300	5 160
Off-Road Agriculture and Forestry	707	873	588	656	576	660	792	778
Off-Road Commercial and Institutional	243	330	356	359	301	284	317	313
Off-Road Manufacturing, Mining and Construction	1 350	1 460	1 260	1 410	1 440	1 650	2 040	1 960
Off-Road Residential	35	183	165	169	145	140	147	141
Off-Road Other Transportation	2 050	867	561	608	634	647	682	622
Pipeline Transport	862	998	1 040	1 300	1 440	1 410	1 320	1 350
c. Fugitive Sources	**4 100**	**5 400**	**5 100**	**4 800**	**4 400**	**4 300**	**4 300**	**4 200**
Coal Mining	800	1 000	1 000	900	1 000	900	1 000	1 000
Oil and Natural Gas	3 300	4 400	4 100	4 000	3 500	3 400	3 300	3 200
Oil	190	85	46	45	49	46	45	36
Natural Gas	870	880	760	770	770	780	810	780
Venting	1 900	2 700	2 600	2 600	2 100	2 000	1 900	1 900
Flaring	360	690	670	590	510	570	570	500
d. CO_2 Transport and Storage	-	-	-	-	-	-	-	-
INDUSTRIAL PROCESSES AND PRODUCT USE	**3 320**	**4 630**	**3 850**	**3 640**	**4 030**	**3 810**	**4 070**	**3 760**
a. Mineral Products	**880**	**1 500**	**1 200**	**1 200**	**1 100**	**960**	**1 000**	**990**
Cement Production	660	1 300	970	1 000	970	x	x	x
Lime Production	170	190	160	170	110	x	x	x
Mineral Products Use	53	51	23	23	22	20	19	18
b. Chemical Industry[b]	-	-	-	-	-	-	-	-
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**1 670**	**1 220**	**547**	**477**	**867**	**793**	**771**	**754**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	1 670	1 220	546	476	867	793	771	754
SF_6 Used in Magnesium Smelters and Casters	-	1	0.66	0.66	0.84	0.01	0.01	0.01
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	-	**620**	**1 400**	**1 400**	**1 500**	**1 500**	**1 600**	**1 600**
e. Non-Energy Products from Fuels and Solvent Use	**690**	**1 200**	**710**	**470**	**540**	**470**	**540**	**310**
f. Other Product Manufacture and Use	**77**	**97**	**71**	**70**	**71**	**88**	**88**	**98**
AGRICULTURE	**2 200**	**2 700**	**2 200**	**2 300**	**2 400**	**2 400**	**2 500**	**2 500**
a. Enteric Fermentation	**1 400**	**1 800**	**1 300**	**1 400**	**1 400**	**1 400**	**1 500**	**1 500**
b. Manure Management	**310**	**440**	**390**	**400**	**400**	**410**	**420**	**420**
c. Agricultural Soils	**510**	**500**	**470**	**490**	**520**	**510**	**550**	**550**
Direct Sources	410	390	380	390	410	410	440	440
Indirect Sources	100	100	100	100	100	100	100	100
d. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**25**	**24**	**21**	**23**	**26**	**28**	**33**	**33**
WASTE	**4 600**	**5 600**	**4 500**	**4 400**	**4 300**	**4 300**	**4 200**	**4 200**
a. Solid Waste Disposal (Landfills)	**2 300**	**3 000**	**2 400**	**2 400**	**2 300**	**2 300**	**2 300**	**2 300**
b. Biological Treatment of Solid Waste	**1**	**40**	**60**	**60**	**60**	**60**	**70**	**80**
c. Wastewater Treatment and Discharge	**99**	**130**	**140**	**130**	**130**	**140**	**140**	**140**
d. Incineration and Open Burning of Waste	**5**	**0.20**	-	-	-	-	-	-
e. Industrial Wood Waste Landfills	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**	**2 000**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–21 2019 GHG Emission Summary for British Columbia

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**52 900**	**370**	**9 200**	**6**	**1 900**	**1 600**	**63**	**21**	**-**	**65 700**
ENERGY	**50 900**	**140**	**3 500**	**3**	**900**	**-**	**-**	**-**	**-**	**55 300**
a. Stationary Combustion Sources	**22 100**	**20**	**600**	**0.90**	**300**	**-**	**-**	**-**	**-**	**22 900**
Public Electricity and Heat Production	952	0.25	6	0.04	10	-	-	-	-	971
Petroleum Refining Industries	420	0.01	0.20	0.00	0.80	-	-	-	-	420
Oil and Gas Extraction	7 900	20	500	0.20	60	-	-	-	-	8 420
Mining	512	0.01	0.20	0.01	3	-	-	-	-	515
Manufacturing Industries	4 810	0.75	19	0.40	120	-	-	-	-	4 940
Construction	99	0.00	0.05	0.00	0.62	-	-	-	-	99
Commercial and Institutional	2 850	0.05	1	0.07	20	-	-	-	-	2 870
Residential	3 990	3	80	0.10	40	-	-	-	-	4 110
Agriculture and Forestry	571	0.01	0.30	0.01	3	-	-	-	-	575
b. Transport[b]	**27 400**	**5**	**130**	**2**	**630**	**-**	**-**	**-**	**-**	**28 200**
Aviation	1 580	0.04	1	0.05	10	-	-	-	-	1 590
Road Transportation	18 500	1	30	2	440	-	-	-	-	19 000
Light-Duty Gasoline Vehicles	3 690	0.30	7	0.30	89	-	-	-	-	3 780
Light-Duty Gasoline Trucks	5 420	0.40	10	0.57	170	-	-	-	-	5 600
Heavy-Duty Gasoline Vehicles	1 920	0.08	2	0.16	48	-	-	-	-	1 970
Motorcycles	28	0.01	0.30	0.00	0.16	-	-	-	-	29
Light-Duty Diesel Vehicles	127	0.00	0.06	0.01	3	-	-	-	-	130
Light-Duty Diesel Trucks	162	0.00	0.10	0.01	4	-	-	-	-	166
Heavy-Duty Diesel Vehicles	7 190	0.30	8	0.41	120	-	-	-	-	7 320
Propane and Natural Gas Vehicles	6	0.00	0.07	0.00	0.04	-	-	-	-	7
Railways	880	0.05	1	0.30	100	-	-	-	-	985
Marine	1 390	0.13	3	0.04	10	-	-	-	-	1 400
Other Transportation	5 000	4	91	0.20	60	-	-	-	-	5 160
Off-Road Agriculture and Forestry	763	0.05	1	0.05	10	-	-	-	-	778
Off-Road Commercial and Institutional	299	0.46	11	0.01	3	-	-	-	-	313
Off-Road Manufacturing, Mining and Construction	1 920	0.28	7	0.10	30	-	-	-	-	1 960
Off-Road Residential	132	0.29	7	0.00	1	-	-	-	-	141
Off-Road Other Transportation	584	1	32	0.02	5	-	-	-	-	622
Pipeline Transport	1 310	1	32	0.03	10	-	-	-	-	1 350
c. Fugitive Sources	**1 400**	**110**	**2 800**	**0.00**	**1**	**-**	**-**	**-**	**-**	**4 200**
Coal Mining	-	40	1 000	-	-	-	-	-	-	1 000
Oil and Natural Gas	1 400	72	1 800	0.00	1	-	-	-	-	3 200
Oil	0.18	1	35	0.00	1	-	-	-	-	36
Natural Gas	6	31	780	-	-	-	-	-	-	780
Venting	920	38	940	-	-	-	-	-	-	1 900
Flaring	440	3	62	0.00	0.20	-	-	-	-	500
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**2 000**	**-**	**-**	**0.24**	**70**	**1 600**	**63**	**21**	**-**	**3 760**
a. Mineral Products	**990**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**990**
Cement Production	x	-	-	-	-	-	-	-	-	x
Lime Production	x	-	-	-	-	-	-	-	-	x
Mineral Products Use	18	-	-	-	-	-	-	-	-	18
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**694**	**-**	**-**	**-**	**-**	**-**	**60**	**0.01**	**-**	**754**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	694	-	-	-	-	-	60	-	-	754
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	0.01	-	0.01
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**1 600**	**0.31**	**-**	**-**	**1 600**
e. Non-Energy Products from Fuels and Solvent Use	**310**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**310**
f. Other Product Manufacture and Use	**5**	**-**	**-**	**0.24**	**70**	**-**	**3**	**21**	**-**	**98**
AGRICULTURE	**33**	**66**	**1 700**	**3**	**780**	**-**	**-**	**-**	**-**	**2 500**
a. Enteric Fermentation	**-**	**59**	**1 500**	**-**	**-**	**-**	**-**	**-**	**-**	**1 500**
b. Manure Management	**-**	**7**	**180**	**0.80**	**200**	**-**	**-**	**-**	**-**	**420**
c. Agricultural Soils	**-**	**-**	**-**	**2**	**550**	**-**	**-**	**-**	**-**	**550**
Direct Sources	-	-	-	2	440	-	-	-	-	440
Indirect Sources	-	-	-	0.40	100	-	-	-	-	100
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**33**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**33**
WASTE	**-**	**160**	**4 100**	**0.40**	**100**	**-**	**-**	**-**	**-**	**4 200**
a. Solid Waste Disposal (Landfills)	**-**	**93**	**2 300**	**-**	**-**	**-**	**-**	**-**	**-**	**2 300**
b. Biological Treatment of Solid Waste	**-**	**2**	**40**	**0.10**	**40**	**-**	**-**	**-**	**-**	**80**
c. Wastewater Treatment and Discharge	**-**	**3**	**74**	**0.20**	**70**	**-**	**-**	**-**	**-**	**140**
d. Incineration and Open Burning of Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**-**	**70**	**2 000**	**-**	**-**	**-**	**-**	**-**	**-**	**2 000**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

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Table A11–22 GHG Emission Summary for Yukon, Selected Years

Greenhouse Gas Categories	1990	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**550**	**568**	**499**	**529**	**527**	**564**	**645**	**690**
ENERGY	**525**	**528**	**453**	**483**	**479**	**513**	**590**	**633**
a. Stationary Combustion Sources	**216**	**192**	**66**	**67**	**65**	**67**	**85**	**106**
Public Electricity and Heat Production	90	22	16	18	19	24	33	47
Petroleum Refining Industries	-	-	-	-	-	-	-	-
Oil and Gas Extraction	0.31	67	-	-	-	-	-	-
Mining	8	8	4	4	4	x	x	x
Manufacturing Industries	6	-	14	14	15	16	16	17
Construction	4	2	1	0.62	1.00	x	x	x
Commercial and Institutional	77	41	25	25	22	17	23	19
Residential	30	44	6	5	4	5	6	7
Agriculture and Forestry	1	8	-	-	-	-	0.83	-
b. Transport[a]	**309**	**326**	**387**	**416**	**414**	**446**	**504**	**528**
Aviation	35	36	46	42	43	48	54	54
Road Transportation	220	256	314	343	346	375	422	443
Light-Duty Gasoline Vehicles	73	36	30	31	35	34	38	43
Light-Duty Gasoline Trucks	32	80	78	81	91	92	103	120
Heavy-Duty Gasoline Vehicles	15	25	33	37	43	45	54	58
Motorcycles	0.26	0.24	0.42	0.41	0.42	0.38	0.40	0.43
Light-Duty Diesel Vehicles	2	0.92	1	1	0.99	1	1	1
Light-Duty Diesel Trucks	0.28	7	6	6	5	6	6	6
Heavy-Duty Diesel Vehicles	96	107	165	186	171	196	220	214
Propane and Natural Gas Vehicles	1	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-
Marine	2	4	4	4	2	0.58	0.46	3
Other Transportation	52	31	23	26	23	23	28	28
Off-Road Agriculture and Forestry	0.48	0.31	0.20	0.25	1	0.28	0.34	0.32
Off-Road Commercial and Institutional	3	3	3	3	1	0.67	0.84	0.96
Off-Road Manufacturing, Mining and Construction	28	18	13	15	13	13	16	15
Off-Road Residential	0.69	x	x	x	x	x	x	x
Off-Road Other Transportation	20	8	6	7	7	7	9	9
Pipeline Transport	-	x	x	x	x	x	x	x
c. Fugitive Sources	**0.02**	**10**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	0.02	10	0.03	0.03	0.03	0.03	0.03	0.03
Oil	-	-	-	-	-	-	-	-
Natural Gas	0.02	2	0.03	0.03	0.03	0.03	0.03	0.03
Venting	-	6	-	-	-	-	-	-
Flaring	-	1	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**2**	**8**	**16**	**16**	**17**	**19**	**21**	**22**
a. Mineral Products	**0.11**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Cement Production	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	0.11	-	-	-	-	-	-	-
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**7**	**14**	**15**	**16**	**17**	**19**	**20**
e. Non-Energy Products from Fuels and Solvent Use	**2**	**0.48**	**1**	**0.28**	**0.08**	**0.08**	**0.07**	**0.75**
f. Other Product Manufacture and Use	**0.17**	**0.37**	**0.41**	**0.46**	**0.64**	**1**	**1**	**1**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**23**	**32**	**30**	**30**	**32**	**33**	**34**	**35**
a. Solid Waste Disposal (Landfills)	**19**	**27**	**25**	**24**	**26**	**27**	**28**	**29**
b. Biological Treatment of Solid Waste	**0.01**	**0.10**	**0.20**	**0.30**	**0.30**	**0.20**	**0.40**	**0.40**
c. Wastewater Treatment and Discharge	**4**	**5**	**6**	**6**	**6**	**6**	**6**	**6**
d. Incineration and Open Burning of Waste	**-**	**0.02**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

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Table A11–23 **2019 GHG Emission Summary for Yukon**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**624**	**2**	**36**	**0.03**	**10**	**20**	**0.01**	**0.68**	**-**	**690**
ENERGY	**623**	**0.07**	**2**	**0.03**	**8**	**-**	**-**	**-**	**-**	**633**
a. Stationary Combustion Sources	**104**	**0.01**	**0.20**	**0.00**	**0.90**	**-**	**-**	**-**	**-**	**106**
Public Electricity and Heat Production	47	0.01	0.20	0.00	0.30	-	-	-	-	47
Petroleum Refining Industries	-	-	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	x	x	x	x	x	x	x	x	x	x
Manufacturing Industries	17	0.00	0.00	0.00	0.06	-	-	-	-	17
Construction	x	x	x	x	x	x	x	x	x	x
Commercial and Institutional	19	0.00	0.01	0.00	0.30	-	-	-	-	19
Residential	7	0.00	0.00	0.00	0.10	-	-	-	-	7
Agriculture and Forestry	-	-	-	-	-	-	-	-	-	-
b. Transport[b]	**519**	**0.06**	**1**	**0.03**	**8**	**-**	**-**	**-**	**-**	**528**
Aviation	54	0.00	0.10	0.00	0.50	-	-	-	-	54
Road Transportation	435	0.02	0.60	0.02	7	-	-	-	-	443
Light-Duty Gasoline Vehicles	42	0.00	0.08	0.00	0.40	-	-	-	-	43
Light-Duty Gasoline Trucks	119	0.01	0.20	0.00	1	-	-	-	-	120
Heavy-Duty Gasoline Vehicles	57	0.00	0.05	0.00	1	-	-	-	-	58
Motorcycles	0.43	0.00	0.00	0.00	0.00	-	-	-	-	0.43
Light-Duty Diesel Vehicles	1	0.00	0.00	0.00	0.03	-	-	-	-	1
Light-Duty Diesel Trucks	6	0.00	0.00	0.00	0.15	-	-	-	-	6
Heavy-Duty Diesel Vehicles	210	0.01	0.20	0.01	4	-	-	-	-	214
Propane and Natural Gas Vehicles	-	-	-	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-	-	-
Marine	3	0.00	0.01	0.00	0.02	-	-	-	-	3
Other Transportation	27	0.03	0.71	0.00	0.30	-	-	-	-	28
Off-Road Agriculture and Forestry	0.31	0.00	0.00	0.00	0.01	-	-	-	-	0.32
Off-Road Commercial and Institutional	0.92	0.00	0.03	0.00	0.01	-	-	-	-	0.96
Off-Road Manufacturing, Mining and Construction	15	0.00	0.06	0.00	0.20	-	-	-	-	15
Off-Road Residential	x	x	x	x	x	x	x	x	x	x
Off-Road Other Transportation	9	0.02	0.52	0.00	0.07	-	-	-	-	9
Pipeline Transport	x	x	x	x	x	x	x	x	x	x
c. Fugitive Sources	**-**	**0.00**	**0.03**	**-**	**-**	**-**	**-**	**-**	**-**	**0.03**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	0.00	0.03	-	-	-	-	-	-	0.03
Oil	-	-	-	-	-	-	-	-	-	-
Natural Gas	-	0.00	0.03	-	-	-	-	-	-	0.03
Venting	-	-	-	-	-	-	-	-	-	-
Flaring	-	-	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**0.88**	**-**	**-**	**0.00**	**0.57**	**20**	**0.01**	**0.68**	**-**	**22**
a. Mineral Products	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	-	-	-	-	-	-	-	-	-	-
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**20**	**0.01**	**-**	**-**	**20**
e. Non-Energy Products from Fuels and Solvent Use	**0.75**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.75**
f. Other Product Manufacture and Use	**0.13**	**-**	**-**	**0.00**	**0.57**	**-**	**-**	**0.68**	**-**	**1**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**-**	**1**	**35**	**0.00**	**0.80**	**-**	**-**	**-**	**-**	**35**
a. Solid Waste Disposal (Landfills)	**-**	**1**	**29**	**-**	**-**	**-**	**-**	**-**	**-**	**29**
b. Biological Treatment of Solid Waste	**-**	**0.01**	**0.20**	**0.00**	**0.20**	**-**	**-**	**-**	**-**	**0.40**
c. Wastewater Treatment and Discharge	**-**	**0.22**	**6**	**0.00**	**0.50**	**-**	**-**	**-**	**-**	**6**
d. Incineration and Open Burning of Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

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0.00 Indicates emissions were truncated due to rounding.
\- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–24 GHG Emission Summary for Northwest Territories, Selected Years

Greenhouse Gas Categories	1999	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**1 260**	**1 630**	**1 530**	**1 740**	**1 620**	**1 320**	**1 420**	**1 380**
ENERGY	**1 220**	**1 570**	**1 470**	**1 680**	**1 560**	**1 260**	**1 350**	**1 310**
a. Stationary Combustion Sources	**598**	**720**	**580**	**612**	**563**	**385**	**467**	**419**
Public Electricity and Heat Production	88	x	x	x	x	x	x	x
Petroleum Refining Industries	-	-	-	-	-	-	-	-
Oil and Gas Extraction	128	214	2	1	5	13	11	41
Mining	104	164	210	205	220	198	215	192
Manufacturing Industries	-	x	x	x	x	x	x	x
Construction	0.83	1	x	x	x	x	x	x
Commercial and Institutional	192	141	181	190	200	62	115	69
Residential	85	102	104	97	67	49	58	43
Agriculture and Forestry	0.02	2	-	-	-	-	-	-
b. Transport[a]	**604**	**833**	**872**	**1 050**	**981**	**865**	**877**	**875**
Aviation	131	182	141	144	132	136	153	146
Road Transportation	277	473	551	670	672	586	607	612
Light-Duty Gasoline Vehicles	41	12	15	14	16	15	15	15
Light-Duty Gasoline Trucks	26	41	68	69	77	74	77	80
Heavy-Duty Gasoline Vehicles	16	9	18	20	24	24	25	25
Motorcycles	0.16	0.12	0.30	0.29	0.30	0.26	0.26	0.23
Light-Duty Diesel Vehicles	3	2	2	2	3	2	2	3
Light-Duty Diesel Trucks	0.74	19	13	16	16	13	14	15
Heavy-Duty Diesel Vehicles	191	390	435	548	537	457	473	475
Propane and Natural Gas Vehicles	0.80	-	-	-	-	-	-	-
Railways	3	6	18	16	14	14	14	14
Marine	22	32	12	9	7	6	4	10
Other Transportation	170	141	150	210	157	125	100	93
Off-Road Agriculture and Forestry	0.65	0.58	0.44	0.64	0.57	0.61	0.48	0.46
Off-Road Commercial and Institutional	11	9	9	12	2	0.76	0.69	0.68
Off-Road Manufacturing, Mining and Construction	130	116	125	180	136	107	83	78
Off-Road Residential	2	2	3	3	3	2	2	2
Off-Road Other Transportation	21	10	12	14	15	14	12	12
Pipeline Transport	4	3	1	0.77	0.27	0.27	0.27	0.27
c. Fugitive Sources	**15**	**18**	**19**	**15**	**16**	**5**	**6**	**14**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	15	18	19	15	16	5	6	14
Oil	4	4	2	2	2	0.27	0.54	2
Natural Gas	5	5	5	4	5	3	4	5
Venting	2	2	0.86	0.74	0.69	0.03	0.13	0.57
Flaring	4	7	12	8	8	0.83	1	7
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**9**	**20**	**28**	**27**	**27**	**26**	**28**	**29**
a. Mineral Products	**0.01**	**0.15**	**0.05**	**0.04**	**0.04**	**0.02**	**0.03**	**0.02**
Cement Production	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	0.01	0.15	0.05	0.04	0.04	0.02	0.03	0.02
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**5**	**12**	**21**	**21**	**22**	**23**	**26**	**26**
e. Non-Energy Products from Fuels and Solvent Use	**4**	**7**	**7**	**5**	**4**	**2**	**1**	**2**
f. Other Product Manufacture and Use	**0.52**	**0.51**	**0.58**	**0.71**	**0.81**	**0.86**	**0.91**	**0.91**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**38**	**39**	**36**	**36**	**37**	**38**	**39**	**40**
a. Solid Waste Disposal (Landfills)	**35**	**36**	**33**	**33**	**34**	**35**	**36**	**37**
b. Biological Treatment of Solid Waste	**-**	**-**	**0.01**	**0.03**	**0.04**	**0.06**	**0.10**	**0.10**
c. Wastewater Treatment and Discharge	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
d. Incineration and Open Burning of Waste	**0.20**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–25 **2019 GHG Emission Summary for Northwest Territories**

	Greenhouse Gases									
Greenhouse Gas Categories	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**1 280**	**2**	**53**	**0.06**	**18**	**26**	**0.01**	**-**	**-**	**1 380**
ENERGY	**1 280**	**0.52**	**13**	**0.05**	**20**	**-**	**-**	**-**	**-**	**1 310**
a. Stationary Combustion Sources	**412**	**0.20**	**4**	**0.01**	**3**	**-**	**-**	**-**	**-**	**419**
Public Electricity and Heat Production	x	x	x	x	x	x	x	x	x	x
Petroleum Refining Industries	-	-	-	-	-	-	-	-	-	-
Oil and Gas Extraction	39	0.10	2	0.00	0.30	-	-	-	-	41
Mining	191	0.01	0.10	0.00	0.90	-	-	-	-	192
Manufacturing Industries	x	x	x	x	x	x	x	x	x	x
Construction	x	x	x	x	x	x	x	x	x	x
Commercial and Institutional	69	0.00	0.02	0.00	0.60	-	-	-	-	69
Residential	41	0.05	1	0.00	0.50	-	-	-	-	43
Agriculture and Forestry	-	-	-	-	-	-	-	-	-	-
b. Transport[b]	**859**	**0.06**	**2**	**0.05**	**14**	**-**	**-**	**-**	**-**	**875**
Aviation	144	0.01	0.30	0.01	1	-	-	-	-	146
Road Transportation	602	0.03	0.70	0.03	10	-	-	-	-	612
Light-Duty Gasoline Vehicles	14	0.00	0.03	0.00	0.14	-	-	-	-	15
Light-Duty Gasoline Trucks	79	0.01	0.20	0.00	0.74	-	-	-	-	80
Heavy-Duty Gasoline Vehicles	24	0.00	0.02	0.00	0.61	-	-	-	-	25
Motorcycles	0.23	0.00	0.00	0.00	0.00	-	-	-	-	0.23
Light-Duty Diesel Vehicles	2	0.00	0.00	0.00	0.06	-	-	-	-	3
Light-Duty Diesel Trucks	15	0.00	0.01	0.00	0.35	-	-	-	-	15
Heavy-Duty Diesel Vehicles	467	0.02	0.50	0.03	8	-	-	-	-	475
Propane and Natural Gas Vehicles	-	-	-	-	-	-	-	-	-	-
Railways	12	0.00	0.02	0.01	1	-	-	-	-	14
Marine	10	0.00	0.02	0.00	0.08	-	-	-	-	10
Other Transportation	91	0.02	0.55	0.00	1	-	-	-	-	93
Off-Road Agriculture and Forestry	0.45	0.00	0.00	0.00	0.01	-	-	-	-	0.46
Off-Road Commercial and Institutional	0.66	0.00	0.02	0.00	0.01	-	-	-	-	0.68
Off-Road Manufacturing, Mining and Construction	77	0.00	0.09	0.00	1	-	-	-	-	78
Off-Road Residential	2	0.00	0.07	0.00	0.02	-	-	-	-	2
Off-Road Other Transportation	11	0.02	0.37	0.00	0.10	-	-	-	-	12
Pipeline Transport	0.27	0.00	0.00	0.00	0.00	-	-	-	-	0.27
c. Fugitive Sources	**6**	**0.30**	**8**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**14**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	6	0.30	8	0.00	0.00	-	-	-	-	14
Oil	0.01	0.07	2	-	-	-	-	-	-	2
Natural Gas	0.00	0.20	5	-	-	-	-	-	-	5
Venting	0.00	0.02	0.57	-	-	-	-	-	-	0.57
Flaring	6	0.01	0.28	0.00	0.00	-	-	-	-	7
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**2**	**-**	**-**	**0.00**	**0.62**	**26**	**0.01**	**-**	**-**	**29**
a. Mineral Products	**0.02**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.02**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	0.02	-	-	-	-	-	-	-	-	0.02
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**26**	**0.01**	**-**	**-**	**26**
e. Non-Energy Products from Fuels and Solvent Use	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2**
f. Other Product Manufacture and Use	**0.29**	**-**	**-**	**0.00**	**0.62**	**-**	**-**	**-**	**-**	**0.91**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.01**	**2**	**40**	**0.00**	**0.70**	**-**	**-**	**-**	**-**	**40**
a. Solid Waste Disposal (Landfills)	**-**	**2**	**37**	**-**	**-**	**-**	**-**	**-**	**-**	**37**
b. Biological Treatment of Solid Waste	**-**	**0.00**	**0.05**	**0.00**	**0.07**	**-**	**-**	**-**	**-**	**0.10**
c. Wastewater Treatment and Discharge	**-**	**0.10**	**3**	**0.00**	**0.60**	**-**	**-**	**-**	**-**	**3**
d. Incineration and Open Burning of Waste	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.01**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–26 GHG Emission Summary for Nunavut, Selected Years

Greenhouse Gas Categories	1999	2005	2014	2015	2016	2017	2018	2019
	kt CO_2 eq							
TOTAL	**415**	**584**	**696**	**637**	**742**	**748**	**747**	**733**
ENERGY	**388**	**551**	**656**	**596**	**699**	**702**	**697**	**680**
a. Stationary Combustion Sources	**104**	**128**	**118**	**113**	**135**	**137**	**169**	**167**
Public Electricity and Heat Production	17	x	x	x	x	x	x	x
Petroleum Refining Industries	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-
Mining	87	0.26	-	-	-	-	5	5
Manufacturing Industries	-	x	x	x	x	x	x	x
Construction	-	-	-	-	-	-	-	-
Commercial and Institutional	-	x	-	-	-	-	-	-
Residential	-	-	-	-	-	-	-	-
Agriculture and Forestry	-	-	-	-	-	-	-	-
b. Transport[a]	**284**	**424**	**538**	**483**	**564**	**565**	**529**	**514**
Aviation	112	141	148	143	129	147	171	168
Road Transportation	19	94	202	163	236	243	207	191
Light-Duty Gasoline Vehicles	3	2	2	2	2	2	2	2
Light-Duty Gasoline Trucks	5	18	29	28	36	36	31	32
Heavy-Duty Gasoline Vehicles	3	4	8	8	11	12	11	11
Motorcycles	0.01	0.02	0.05	0.04	0.05	0.05	0.04	0.04
Light-Duty Diesel Vehicles	0.07	0.03	0.16	0.10	0.14	0.13	0.09	0.09
Light-Duty Diesel Trucks	-	1	4	3	4	4	3	3
Heavy-Duty Diesel Vehicles	8	69	159	122	183	190	160	144
Propane and Natural Gas Vehicles	0.86	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-
Marine	137	127	108	113	124	120	115	124
Other Transportation	16	62	80	64	74	55	35	30
Off-Road Agriculture and Forestry	-	-	-	-	-	-	-	-
Off-Road Commercial and Institutional	2	7	8	7	1	0.89	0.61	0.56
Off-Road Manufacturing, Mining and Construction	10	45	54	42	54	36	22	19
Off-Road Residential	0.62	3	4	4	3	2	2	2
Off-Road Other Transportation	4	8	13	12	15	16	11	9
Pipeline Transport	-	-	-	-	-	-	-	-
c. Fugitive Sources	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Coal Mining	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	-	-	-	-	-	-	-
Oil	-	-	-	-	-	-	-	-
Natural Gas	-	-	-	-	-	-	-	-
Venting	-	-	-	-	-	-	-	-
Flaring	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**3**	**7**	**14**	**14**	**15**	**16**	**19**	**20**
a. Mineral Products	**0.01**	**0.15**	**0.05**	**0.04**	**0.04**	**0.02**	**0.03**	**0.02**
Cement Production	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-
Mineral Products Use	0.01	0.15	0.05	0.04	0.04	0.02	0.03	0.02
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**2**	**6**	**13**	**14**	**14**	**16**	**18**	**19**
e. Non-Energy Products from Fuels and Solvent Use	**0.03**	**0.09**	**0.12**	**0.07**	**0.08**	**0.08**	**0.13**	**0.09**
f. Other Product Manufacture and Use	**0.34**	**0.36**	**0.39**	**0.41**	**0.51**	**0.61**	**0.64**	**0.62**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**24**	**26**	**26**	**27**	**28**	**30**	**31**	**32**
a. Solid Waste Disposal (Landfills)	**22**	**24**	**25**	**25**	**27**	**28**	**29**	**31**
b. Biological Treatment of Solid Waste	**-**	**-**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
c. Wastewater Treatment and Discharge	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
d. Incineration and Open Burning of Waste	**-**	**0.06**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

Table A11–27 **2019 GHG Emission Summary for Nunavut**

Greenhouse Gas Categories	Greenhouse Gases									
	CO_2	CH_4	CH_4	N_2O	N_2O	HFCs[a]	PFCs[a]	SF_6	NF_3	TOTAL
Global Warming Potential			25		298			22 800	17 200	
Unit	kt	kt	kt CO_2 eq	kt	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq	kt CO_2 eq
TOTAL	**673**	**1**	**33**	**0.02**	**7**	**19**	**0.00**	**-**	**-**	**733**
ENERGY	**673**	**0.05**	**1**	**0.02**	**6**	**-**	**-**	**-**	**-**	**680**
a. Stationary Combustion Sources	**166**	**0.01**	**0.10**	**0.00**	**0.40**	**-**	**-**	**-**	**-**	**167**
Public Electricity and Heat Production	x	x	x	x	x	x	x	x	x	x
Petroleum Refining Industries	-	-	-	-	-	-	-	-	-	-
Oil and Gas Extraction	-	-	-	-	-	-	-	-	-	-
Mining	5	0.00	0.00	0.00	0.02	-	-	-	-	5
Manufacturing Industries	x	x	x	x	x	x	x	x	x	x
Construction	-	-	-	-	-	-	-	-	-	-
Commercial and Institutional	-	-	-	-	-	-	-	-	-	-
Residential	-	-	-	-	-	-	-	-	-	-
Agriculture and Forestry	-	-	-	-	-	-	-	-	-	-
b. Transport[b]	**507**	**0.04**	**1**	**0.02**	**6**	**-**	**-**	**-**	**-**	**514**
Aviation	166	0.00	0.09	0.01	1	-	-	-	-	168
Road Transportation	188	0.01	0.20	0.01	3	-	-	-	-	191
Light-Duty Gasoline Vehicles	2	0.00	0.00	0.00	0.02	-	-	-	-	2
Light-Duty Gasoline Trucks	32	0.00	0.06	0.00	0.30	-	-	-	-	32
Heavy-Duty Gasoline Vehicles	10	0.00	0.01	0.00	0.26	-	-	-	-	11
Motorcycles	0.04	0.00	0.00	0.00	0.00	-	-	-	-	0.04
Light-Duty Diesel Vehicles	0.08	0.00	0.00	0.00	0.00	-	-	-	-	0.09
Light-Duty Diesel Trucks	3	0.00	0.00	0.00	0.07	-	-	-	-	3
Heavy-Duty Diesel Vehicles	141	0.01	0.10	0.01	2	-	-	-	-	144
Propane and Natural Gas Vehicles	-	-	-	-	-	-	-	-	-	-
Railways	-	-	-	-	-	-	-	-	-	-
Marine	123	0.01	0.28	0.00	1	-	-	-	-	124
Other Transportation	30	0.02	0.52	0.00	0.40	-	-	-	-	30
Off-Road Agriculture and Forestry	-	-	-	-	-	-	-	-	-	-
Off-Road Commercial and Institutional	0.53	0.00	0.02	0.00	0.01	-	-	-	-	0.56
Off-Road Manufacturing, Mining and Construction	19	0.00	0.03	0.00	0.30	-	-	-	-	19
Off-Road Residential	1	0.00	0.06	0.00	0.01	-	-	-	-	2
Off-Road Other Transportation	9	0.02	0.41	0.00	0.09	-	-	-	-	9
Pipeline Transport	-	-	-	-	-	-	-	-	-	-
c. Fugitive Sources	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Coal Mining	-	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	-	-	-	-	-	-	-	-	-	-
Oil	-	-	-	-	-	-	-	-	-	-
Natural Gas	-	-	-	-	-	-	-	-	-	-
Venting	-	-	-	-	-	-	-	-	-	-
Flaring	-	-	-	-	-	-	-	-	-	-
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**0.19**	**-**	**-**	**0.00**	**0.53**	**19**	**0.00**	**-**	**-**	**20**
a. Mineral Products	**0.02**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.02**
Cement Production	-	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-	-
Mineral Products Use	0.02	-	-	-	-	-	-	-	-	0.02
b. Chemical Industry[c]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[d]	**-**	**-**	**-**	**-**	**-**	**19**	**0.00**	**-**	**-**	**19**
e. Non-Energy Products from Fuels and Solvent Use	**0.09**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.09**
f. Other Product Manufacture and Use	**0.09**	**-**	**-**	**0.00**	**0.53**	**-**	**-**	**-**	**-**	**0.62**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.08**	**1**	**32**	**0.00**	**0.50**	**-**	**-**	**-**	**-**	**32**
a. Solid Waste Disposal (Landfills)	**-**	**1**	**31**	**-**	**-**	**-**	**-**	**-**	**-**	**31**
b. Biological Treatment of Solid Waste	**-**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.00**
c. Wastewater Treatment and Discharge	**-**	**0.04**	**1**	**0.00**	**0.50**	**-**	**-**	**-**	**-**	**2**
d. Incineration and Open Burning of Waste	**0.08**	**0.00**	**0.00**	**0.00**	**0.00**	**-**	**-**	**-**	**-**	**0.08**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:
Estimates for the latest year (2019) are based on preliminary energy data; these data, though the best available information at the time of publication, are subject to revision in the next submission year.
Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.
a. IPCC's Fourth Assessment Report provides global warming potentials (GWPs) for the various species of HFCs and PFCs. Chapter 1, Table 1-1 of this report provides a list of GWPs used.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.
d. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
- Indicates no emissions.
x Indicates data has been suppressed to respect confidentiality.

Table A11–28 GHG Emission Summary for Northwest Territories and Nunavut, 1990–1998

Greenhouse Gas Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998
	kt CO_2 eq								
TOTAL	**1 790**	**1 760**	**1 580**	**1 880**	**2 040**	**2 110**	**2 120**	**1 940**	**1 760**
ENERGY	**1 740**	**1 700**	**1 520**	**1 800**	**1 890**	**1 960**	**2 060**	**1 870**	**1 690**
a. Stationary Combustion Sources	**915**	**986**	**848**	**946**	**1 010**	**1 150**	**1 020**	**970**	**728**
Public Electricity and Heat Production	156	156	126	137	139	155	118	129	173
Petroleum Refining Industries	8	6	7	5	12	11	4	-	-
Oil and Gas Extraction	276	195	111	136	135	139	149	130	125
Mining	36	42	18	36	109	212	150	158	133
Manufacturing Industries	26	16	18	8	14	20	-	-	-
Construction	6	5	6	3	4	21	0.68	0.70	0.53
Commercial and Institutional	250	367	357	389	401	474	405	371	207
Residential	156	188	192	230	190	118	196	181	90
Agriculture and Forestry	2	9	12	2	2	0.01	-	0.01	0.02
b. Transport[a]	**725**	**611**	**586**	**759**	**815**	**750**	**976**	**891**	**952**
Aviation	257	228	232	265	265	243	266	257	242
Road Transportation	173	130	116	170	183	155	236	227	273
Light-Duty Gasoline Vehicles	49	43	44	60	60	50	58	59	46
Light-Duty Gasoline Trucks	23	20	21	28	29	26	31	33	27
Heavy-Duty Gasoline Vehicles	11	10	10	14	15	12	16	18	16
Motorcycles	0.18	0.14	0.13	0.16	0.16	0.12	0.14	0.13	0.09
Light-Duty Diesel Vehicles	2	1	0.79	1	1	1	2	2	3
Light-Duty Diesel Trucks	0.08	0.07	0.07	0.14	0.18	0.18	0.40	0.39	0.66
Heavy-Duty Diesel Vehicles	86	54	39	65	75	64	127	114	178
Propane and Natural Gas Vehicles	0.80	0.79	2	1	3	2	1	1	1
Railways	3	2	2	2	1	2	1	3	2
Marine	113	123	133	143	153	164	163	162	160
Other Transportation	180	129	104	179	211	186	309	243	274
Off-Road Agriculture and Forestry	0.38	0.26	0.20	0.37	0.45	0.40	0.70	0.56	0.75
Off-Road Commercial and Institutional	12	9	7	12	15	13	23	18	23
Off-Road Manufacturing, Mining and Construction	128	90	69	126	151	135	234	180	207
Off-Road Residential	3	2	1	3	3	3	5	4	5
Off-Road Other Transportation	37	28	26	38	40	34	47	40	39
Pipeline Transport	-	-	-	-	2	0.13	0.09	0.04	-
c. Fugitive Sources	**97**	**100**	**89**	**94**	**65**	**65**	**61**	**12**	**10**
Coal Mining	-	-	-	-	-	-	-	-	-
Oil and Natural Gas	97	100	89	94	65	65	61	12	10
Oil	5	5	5	5	5	5	4	4	4
Natural Gas	0.92	0.98	0.97	1	0.90	0.92	0.87	0.85	0.82
Venting	2	2	2	2	3	3	2	2	2
Flaring	89	95	81	86	57	57	53	6	4
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
INDUSTRIAL PROCESSES AND PRODUCT USE	**5**	**13**	**4**	**26**	**106**	**88**	**3**	**4**	**6**
a. Mineral Products	**-**	**-**	**-**	**-**	**-**	**0.03**	**0.03**	**0.03**	**0.00**
Cement Production	-	-	-	-	-	-	-	-	-
Lime Production	-	-	-	-	-	-	-	-	-
Mineral Products Use	-	-	-	-	-	0.03	0.03	0.03	0.00
b. Chemical Industry[b]	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Adipic Acid Production	-	-	-	-	-	-	-	-	-
c. Metal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Iron and Steel Production	-	-	-	-	-	-	-	-	-
Aluminium Production	-	-	-	-	-	-	-	-	-
SF_6 Used in Magnesium Smelters and Casters	-	-	-	-	-	-	-	-	-
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**-**	**-**	**-**	**-**	**-**	**1**	**2**	**3**	**5**
e. Non-Energy Products from Fuels and Solvent Use	**5**	**13**	**3**	**26**	**110**	**86**	**0.49**	**0.43**	**0.11**
f. Other Product Manufacture and Use	**0.37**	**0.36**	**0.33**	**0.32**	**0.36**	**0.42**	**0.47**	**0.48**	**0.68**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
a. Enteric Fermentation	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
b. Manure Management	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Agricultural Soils	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Direct Sources	-	-	-	-	-	-	-	-	-
Indirect Sources	-	-	-	-	-	-	-	-	-
d. Field Burning of Agricultural Residues	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**44**	**46**	**48**	**50**	**52**	**54**	**56**	**58**	**60**
a. Solid Waste Disposal (Landfills)	**40**	**42**	**44**	**46**	**48**	**50**	**52**	**53**	**55**
b. Biological Treatment of Solid Waste	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
c. Wastewater Treatment and Discharge	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
d. Incineration and Open Burning of Waste	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**
e. Industrial Wood Waste Landfills	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Provincial/Territorial GHG emissions allocated to Canadian economic sectors are provided in Annex 12 of this report.

a. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.

b. Emissions from Ammonia Production, Nitric Acid Production and Petrochemical Production categories are included in Non-Energy Products from Fuels and Solvent Use as CO_2 eq values within provincial/territorial tables.

c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.

0.00 Indicates emissions were truncated due to rounding.

\- Indicates no emissions.

x Indicates data has been suppressed to respect confidentiality.

A 11

ANNEX 12

PROVINCIAL/ TERRITORIAL GREENHOUSE GAS EMISSION TABLES BY CANADIAN ECONOMIC SECTOR, 1990–2019

This annex contains summary tables (Table A12–2 to Table A12–15) illustrating GHG emissions by province/territory, allocated to Canadian economic sectors, from 1990–2019. To account for the creation of Nunavut in 1999, a time series from 1999–2019 is provided for both Northwest Territories and Nunavut (Table A12–13 and Table A12–14), and the years 1990–1998 are presented as a combined region in Table A12–15. In addition, Table A12–1 provides a brief description of each economic sector.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

Reallocating provincial/territorial emissions from IPCC sectors into Canadian economic sectors is useful for the purposes of analyzing trends and policies, as most people associate GHG emissions with a particular economic activity (e.g. producing electricity, farming, or driving a car). This re-allocation simply re-categorizes emissions under different headings but does not change the overall magnitude of the provincial/territorial emission estimates. Estimates for each economic sector include emissions from energy-related and non-energy-related processes.

Although the UNFCCC Reporting Guidelines require that only national-level detail be reported, provincial- and territorial-level detail is important, owing to the regional differences in emission levels and trends. Note that provincial and territorial emission estimates may not necessarily sum to the national totals due to rounding.

Provincial/territorial greenhouse gas emission tables are also available in electronic file format online at: https://open.canada.ca.

Table A12–1 **Canadian Economic Sector Descriptions**

Economic Sector	Description
OIL AND GAS	
Upstream Oil and Gas	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Natural Gas Production and Processing	– natural gas production and processing
Conventional Oil Production	Emissions resulting from:
Conventional Light Oil Production	– conventional light crude oil production
Conventional Heavy Oil Production	– conventinoal heavy crude oil production
Frontier Oil Production	– offshore and arctic production of crude oil
Oil Sands (Mining, In-situ, Upgrading)	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Mining and Extraction	– crude bitumen mining and extraction
In-situ	– in-situ extraction of crude bitumen including primary extraction, cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD) and other experimental techniques.
Upgrading	– crude bitumen and heavy oil upgrading to synthetic crude oil
Oil, Natural Gas and CO_2 Transmission	Combustion and fugitive emissions from the transport and storage of crude oil and natural gas.
Downstream Oil and Gas	Emissions resulting from:
Petroleum Refining	– stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from petroleum refining industries
Natural Gas Distribution	– combustion and fugitive emissions from local distribution of natural gas
ELECTRICITY	Combustion and process emissions from utility electricity generation, steam production (for sale) and transmission. Excludes utility owned cogeneration at industrial sites.
TRANSPORT	Mobile related emissions including all fossil fuels and non-CO_2 emission from biofuels.
Passenger Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily move people around.
Cars, Light Trucks and Motorcycles	Light duty cars and trucks up to 8500 lb. GVWR and motorcycles.
Bus, Rail and Aviation	All buses and the passenger component of rail and aviation.
Freight Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily move cargo or freight around.
Heavy Duty Trucks, Rail	Vehicles above 8500 lb. GVWR and the freight component of rail.
Aviation and Marine	Cargo component of aviation and all domestic navigation (inclusive of all fishing and military operations).
Other: Recreational, Commercial and Residential	Combustion emissions from the non-industrial use of off-road engines (e.g., ATVs, snowmobiles, personal watercraft), including portable engines (e.g., generators, lawn mowers, chain saws).
HEAVY INDUSTRY	Stationary combustion, onsite transportation, electricty and steam production, and process emissions from:
Mining	– metal and non-metal mines, stone quarries, and gravel pits
Smelting and Refining (Non-Ferrous Metals)	– non-ferrous metals (aluminium, magnesium and other production)
Pulp and Paper	– pulp and paper (primarily pulp, paper, and paper product manufacturers)
Iron and Steel	– iron and steel (steel foundries, casting, rolling mills and iron making)
Cement	– cement and other non-metallic mineral production
Lime and Gypsum	– lime and gypsum product manufacturing
Chemicals and Fertilizers	– chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
BUILDINGS	Stationary combustion and process (i.e. air conditioning) emissions from:
Service Industry	– service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.; offices, health, arts, accommodation, food, information & cultural; Federal, provincial and municipal establishments; National Defence and Canadian Coast Guard; Train stations, airports and warehouses
Residential	– personal residences (homes, apartment hotels, condominiums and farm houses)
AGRICULTURE	Emissions resulting from:
On Farm Fuel Use	– stationary combustion, onsite transportation and process emissions from the agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing, and repair)
Crop Production	– application of biosolids and inorganic nitrogen fertilizers, decomposition of crop residues, loss of soil organic carbon, cultivation of organic soils, indirect emissions from leaching and volatilization, field burning of agricultural residues, liming, and urea application
Animal Production	– animal housing, manure storage, manure deposited by grazing animals, and application of manure to managed soils
WASTE	Non-CO_2 Emissions from biomass resulting from:
Solid Waste	– municipal solid waste management sites (landfills), dedicated wood waste landfills, and other treatment of municipal solid waste
Wastewater	– municipal and industrial wastewater treatment
Waste Incineration	– municipal solid, hazardous and clinical waste, and sewage sludge incineration
Coal Production	Stationary combustion, onsite transportation and fugitive emissions from underground and surface coal mines
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	Stationary combustion, onsite transportation, electricty and steam production, and process emissions from (excluding LULUCF):
Light Manufacturing	– all other manufacturing industries not included in the Heavy Industry category above
Construction	– construction of buildings, highways etc.
Forest Resources	– forestry and logging service industry

Table A12–2 **GHG Emissions for Newfoundland and Labrador by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**9.5**	**10.5**	**10.9**	**11.0**	**11.2**	**11.1**	**10.9**	**11.1**
OIL AND GAS	**1.1**	**2.6**	**2.6**	**2.6**	**2.8**	**2.8**	**2.8**	**2.8**
Upstream Oil and Gas	0.0	1.6	1.7	1.5	1.7	1.8	1.9	1.8
Natural Gas Production and Processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Oil Production	0.0	1.6	1.7	1.5	1.7	1.8	1.9	1.8
Conventional Light Oil Production	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	0.0	1.6	1.7	1.5	1.7	1.8	1.9	1.8
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	1.1	1.0	0.9	1.0	1.2	1.0	1.0	1.0
Petroleum Refining	1.1	1.0	0.9	1.0	1.2	1.0	1.0	1.0
Natural Gas Distribution	-	-	-	-	-	-	-	-
ELECTRICITY	**1.6**	**0.8**	**1.2**	**1.3**	**1.5**	**1.5**	**1.1**	**1.1**
TRANSPORT	**2.9**	**3.6**	**4.1**	**4.2**	**4.2**	**4.1**	**4.2**	**4.3**
Passenger Transport	1.3	1.6	2.1	2.2	2.2	2.2	2.2	2.1
Cars, Light Trucks and Motorcycles	1.1	1.3	1.8	1.9	1.9	1.9	1.8	1.8
Bus, Rail and Aviation	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Freight Transport	1.2	1.8	1.8	1.8	1.9	1.8	1.9	2.0
Heavy Duty Trucks, Rail	0.4	0.8	1.1	1.2	1.3	1.1	1.2	1.2
Aviation and Marine	0.8	1.0	0.7	0.6	0.6	0.6	0.7	0.8
Other: Recreational, Commercial and Residential	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2
HEAVY INDUSTRY	**1.8**	**1.6**	**0.9**	**0.8**	**0.5**	**0.6**	**0.7**	**0.8**
Mining	1.3	1.3	0.8	0.8	0.4	0.5	0.6	0.7
Smelting and Refining (Non-Ferrous Metals)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pulp and Paper	0.4	0.3	0.0	0.0	0.0	0.1	0.0	0.0
Iron and Steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cement	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lime and Gypsum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chemicals and Fertilizers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BUILDINGS	**1.1**	**0.8**	**1.1**	**1.0**	**1.0**	**1.1**	**0.9**	**0.9**
Service Industry	0.3	0.4	0.7	0.7	0.7	0.6	0.4	0.5
Residential	0.7	0.4	0.4	0.3	0.4	0.5	0.5	0.4
AGRICULTURE	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
On Farm Fuel Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crop Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Animal Production	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
WASTE	**0.7**	**0.8**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Solid Waste[a]	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.7
Wastewater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waste Incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Light Manufacturing	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.1
Construction	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.2
Forest Resources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–3 **GHG Emissions for Prince Edward Island by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**1.9**	**2.0**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.8**
OIL AND GAS	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Upstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Natural Gas Production and Processing	-	-	-	-	-	-	-	-
Conventional Oil Production	-	-	-	-	-	-	-	-
Conventional Light Oil Production	-	-	-	-	-	-	-	-
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Distribution	-	-	-	-	-	-	-	-
ELECTRICITY	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TRANSPORT	**0.6**	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.8**	**0.8**
Passenger Transport	**0.4**	**0.5**	**0.4**	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**
Cars, Light Trucks and Motorcycles	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.5
Bus, Rail and Aviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Freight Transport	**0.1**	**0.2**	**0.2**	**0.3**	**0.3**	**0.2**	**0.3**	**0.3**
Heavy Duty Trucks, Rail	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aviation and Marine	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Other: Recreational, Commercial and Residential	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
HEAVY INDUSTRY	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Mining	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Pulp and Paper	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**-**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**0.6**	**0.5**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Service Industry	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Residential	**0.4**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
AGRICULTURE	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
On Farm Fuel Use	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Crop Production	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Animal Production	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
WASTE	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Solid Waste[a]	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Light Manufacturing	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Construction	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–4 **GHG Emissions for Nova Scotia by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**19.6**	**23.2**	**16.6**	**16.7**	**15.6**	**16.2**	**16.8**	**16.2**
OIL AND GAS	**0.7**	**1.5**	**0.8**	**0.6**	**0.5**	**0.3**	**0.2**	**0.0**
Upstream Oil and Gas	**0.0**	**0.4**	**0.8**	**0.6**	**0.5**	**0.3**	**0.2**	**0.0**
Natural Gas Production and Processing	0.0	0.4	0.8	0.6	0.5	0.3	0.2	0.0
Conventional Oil Production	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Light Oil Production	-	-	-	-	-	-	-	-
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	**0.7**	**1.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Petroleum Refining	0.7	1.1	-	0.0	0.0	0.0	0.0	0.0
Natural Gas Distribution	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELECTRICITY	**6.9**	**10.8**	**7.2**	**7.0**	**6.4**	**6.7**	**7.0**	**6.7**
TRANSPORT	**4.5**	**5.4**	**4.5**	**5.0**	**4.9**	**5.2**	**5.5**	**5.4**
Passenger Transport	**2.5**	**2.9**	**2.4**	**2.9**	**3.0**	**3.1**	**3.1**	**3.1**
Cars, Light Trucks and Motorcycles	2.3	2.6	2.1	2.6	2.7	2.8	2.8	2.8
Bus, Rail and Aviation	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Freight Transport	**1.4**	**2.2**	**1.8**	**1.8**	**1.7**	**1.9**	**2.0**	**2.0**
Heavy Duty Trucks, Rail	0.9	1.6	1.4	1.4	1.4	1.5	1.5	1.5
Aviation and Marine	0.6	0.7	0.4	0.4	0.3	0.4	0.5	0.5
Other: Recreational, Commercial and Residential	**0.5**	**0.3**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
HEAVY INDUSTRY	**1.0**	**0.8**	**0.5**	**0.5**	**0.5**	**0.4**	**0.4**	**0.4**
Mining	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Pulp and Paper	**0.4**	**0.3**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Iron and Steel	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**
Lime and Gypsum	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Chemicals and Fertilizers	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**3.0**	**2.7**	**2.1**	**2.2**	**1.9**	**2.0**	**2.0**	**2.0**
Service Industry	**0.8**	**1.4**	**0.7**	**0.8**	**0.7**	**0.8**	**0.7**	**0.7**
Residential	**2.1**	**1.3**	**1.4**	**1.4**	**1.2**	**1.2**	**1.3**	**1.3**
AGRICULTURE	**0.6**	**0.6**	**0.5**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**
On Farm Fuel Use	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Crop Production	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Animal Production	**0.4**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
WASTE	**0.9**	**0.8**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Solid Waste[a]	**0.9**	**0.8**	**0.6**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
COAL PRODUCTION	**1.6**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.2**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.4**	**0.4**	**0.4**	**0.3**	**0.3**	**0.4**	**0.5**	**0.5**
Light Manufacturing	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**
Construction	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–5 GHG Emissions for New Brunswick by Canadian Economic Sector, Selected Years

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**16.3**	**20.0**	**13.5**	**13.7**	**14.4**	**13.3**	**13.1**	**12.4**
OIL AND GAS	**1.2**	**2.7**	**3.0**	**2.8**	**3.1**	**3.3**	**2.8**	**2.9**
Upstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.1**	**0.1**
Natural Gas Production and Processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Oil Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Light Oil Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	**1.2**	**2.7**	**2.9**	**2.8**	**3.0**	**3.2**	**2.8**	**2.8**
Petroleum Refining	1.2	2.7	2.9	2.8	3.0	3.2	2.8	2.8
Natural Gas Distribution	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELECTRICITY	**6.0**	**7.8**	**3.4**	**3.4**	**3.6**	**3.0**	**3.1**	**2.8**
TRANSPORT	**3.7**	**4.7**	**3.6**	**3.8**	**4.2**	**3.8**	**3.7**	**3.6**
Passenger Transport	**1.6**	**2.3**	**1.8**	**2.1**	**2.4**	**2.2**	**2.2**	**2.1**
Cars, Light Trucks and Motorcycles	1.5	2.1	1.7	2.0	2.3	2.0	2.0	2.0
Bus, Rail and Aviation	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Freight Transport	**1.1**	**2.0**	**1.5**	**1.4**	**1.4**	**1.3**	**1.3**	**1.3**
Heavy Duty Trucks, Rail	0.9	1.8	1.4	1.3	1.3	1.1	1.1	1.1
Aviation and Marine	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2
Other: Recreational, Commercial and Residential	**1.0**	**0.5**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
HEAVY INDUSTRY	**1.8**	**1.2**	**0.7**	**0.7**	**0.8**	**0.8**	**0.8**	**0.6**
Mining	**0.2**	**0.3**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Smelting and Refining (Non-Ferrous Metals)	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.0**
Pulp and Paper	**1.3**	**0.7**	**0.4**	**0.4**	**0.4**	**0.3**	**0.4**	**0.4**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**0.1**	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**1.7**	**1.4**	**1.3**	**1.4**	**1.2**	**1.1**	**1.1**	**1.1**
Service Industry	**0.6**	**0.7**	**0.6**	**0.6**	**0.5**	**0.4**	**0.5**	**0.5**
Residential	**1.1**	**0.8**	**0.7**	**0.8**	**0.7**	**0.7**	**0.7**	**0.6**
AGRICULTURE	**0.6**	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
On Farm Fuel Use	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Crop Production	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Animal Production	**0.3**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.3**	**0.2**
WASTE	**0.8**	**0.9**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Solid Waste[a]	**0.8**	**0.9**	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**	**0.5**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**-**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**
COAL PRODUCTION	**0.0**	**0.0**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.4**	**0.5**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**
Light Manufacturing	**0.2**	**0.4**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Construction	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Forest Resources	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–6 **GHG Emissions for Quebec by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**86.4**	**87.6**	**79.2**	**79.1**	**79.0**	**81.2**	**82.5**	**83.7**
OIL AND GAS	**3.9**	**4.4**	**2.5**	**2.6**	**2.3**	**1.9**	**2.4**	**2.2**
Upstream Oil and Gas	**0.2**	**0.3**	**0.3**	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**
Natural Gas Production and Processing	-	-	-	-	-	-	-	-
Conventional Oil Production	-	-	-	-	-	-	-	-
Conventional Light Oil Production	-	-	-	-	-	-	-	-
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	0.2	0.3	0.3	0.3	0.2	0.1	0.1	0.1
Downstream Oil and Gas	**3.7**	**4.1**	**2.2**	**2.3**	**2.1**	**1.8**	**2.3**	**2.1**
Petroleum Refining	3.6	4.0	2.1	2.2	2.1	1.8	2.2	2.1
Natural Gas Distribution	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
ELECTRICITY	**1.5**	**0.7**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
TRANSPORT	**24.2**	**31.0**	**30.8**	**31.1**	**31.8**	**33.4**	**33.5**	**34.2**
Passenger Transport	**15.6**	**19.3**	**18.1**	**18.5**	**18.8**	**19.6**	**19.5**	**20.0**
Cars, Light Trucks and Motorcycles	14.6	18.2	17.0	17.4	17.7	18.3	18.2	18.6
Bus, Rail and Aviation	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3
Freight Transport	**4.9**	**9.8**	**11.1**	**11.0**	**11.2**	**11.8**	**11.9**	**12.1**
Heavy Duty Trucks, Rail	4.0	8.7	10.2	10.1	10.3	10.8	10.8	10.9
Aviation and Marine	0.9	1.1	0.9	0.9	0.9	1.0	1.1	1.3
Other: Recreational, Commercial and Residential	**3.7**	**1.8**	**1.6**	**1.7**	**1.8**	**2.0**	**2.1**	**2.1**
HEAVY INDUSTRY	**25.0**	**19.6**	**17.4**	**16.5**	**15.3**	**16.5**	**16.6**	**16.7**
Mining	**2.1**	**1.5**	**1.7**	**1.6**	**1.6**	**1.7**	**2.4**	**2.4**
Smelting and Refining (Non-Ferrous Metals)	**12.9**	**9.8**	**7.3**	**7.4**	**7.3**	**7.4**	**6.6**	**6.4**
Pulp and Paper	**4.5**	**2.8**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.6**
Iron and Steel	**1.2**	**0.9**	**2.2**	**1.2**	**1.1**	**1.2**	**1.2**	**1.1**
Cement	**2.5**	**2.5**	**2.2**	**2.3**	**2.2**	**2.7**	**2.7**	**3.3**
Lime and Gypsum	**0.5**	**0.9**	**0.8**	**0.7**	**0.6**	**0.8**	**0.7**	**0.6**
Chemicals and Fertilizers	**1.2**	**1.2**	**2.0**	**2.0**	**1.1**	**1.2**	**1.3**	**1.3**
BUILDINGS	**11.7**	**12.4**	**9.8**	**9.9**	**10.0**	**10.1**	**10.1**	**10.5**
Service Industry	**4.6**	**6.5**	**6.0**	**6.2**	**6.2**	**6.7**	**6.5**	**6.7**
Residential	**7.1**	**5.9**	**3.8**	**3.7**	**3.8**	**3.4**	**3.6**	**3.8**
AGRICULTURE	**8.1**	**8.5**	**8.6**	**8.8**	**9.0**	**8.5**	**9.0**	**8.8**
On Farm Fuel Use	**1.1**	**0.9**	**0.9**	**1.0**	**0.9**	**0.9**	**0.9**	**0.9**
Crop Production	**1.8**	**1.9**	**2.5**	**2.7**	**2.8**	**2.3**	**2.9**	**2.6**
Animal Production	**5.1**	**5.7**	**5.2**	**5.2**	**5.3**	**5.3**	**5.3**	**5.3**
WASTE	**6.7**	**7.1**	**5.5**	**5.8**	**6.3**	**6.4**	**6.5**	**6.7**
Solid Waste[a]	**6.4**	**6.7**	**5.3**	**5.6**	**6.0**	**6.2**	**6.3**	**6.4**
Wastewater	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Waste Incineration	**0.2**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**5.3**	**4.1**	**4.2**	**3.9**	**4.0**	**4.1**	**4.0**	**4.2**
Light Manufacturing	**3.7**	**2.9**	**3.0**	**2.7**	**2.6**	**2.6**	**2.5**	**2.7**
Construction	**1.4**	**1.0**	**1.0**	**1.0**	**1.1**	**1.3**	**1.2**	**1.2**
Forest Resources	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–7 **GHG Emissions for Ontario by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**180.0**	**205.7**	**163.9**	**162.9**	**161.2**	**157.6**	**163.4**	**163.2**
OIL AND GAS	**10.3**	**11.7**	**10.1**	**9.6**	**9.0**	**7.3**	**7.6**	**7.6**
Upstream Oil and Gas	**3.3**	**3.9**	**2.3**	**2.3**	**1.9**	**1.6**	**1.8**	**1.7**
Natural Gas Production and Processing	0.3	0.4	0.2	0.2	0.2	0.1	0.2	0.2
Conventional Oil Production	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Light Oil Production	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	3.0	3.6	2.1	2.1	1.7	1.5	1.6	1.5
Downstream Oil and Gas	**7.0**	**7.8**	**7.8**	**7.3**	**7.1**	**5.7**	**5.8**	**5.9**
Petroleum Refining	6.6	7.2	7.2	6.7	6.5	5.2	5.3	5.3
Natural Gas Distribution	0.4	0.6	0.5	0.5	0.6	0.5	0.5	0.5
ELECTRICITY	**26.0**	**34.0**	**5.0**	**5.4**	**4.8**	**2.2**	**3.4**	**3.3**
TRANSPORT	**41.0**	**56.5**	**53.5**	**54.4**	**54.7**	**55.5**	**57.5**	**58.1**
Passenger Transport	**26.4**	**35.8**	**33.0**	**33.7**	**34.4**	**34.3**	**35.5**	**36.2**
Cars, Light Trucks and Motorcycles	24.1	33.3	30.4	31.1	31.7	31.6	32.6	33.3
Bus, Rail and Aviation	2.2	2.5	2.6	2.7	2.6	2.7	2.9	2.9
Freight Transport	**7.7**	**16.8**	**17.3**	**17.5**	**17.1**	**17.6**	**18.4**	**18.3**
Heavy Duty Trucks, Rail	7.0	16.2	16.7	16.9	16.5	17.0	17.7	17.6
Aviation and Marine	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7
Other: Recreational, Commercial and Residential	**7.0**	**3.9**	**3.2**	**3.2**	**3.3**	**3.5**	**3.6**	**3.6**
HEAVY INDUSTRY	**43.2**	**35.2**	**30.5**	**29.4**	**30.5**	**28.5**	**28.7**	**28.1**
Mining	**1.0**	**0.9**	**1.3**	**1.2**	**1.3**	**1.3**	**1.2**	**1.2**
Smelting and Refining (Non-Ferrous Metals)	**1.5**	**1.9**	**0.8**	**0.7**	**0.9**	**1.0**	**0.9**	**1.1**
Pulp and Paper	**3.2**	**2.0**	**1.8**	**1.6**	**1.5**	**1.5**	**1.5**	**1.7**
Iron and Steel	**15.0**	**15.1**	**13.6**	**12.9**	**13.6**	**13.3**	**14.0**	**13.2**
Cement	**4.6**	**6.4**	**4.4**	**4.2**	**4.1**	**4.4**	**4.3**	**4.3**
Lime and Gypsum	**1.8**	**1.7**	**1.2**	**1.2**	**1.2**	**1.3**	**1.3**	**1.3**
Chemicals and Fertilizers	**16.2**	**7.1**	**7.4**	**7.6**	**7.8**	**5.7**	**5.5**	**5.4**
BUILDINGS	**27.1**	**35.8**	**36.8**	**36.2**	**34.8**	**36.2**	**38.2**	**38.6**
Service Industry	**9.8**	**15.4**	**16.8**	**16.1**	**15.9**	**16.5**	**17.3**	**17.9**
Residential	**17.3**	**20.4**	**20.0**	**20.1**	**18.9**	**19.7**	**20.9**	**20.7**
AGRICULTURE	**12.4**	**12.4**	**12.2**	**12.0**	**12.4**	**12.3**	**12.4**	**12.1**
On Farm Fuel Use	**2.1**	**2.3**	**2.5**	**2.5**	**2.5**	**2.3**	**2.4**	**2.5**
Crop Production	**3.1**	**2.8**	**3.6**	**3.4**	**3.8**	**3.8**	**3.7**	**3.4**
Animal Production	**7.2**	**7.3**	**6.1**	**6.2**	**6.2**	**6.2**	**6.2**	**6.3**
WASTE	**7.7**	**9.0**	**7.1**	**7.0**	**6.6**	**6.6**	**6.6**	**6.7**
Solid Waste[a]	**7.4**	**8.6**	**6.7**	**6.5**	**6.1**	**6.1**	**6.2**	**6.3**
Wastewater	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**
Waste Incineration	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**12.4**	**11.1**	**8.6**	**8.9**	**8.4**	**9.0**	**9.1**	**8.7**
Light Manufacturing	**9.8**	**8.0**	**6.4**	**6.4**	**6.1**	**6.3**	**6.2**	**6.0**
Construction	**2.5**	**2.9**	**2.2**	**2.5**	**2.2**	**2.5**	**2.7**	**2.6**
Forest Resources	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–8 GHG Emissions for Manitoba by Canadian Economic Sector, Selected Years

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**18.6**	**20.6**	**21.5**	**21.2**	**21.5**	**22.2**	**23.0**	**22.6**
OIL AND GAS	**1.3**	**0.8**	**0.7**	**0.7**	**0.6**	**0.5**	**0.7**	**0.7**
Upstream Oil and Gas	**1.3**	**0.8**	**0.7**	**0.7**	**0.6**	**0.5**	**0.7**	**0.6**
Natural Gas Production and Processing	-	-	-	-	-	-	-	-
Conventional Oil Production	0.1	0.2	0.4	0.4	0.4	0.3	0.4	0.4
Conventional Light Oil Production	0.1	0.2	0.4	0.4	0.4	0.3	0.4	0.4
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	1.2	0.6	0.3	0.3	0.3	0.2	0.3	0.3
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Petroleum Refining	0.0	-	-	-	-	-	0.0	0.0
Natural Gas Distribution	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELECTRICITY	**0.5**	**0.4**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**
TRANSPORT	**5.0**	**5.4**	**7.2**	**6.8**	**7.1**	**7.4**	**7.9**	**7.8**
Passenger Transport	**2.9**	**3.3**	**3.9**	**3.8**	**3.8**	**3.8**	**4.1**	**4.1**
Cars, Light Trucks and Motorcycles	2.5	2.8	3.4	3.3	3.4	3.3	3.5	3.5
Bus, Rail and Aviation	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Freight Transport	**1.4**	**1.8**	**2.9**	**2.7**	**2.9**	**3.3**	**3.5**	**3.4**
Heavy Duty Trucks, Rail	1.3	1.7	2.8	2.7	2.9	3.2	3.4	3.3
Aviation and Marine	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other: Recreational, Commercial and Residential	**0.6**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**
HEAVY INDUSTRY	**1.3**	**1.6**	**1.2**	**1.3**	**1.3**	**1.3**	**1.3**	**1.2**
Mining	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**
Smelting and Refining (Non-Ferrous Metals)	**0.3**	**0.2**	**0.1**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**
Pulp and Paper	**0.2**	**0.2**	**0.1**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**
Iron and Steel	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Cement	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Chemicals and Fertilizers	**0.3**	**0.9**	**0.8**	**0.9**	**1.0**	**0.8**	**0.9**	**0.8**
BUILDINGS	**3.1**	**2.7**	**2.9**	**2.6**	**2.6**	**2.8**	**3.1**	**3.1**
Service Industry	**1.4**	**1.6**	**1.7**	**1.6**	**1.5**	**1.7**	**1.8**	**1.8**
Residential	**1.6**	**1.1**	**1.2**	**1.0**	**1.0**	**1.2**	**1.2**	**1.2**
AGRICULTURE	**5.8**	**7.7**	**7.1**	**7.3**	**7.4**	**7.6**	**7.7**	**7.6**
On Farm Fuel Use	**1.1**	**1.4**	**1.0**	**0.9**	**0.9**	**1.0**	**1.0**	**1.0**
Crop Production	**2.2**	**2.0**	**2.8**	**3.0**	**3.2**	**3.2**	**3.3**	**3.4**
Animal Production	**2.5**	**4.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.4**	**3.3**
WASTE	**1.0**	**1.4**	**1.4**	**1.4**	**1.3**	**1.3**	**1.3**	**1.4**
Solid Waste[a]	**0.9**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	-	-	-	-	-	-	-	-
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.6**	**0.8**	**0.8**	**1.0**	**1.1**	**1.2**	**0.9**	**0.9**
Light Manufacturing	**0.4**	**0.5**	**0.6**	**0.8**	**0.8**	**0.9**	**0.6**	**0.6**
Construction	**0.2**	**0.3**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–9 **GHG Emissions for Saskatchewan by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**43.3**	**67.8**	**74.2**	**76.2**	**73.8**	**76.0**	**76.2**	**74.8**
OIL AND GAS	**10.3**	**24.1**	**24.1**	**24.6**	**22.5**	**22.2**	**21.0**	**20.1**
Upstream Oil and Gas	**9.2**	**23.0**	**22.7**	**23.1**	**21.0**	**20.7**	**19.6**	**18.6**
Natural Gas Production and Processing	2.1	3.4	3.1	3.0	3.2	3.3	3.2	3.2
Conventional Oil Production	4.7	14.6	14.6	15.5	13.2	13.6	12.3	11.3
Conventional Light Oil Production	1.4	3.2	6.7	7.4	6.8	8.0	7.7	7.3
Conventional Heavy Oil Production	3.3	11.4	7.8	8.0	6.3	5.7	4.5	4.0
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	0.0	2.6	2.2	2.2	2.3	2.1	2.3	2.3
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	0.0	2.6	2.2	2.2	2.3	2.1	2.3	2.3
Oil, Natural Gas and CO_2 Transmission	2.4	2.3	2.8	2.5	2.3	1.7	1.8	1.8
Downstream Oil and Gas	**1.2**	**1.1**	**1.4**	**1.5**	**1.5**	**1.5**	**1.4**	**1.5**
Petroleum Refining	0.7	0.8	1.2	1.3	1.3	1.3	1.2	1.3
Natural Gas Distribution	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELECTRICITY	**11.1**	**14.3**	**13.8**	**14.7**	**14.6**	**15.2**	**14.8**	**14.7**
TRANSPORT	**5.3**	**6.2**	**10.2**	**10.7**	**10.7**	**11.3**	**11.5**	**11.3**
Passenger Transport	**3.0**	**3.4**	**4.6**	**5.0**	**5.2**	**5.1**	**5.1**	**5.0**
Cars, Light Trucks and Motorcycles	2.8	3.2	4.3	4.7	4.9	4.8	4.7	4.7
Bus, Rail and Aviation	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Freight Transport	**1.6**	**2.5**	**5.2**	**5.2**	**5.1**	**5.7**	**6.1**	**6.0**
Heavy Duty Trucks, Rail	1.6	2.4	5.1	5.2	5.1	5.7	6.0	6.0
Aviation and Marine	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other: Recreational, Commercial and Residential	**0.6**	**0.4**	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**
HEAVY INDUSTRY	**1.6**	**2.2**	**3.3**	**3.4**	**3.2**	**3.6**	**4.5**	**4.3**
Mining	**1.0**	**1.3**	**2.6**	**2.6**	**2.5**	**2.8**	**3.3**	**3.2**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Pulp and Paper	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Iron and Steel	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**
Cement	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Chemicals and Fertilizers	**0.2**	**0.6**	**0.5**	**0.6**	**0.6**	**0.6**	**0.9**	**0.9**
BUILDINGS	**3.1**	**3.3**	**3.3**	**3.1**	**3.2**	**3.6**	**3.9**	**4.1**
Service Industry	**1.0**	**1.7**	**1.4**	**1.4**	**1.5**	**1.7**	**1.9**	**1.9**
Residential	**2.1**	**1.6**	**1.9**	**1.7**	**1.7**	**1.8**	**2.0**	**2.1**
AGRICULTURE	**10.2**	**16.0**	**17.2**	**17.5**	**17.6**	**18.1**	**18.6**	**18.4**
On Farm Fuel Use	**2.4**	**3.5**	**4.8**	**4.7**	**4.5**	**4.9**	**5.3**	**5.1**
Crop Production	**3.5**	**4.6**	**6.4**	**6.8**	**7.1**	**7.2**	**7.4**	**7.4**
Animal Production	**4.3**	**7.9**	**6.0**	**5.9**	**6.0**	**6.0**	**6.0**	**5.9**
WASTE	**1.0**	**1.4**	**1.4**	**1.4**	**1.3**	**1.4**	**1.4**	**1.4**
Solid Waste[a]	**1.0**	**1.4**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.6**	**0.4**	**0.9**	**0.8**	**0.7**	**0.6**	**0.6**	**0.6**
Light Manufacturing	**0.5**	**0.2**	**0.6**	**0.5**	**0.4**	**0.5**	**0.5**	**0.5**
Construction	**0.1**	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	**0.1**	**0.1**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–10 **GHG Emissions for Alberta by Canadian Economic Sector, Selected Years**								
	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**171.8**	**235.5**	**278.1**	**278.4**	**263.8**	**271.0**	**272.5**	**275.8**
OIL AND GAS	**65.2**	**99.8**	**132.2**	**133.0**	**126.5**	**130.9**	**139.9**	**141.3**
Upstream Oil and Gas	**61.6**	**95.1**	**127.3**	**128.0**	**121.4**	**125.7**	**134.4**	**135.6**
Natural Gas Production and Processing	27.8	47.4	42.0	40.8	38.1	36.1	38.5	38.3
Conventional Oil Production	15.3	11.3	14.7	13.5	11.7	10.8	11.9	11.2
Conventional Light Oil Production	8.8	8.8	10.8	9.8	8.6	7.8	8.6	8.3
Conventional Heavy Oil Production	6.5	2.5	3.9	3.7	3.1	2.9	3.3	2.9
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	14.6	32.4	67.4	70.2	67.2	74.2	79.0	80.8
Mining and Extraction	2.2	5.6	10.5	11.1	11.3	12.9	14.8	15.5
In-situ	4.1	12.2	34.9	37.7	37.2	40.9	42.9	42.7
Upgrading	8.4	14.6	22.1	21.4	18.8	20.5	21.4	22.7
Oil, Natural Gas and CO_2 Transmission	3.9	4.0	3.1	3.4	4.4	4.6	5.0	5.3
Downstream Oil and Gas	**3.6**	**4.7**	**4.9**	**5.0**	**5.2**	**5.3**	**5.5**	**5.7**
Petroleum Refining	3.2	4.4	4.7	4.8	5.0	5.1	5.3	5.5
Natural Gas Distribution	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2
ELECTRICITY	**39.8**	**47.7**	**44.3**	**46.3**	**41.6**	**42.4**	**31.3**	**31.0**
TRANSPORT	**17.0**	**25.1**	**34.5**	**32.1**	**30.6**	**32.3**	**33.4**	**34.2**
Passenger Transport	**9.1**	**10.6**	**12.5**	**12.1**	**12.5**	**12.8**	**13.1**	**13.5**
Cars, Light Trucks and Motorcycles	8.0	9.1	10.8	10.4	10.9	11.1	11.3	11.7
Bus, Rail and Aviation	1.1	1.4	1.7	1.7	1.6	1.7	1.8	1.8
Freight Transport	**5.8**	**13.3**	**20.8**	**19.0**	**17.1**	**18.6**	**19.3**	**19.7**
Heavy Duty Trucks, Rail	5.5	13.1	20.6	18.8	17.0	18.4	19.1	19.5
Aviation and Marine	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Other: Recreational, Commercial and Residential	**2.1**	**1.2**	**1.1**	**1.1**	**1.0**	**1.0**	**1.0**	**1.0**
HEAVY INDUSTRY	**12.6**	**17.7**	**18.8**	**18.7**	**17.2**	**16.8**	**17.3**	**18.1**
Mining	**0.2**	**0.3**	**0.5**	**0.5**	**0.4**	**0.3**	**0.3**	**0.2**
Smelting and Refining (Non-Ferrous Metals)	**0.4**	**0.6**	**0.7**	**1.1**	**0.8**	**0.8**	**0.8**	**1.4**
Pulp and Paper	**0.5**	**0.8**	**1.0**	**0.9**	**1.0**	**1.2**	**1.8**	**2.0**
Iron and Steel	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Cement	**1.2**	**1.8**	**1.4**	**1.5**	**1.5**	**1.7**	**1.8**	**1.7**
Lime and Gypsum	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Chemicals and Fertilizers	**10.0**	**13.9**	**14.8**	**14.4**	**13.2**	**12.6**	**12.2**	**12.6**
BUILDINGS	**12.0**	**16.1**	**18.8**	**18.7**	**18.6**	**20.2**	**21.6**	**21.6**
Service Industry	**5.3**	**8.5**	**10.1**	**10.4**	**10.4**	**11.2**	**12.1**	**12.4**
Residential	**6.7**	**7.6**	**8.6**	**8.3**	**8.2**	**9.1**	**9.5**	**9.2**
AGRICULTURE	**16.6**	**22.7**	**21.5**	**21.3**	**20.8**	**20.2**	**20.8**	**21.0**
On Farm Fuel Use	**2.9**	**3.5**	**3.2**	**3.1**	**2.7**	**2.9**	**3.2**	**3.3**
Crop Production	**3.7**	**4.0**	**6.1**	**6.2**	**5.9**	**5.2**	**5.6**	**5.9**
Animal Production	**9.9**	**15.2**	**12.1**	**12.1**	**12.2**	**12.1**	**12.0**	**11.9**
WASTE	**2.4**	**3.8**	**4.6**	**4.6**	**4.8**	**4.9**	**5.0**	**5.2**
Solid Waste[a]	**2.3**	**3.6**	**4.4**	**4.5**	**4.6**	**4.7**	**4.9**	**5.0**
Wastewater	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**0.6**	**0.5**	**0.5**	**0.6**	**0.6**	**0.4**	**0.4**	**0.4**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**5.6**	**2.2**	**3.2**	**3.0**	**3.1**	**2.8**	**2.7**	**3.1**
Light Manufacturing	**4.8**	**1.4**	**2.5**	**2.3**	**2.3**	**2.0**	**1.9**	**2.2**
Construction	**0.7**	**0.7**	**0.6**	**0.5**	**0.6**	**0.7**	**0.7**	**0.7**
Forest Resources	**0.1**	**0.2**	**0.1**	**0.2**	**0.1**	**0.2**	**0.2**	**0.2**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–11 GHG Emissions for British Columbia by Canadian Economic Sector, Selected Years

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**51.8**	**63.0**	**60.4**	**59.2**	**61.8**	**63.2**	**65.5**	**65.7**
OIL AND GAS	**7.6**	**11.9**	**14.4**	**13.3**	**13.4**	**13.4**	**13.6**	**13.7**
Upstream Oil and Gas	**6.2**	**11.3**	**13.7**	**12.6**	**12.5**	**12.7**	**13.0**	**13.1**
Natural Gas Production and Processing	3.9	9.2	11.9	10.6	10.3	10.5	10.9	11.0
Conventional Oil Production	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.5
Conventional Light Oil Production	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.5
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	1.5	1.4	1.2	1.5	1.6	1.6	1.5	1.6
Downstream Oil and Gas	**1.5**	**0.6**	**0.7**	**0.7**	**0.8**	**0.7**	**0.6**	**0.6**
Petroleum Refining	1.3	0.5	0.6	0.6	0.7	0.6	0.5	0.5
Natural Gas Distribution	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
ELECTRICITY	**0.9**	**1.0**	**0.3**	**0.3**	**0.4**	**0.4**	**0.5**	**0.8**
TRANSPORT	**15.4**	**19.9**	**20.8**	**21.4**	**22.8**	**23.4**	**24.5**	**24.4**
Passenger Transport	**7.9**	**10.2**	**9.8**	**10.2**	**11.1**	**11.3**	**11.6**	**11.4**
Cars, Light Trucks and Motorcycles	6.7	8.8	8.4	8.9	9.8	9.8	10.0	9.8
Bus, Rail and Aviation	1.2	1.4	1.3	1.3	1.4	1.5	1.6	1.6
Freight Transport	**5.1**	**8.3**	**10.0**	**10.1**	**10.6**	**11.0**	**11.8**	**11.9**
Heavy Duty Trucks, Rail	4.3	7.2	8.7	8.7	9.1	9.6	10.3	10.3
Aviation and Marine	0.9	1.1	1.3	1.4	1.5	1.4	1.5	1.6
Other: Recreational, Commercial and Residential	**2.3**	**1.4**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
HEAVY INDUSTRY	**8.7**	**7.1**	**5.6**	**5.7**	**6.2**	**6.3**	**6.4**	**6.5**
Mining	**0.5**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.5**	**0.5**
Smelting and Refining (Non-Ferrous Metals)	**2.0**	**1.7**	**1.0**	**0.9**	**1.3**	**1.2**	**1.1**	**1.2**
Pulp and Paper	**4.0**	**1.8**	**1.9**	**1.9**	**2.0**	**2.1**	**2.1**	**2.4**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**1.0**	**2.0**	**1.8**	**2.0**	**2.1**	**2.1**	**2.2**	**2.0**
Lime and Gypsum	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
Chemicals and Fertilizers	**0.9**	**0.9**	**0.3**	**0.3**	**0.4**	**0.4**	**0.3**	**0.3**
BUILDINGS	**7.5**	**8.4**	**7.8**	**7.3**	**7.4**	**8.3**	**8.2**	**8.3**
Service Industry	**3.1**	**3.8**	**3.8**	**3.4**	**3.5**	**3.9**	**3.9**	**3.9**
Residential	**4.5**	**4.6**	**4.0**	**3.9**	**3.9**	**4.4**	**4.3**	**4.4**
AGRICULTURE	**2.8**	**3.1**	**2.8**	**2.9**	**3.1**	**3.1**	**3.3**	**3.2**
On Farm Fuel Use	**0.6**	**0.3**	**0.6**	**0.6**	**0.7**	**0.7**	**0.8**	**0.8**
Crop Production	**0.4**	**0.3**	**0.3**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**
Animal Production	**1.8**	**2.4**	**1.9**	**2.0**	**2.0**	**2.0**	**2.1**	**2.1**
WASTE	**4.6**	**5.6**	**4.5**	**4.4**	**4.3**	**4.3**	**4.2**	**4.2**
Solid Waste[a]	**4.5**	**5.5**	**4.4**	**4.3**	**4.2**	**4.1**	**4.1**	**4.1**
Wastewater	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Waste Incineration	**0.0**	**0.0**	-	-	-	-	-	-
COAL PRODUCTION	**1.8**	**1.7**	**1.9**	**1.6**	**1.8**	**1.7**	**2.0**	**2.0**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**2.6**	**4.3**	**2.2**	**2.4**	**2.4**	**2.5**	**2.9**	**2.5**
Light Manufacturing	**1.4**	**3.1**	**1.4**	**1.5**	**1.4**	**1.4**	**1.5**	**1.3**
Construction	**0.6**	**0.5**	**0.3**	**0.4**	**0.6**	**0.6**	**0.7**	**0.6**
Forest Resources	**0.5**	**0.7**	**0.4**	**0.5**	**0.4**	**0.5**	**0.6**	**0.6**

Notes:

Totals may not add up due to rounding.

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Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–12 **GHG Emissions for Yukon by Canadian Economic Sector, Selected Years**

	1990	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**	**0.6**	**0.6**	**0.7**
OIL AND GAS	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Upstream Oil and Gas	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Natural Gas Production and Processing	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Oil Production	-	-	-	-	-	-	-	-
Conventional Light Oil Production	-	-	-	-	-	-	-	-
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	-	-	-	-	-	-	-	-
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Natural Gas Distribution	-	-	-	-	-	-	-	-
ELECTRICITY	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TRANSPORT	**0.3**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**	**0.5**	**0.5**
Passenger Transport	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Cars, Light Trucks and Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Bus, Rail and Aviation	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Freight Transport	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**
Heavy Duty Trucks, Rail	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
Aviation and Marine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other: Recreational, Commercial and Residential	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
HEAVY INDUSTRY	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Mining	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**
Pulp and Paper	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**
Cement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**
Lime and Gypsum	**0.0**	**-**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Service Industry	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Residential	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
AGRICULTURE	**0.0**	**0.0**	**-**	**-**	**0.0**	**-**	**0.0**	**-**
On Farm Fuel Use	**0.0**	**0.0**	**-**	**-**	**0.0**	**-**	**0.0**	**-**
Crop Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Animal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Solid Waste[a]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**-**	**0.0**	**-**	**-**	**-**	**-**	**-**	**-**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Light Manufacturing	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Construction	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

Table A12–13 GHG Emissions for Northwest Territories by Canadian Economic Sector, Selected Years

	1999	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**1.3**	**1.6**	**1.5**	**1.7**	**1.6**	**1.3**	**1.4**	**1.4**
OIL AND GAS	**0.2**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**
Upstream Oil and Gas	**0.2**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**
Natural Gas Production and Processing	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Oil Production	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Light Oil Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Petroleum Refining	-	-	-	-	-	-	-	-
Natural Gas Distribution	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELECTRICITY	**0.1**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
TRANSPORT	**0.5**	**0.7**	**0.8**	**0.9**	**0.9**	**0.8**	**0.8**	**0.8**
Passenger Transport	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**
Cars, Light Trucks and Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Bus, Rail and Aviation	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Freight Transport	**0.2**	**0.5**	**0.5**	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**
Heavy Duty Trucks, Rail	0.2	0.4	0.5	0.6	0.6	0.5	0.5	0.5
Aviation and Marine	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Other: Recreational, Commercial and Residential	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
HEAVY INDUSTRY	**0.2**	**0.3**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**
Mining	**0.2**	**0.3**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**
Smelting and Refining (Non-Ferrous Metals)	**-**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Pulp and Paper	**-**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Iron and Steel	**-**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Cement	**-**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Lime and Gypsum	**-**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**	**-**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**0.3**	**0.2**	**0.3**	**0.3**	**0.3**	**0.1**	**0.2**	**0.1**
Service Industry	**0.2**	**0.1**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
Residential	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**
AGRICULTURE	**0.0**	**0.0**	**-**	**-**	**-**	**-**	**-**	**-**
On Farm Fuel Use	**0.0**	**0.0**	**-**	**-**	**-**	**-**	**-**	**-**
Crop Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Animal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Solid Waste[a]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.0**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Light Manufacturing	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Construction	**0.0**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

x Indicates data has been suppressed to respect confidentiality.

Table A12–14 **GHG Emissions for Nunavut by Canadian Economic Sector, Selected Years**

	1999	2005	2014	2015	2016	2017	2018	2019
	Mt CO_2 eq							
GHG TOTAL	**0.4**	**0.6**	**0.7**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**
OIL AND GAS	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**
Upstream Oil and Gas	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Natural Gas Production and Processing	-	-	-	-	-	-	-	-
Conventional Oil Production	-	-	-	-	-	-	-	-
Conventional Light Oil Production	-	-	-	-	-	-	-	-
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-
Frontier Oil Production	-	-	-	-	-	-	-	-
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	-	-	-	-	-	-	-	-
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	-	-	-
Natural Gas Distribution	-	-	-	-	-	-	-	-
ELECTRICITY	**0.0**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
TRANSPORT	**0.3**	**0.4**	**0.5**	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**
Passenger Transport	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Cars, Light Trucks and Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus, Rail and Aviation	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Freight Transport	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Heavy Duty Trucks, Rail	0.0	0.1	0.2	0.1	0.2	0.2	0.2	0.2
Aviation and Marine	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Other: Recreational, Commercial and Residential	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
HEAVY INDUSTRY	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**
Mining	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Pulp and Paper	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Service Industry	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Residential	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
AGRICULTURE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
On Farm Fuel Use	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Crop Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Animal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Solid Waste[a]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**-**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.0**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Light Manufacturing	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Construction	**0.0**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Forest Resources	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

x Indicates data has been suppressed to respect confidentiality.

Table A12–15 GHG Emissions for Northwest Territories & Nunavut by Canadian Economic Sector, 1990–1998

	1990	1991	1992	1993	1994	1995	1996	1997	1998
	Mt CO_2 eq								
GHG TOTAL	**1.8**	**1.8**	**1.6**	**1.9**	**2.0**	**2.1**	**2.1**	**1.9**	**1.8**
OIL AND GAS	**0.4**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**
Upstream Oil and Gas	**0.4**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**
Natural Gas Production and Processing	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Conventional Oil Production	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Conventional Light Oil Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional Heavy Oil Production	-	-	-	-	-	-	-	-	-
Frontier Oil Production	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Oil Sands (Mining, In-situ, Upgrading)	-	-	-	-	-	-	-	-	-
Mining and Extraction	-	-	-	-	-	-	-	-	-
In-situ	-	-	-	-	-	-	-	-	-
Upgrading	-	-	-	-	-	-	-	-	-
Oil, Natural Gas and CO_2 Transmission	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downstream Oil and Gas	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Distribution	-	-	-	-	-	-	-	-	-
ELECTRICITY	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**	**0.2**
TRANSPORT	**0.6**	**0.5**	**0.5**	**0.6**	**0.7**	**0.6**	**0.7**	**0.7**	**0.7**
Passenger Transport	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Cars, Light Trucks and Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Bus, Rail and Aviation	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Freight Transport	**0.3**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**
Heavy Duty Trucks, Rail	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2
Aviation and Marine	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Other: Recreational, Commercial and Residential	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**	**0.0**	**0.1**	**0.1**	**0.1**
HEAVY INDUSTRY	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**
Mining	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**
Smelting and Refining (Non-Ferrous Metals)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Pulp and Paper	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Iron and Steel	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Cement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lime and Gypsum	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**-**	**-**
Chemicals and Fertilizers	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BUILDINGS	**0.4**	**0.6**	**0.6**	**0.6**	**0.7**	**0.7**	**0.6**	**0.6**	**0.3**
Service Industry	**0.3**	**0.4**	**0.4**	**0.4**	**0.5**	**0.6**	**0.4**	**0.4**	**0.2**
Residential	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.2**	**0.2**	**0.1**
AGRICULTURE	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**0.0**	**0.0**
On Farm Fuel Use	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-**	**0.0**	**0.0**
Crop Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Animal Production	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WASTE	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Solid Waste[a]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**
Wastewater	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Waste Incineration	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
COAL PRODUCTION	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Light Manufacturing	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Construction	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Forest Resources	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Notes:

Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be change in future publications as new data becomes available and methods and models are refined and improved.

National GHG emissions allocated to IPCC sectors are provided in Annex 9 of this report.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 of this report.

a. Emission estimates for Solid Waste include emissions from municipal solid waste landfills, wood waste landfills and municipal solid waste composting.

0.0 Indicates emissions of less than 0.05 Mt CO_2 eq were truncated due to rounding.

- Indicates no emissions

ELECTRICITY IN CANADA: SUMMARY AND INTENSITY TABLES

This annex presents detailed greenhouse gas (GHG) information related to the generation of electricity by the Public Electricity and Heat Production category (IPCC Category 1.A.1.a), on a national, provincial and territorial level.

The Canadian electricity generation industry produces electricity by transforming the energy in falling water, coal, natural gas, refined petroleum products (RPPs), other miscellaneous fuels, biomass, nuclear, wind and solar resources. The process of supplying electricity to the public involves not only power generation at the plant, but also distribution through the electricity grid. The efficiency of the transmission system has an impact on the amount of electricity available to consumers. GHG emission estimates and electricity generation values are therefore based on activities that occur at the generating plant, and efforts have been made to include the impact of the transmission and distribution infrastructure (including sulphur hexafluoride [SF_6] emissions associated with switchgear and other electrical equipment, which is accounted for in the Industrial Processes and Product Use [IPPU] sector).

The electricity generation industry in Canada is composed of entities whose main activity is the production of electricity (main activity producers) and those who generate either partially or wholly for their own use (autoproducers). Main activity producers sell their electricity to the grid, can be either public or private generators and are reported under North American Industrial Classification System (NAICS) code 22111. Autoproducers are generally private companies that are generating electricity either to feed their operations or as a by-product of their operation. They may sell some or all of their electricity to the grid. Any industry that generates electricity, but whose main business is something other than electric power generation, is reported under the NAICS code associated with their primary business activity. However, in some cases, a company may have divided their operations so that the electric power generation is a separate business entity (even if the operations are on the same site). In this case, the electric power generation is included under the Public Electricity and Heat Production category.

The analysis in this section only includes main activity producers. This analysis relies on a variety of data sources; fuel consumption and electricity production data are published by Statistics Canada in the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, n.d.[a], 57-003-X), in the publication *Electric Power Generation, Transmission and Distribution* (EPGTD) (Statistics Canada, n.d.[b], 57-202-X) and online via Statistics Canada data tables 25-10-0019-01, 25-10-0020-01, 25-10-0021-01 and 25-10-0017-01 (Statistics Canada, n.d. [c], n.d. [d], n.d. [e], n.d. [f]).

A “generation intensity” indicator is derived to reflect the GHG emissions intensity of electricity as it is delivered to the electricity grid. Electricity generation intensity values were derived for each fuel type using GHG emission estimates and electricity generation data. The methodology used to develop the GHG emissions is discussed in Chapter 3 and Annex 3.1 of this report. GHG emissions are based on the total fuel consumed by the public utility sector, as provided in the RESD,[1] while generation data are from StatCan data tables (2005–2019) and the EPGTD publication (1990–2004).

1 Occasionally, Statistics Canada revises some of its historic data, which can affect the values provided in Table A13–1 to Table A13–14.

A “consumption intensity” indicator was also derived to reflect the GHG emissions intensity of electricity as it is delivered to the consumer. Accordingly, electric energy losses (mainly) in transmission and distribution are subtracted from overall total electricity generation, while SF_6 emissions associated with equipment used in electricity transmission and distribution are added to overall total GHG emissions. The electric energy losses in transmission, distribution and anywhere else are taken to be the utility sector’s share of “unallocated energy,” as presented in Table A13–1 to Table A13–14 and calculated from data provided by StatCan data table 25-10-0021-01. Likewise, the SF_6 emission values are based on the electric utility sector’s share of total SF_6 emissions from equipment used in electricity transmission and distribution.

Electricity intensity values for Canada, the provinces and the territories are provided in Table A13–1 to Table A13–14.

Table A13–1 **Electricity Generation and GHG Emission Details for Canada**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
	kt CO_2 equivalent									
Combustion	**94 500**	**132 000**	**125 000**	**87 400**	**83 800**	**87 000**	**80 400**	**78 400**	**69 700**	**68 600**
Coal	80 500	109 000	98 200	63 800	60 300	62 300	57 100	57 200	44 100	42 500
Natural Gas	2 720	13 800	15 400	19 300	18 600	19 300	18 300	16 300	20 900	21 900
Other Fuels[c]	11 300	9 380	11 200	4 260	4 860	5 400	5 020	4 800	4 610	4 200
Other Emissions[d]	**0**	**27**	**52**	**63**	**73**	**87**	**80**	**80**	**78**	**80**
Overall Total[e, f, g]	**94 500**	**132 000**	**125 000**	**87 500**	**83 800**	**87 000**	**80 500**	**78 400**	**69 800**	**68 600**
Electricity Generation[h, i]										
	GWh									
Combustion[j]	**101 000**	**146 000**	**140 000**	**104 000**	**110 000**	**108 000**	**106 000**	**99 300**	**98 900**	**98 000**
Coal	82 200	106 000	93 900	60 900	61 600	57 800	57 900	55 900	47 000	44 500
Natural Gas	4 140	26 600	29 800	35 600	40 000	41 200	39 100	35 100	43 300	46 100
Other Fuels	14 800	13 400	16 700	7 900	8 640	8 560	9 120	8 290	8 630	7 440
Refined Petroleum Products	14 700	10 600	10 800	2 160	3 170	3 550	3 570	3 100	2 920	2 390
Biomass	14	1 830	1 780	2 050	2 030	1 980	2 250	2 170	2 250	1 880
Other	91	960	4 100	3 700	3 400	3 000	3 300	3 000	3 500	3 200
Nuclear	**68 800**	**68 700**	**86 800**	**97 600**	**101 000**	**96 000**	**95 700**	**95 600**	**95 000**	**95 500**
Hydro	**263 000**	**323 000**	**327 000**	**357 000**	**348 000**	**345 000**	**354 000**	**361 000**	**353 000**	**347 000**
Other Renewables[k]	**26**	**264**	**1 580**	**11 400**	**12 900**	**27 500**	**31 600**	**32 100**	**34 000**	**33 500**
Other Generation[l, m]	**0**	**0**	**32**	**9 550**	**2 240**	**140**	**180**	**200**	**210**	**170**
Overall Total[f]	**433 000**	**539 000**	**556 000**	**580 000**	**575 000**	**576 000**	**587 000**	**588 000**	**581 000**	**575 000**
Greenhouse Gas Intensity[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	220	240	220	150	140	150	140	130	120	120
CH_4 intensity (g CH_4 / kWh)	0	0	0	0	0	0	0	0	0	0
N_2O intensity (g N_2O / kWh)	0	0	0	0	0	0	0	0	0	0
Generation Intensity (g CO_2 eq / kWh)[f]	**220**	**250**	**220**	**150**	**150**	**150**	**140**	**130**	**120**	**120**
	Losses									
Unallocated Energy (GWh)[o, p]	31 000	42 000	37 000	41 000	29 000	13 000	3 000	17 000	22 000	3 000
SF_6 Emissions (kt CO_2 eq)[q]	200	200	160	220	130	190	190	140	160	170
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**240**	**270**	**240**	**160**	**150**	**150**	**140**	**140**	**130**	**120**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the Report on Energy Supply-Demand in Canada, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total.
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

Table A13–2 Electricity Generation and GHG Emission Details for Newfoundland and Labrador

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**1 640**	**822**	**819**	**867**	**1 210**	**1 340**	**1 520**	**1 530**	**1 130**	**1 140**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	–	–	–	–	–
Other Fuels[c]	1 640	822	819	867	1 210	1 340	1 520	1 530	1 130	1 140
Other Emissions[d]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[e, f, g]	**1 640**	**822**	**819**	**867**	**1 210**	**1 340**	**1 520**	**1 530**	**1 130**	**1 140**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**2 090**	**1 020**	**1 360**	**1 090**	**1 470**	**1 560**	**1 800**	**1 800**	**1 370**	**1 320**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	–	–	–	–	–
Other Fuels	2 090	1 020	1 360	1 090	1 470	1 560	1 800	1 800	1 370	1 320
Nuclear	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hydro	**34 300**	**41 800**	**38 900**	**40 500**	**38 200**	**38 800**	**39 500**	**36 500**	**41 800**	**40 800**
Other Renewables[k]	**0**	**–**	**–**	**192**	**177**	**172**	**190**	**186**	**206**	**182**
Other Generation[l, m]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**36 400**	**42 800**	**40 300**	**41 800**	**39 800**	**40 500**	**41 500**	**38 500**	**43 400**	**42 300**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	45	19	20	21	30	33	36	39	26	27
CH_4 intensity (g CH_4 / kWh)	0.0005	0.0002	0.0002	0.0003	0.0004	0.0005	0.0006	0.0006	0.0004	0.0004
N_2O intensity (g N_2O / kWh)	0.001	0.0004	0	0	0.001	0.001	0.001	0.001	0	0.001
Generation Intensity (g CO_2 eq / kWh)[f]	**45**	**19**	**20**	**21**	**30**	**33**	**37**	**40**	**26**	**27**
	Losses									
Unallocated Energy (GWh)[o, p]	990	1 300	810	1 400	1 200	1 100	780	673	941	1 090
SF_6 Emissions (kt CO_2 eq)[q]	0.94	0.92	0.50	1.0	1.3	3.4	3.8	1.7	2.2	2.2
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**46**	**20**	**21**	**21**	**31**	**34**	**38**	**40**	**27**	**28**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

Table A13–3 **Electricity Generation and GHG Emission Details for Prince Edward Island**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**104**	**53.0**	**4.8**	**3.9**	**4.3**	**13.9**	**4.2**	**8.6**	**2.8**	**1.1**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	–	–	–	–	–
Other Fuels[c]	104	53.0	4.8	3.9	4.3	13.9	4.2	8.6	2.8	1.1
Other Emissions[d]	–	–	–	–	–	–	–	–	–	–
Overall Total[e, f, g]	**104**	**53.0**	**4.8**	**3.9**	**4.3**	**13.9**	**4.2**	**8.6**	**2.8**	**1.1**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**81.1**	**48.1**	**6.3**	**8.2**	**8.3**	**9.8**	**9.8**	**5.6**	**3.0**	**0.9**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	–	–	–	–	–
Other Fuels	81.1	48.1	6.3	8.2	8.3	9.8	9.8	5.6	3.0	0.9
Nuclear	–	–	–	–	–	–	–	–	–	–
Hydro	–	–	–	–	–	–	–	–	–	–
Other Renewables[k]	–	–	**40.1**	**499**	**611**	**606**	**594**	**604**	**640**	**646**
Other Generation[l, m]	–	–	–	–	–	–	–	–	–	–
Overall Total[f]	**81.1**	**48.1**	**46.4**	**507**	**620**	**616**	**603**	**610**	**643**	**647**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	1 300	1 100	100	8	7	22	7	14	4	2
CH_4 intensity (g CH_4 / kWh)	0.01	0.01	0.001	0.0002	0.0001	0.0007	0.0002	0.0005	0.0003	0.0001
N_2O intensity (g N_2O / kWh)	0.03	0.02	0.002	0.0001	0.0001	0.0004	0.0001	0.0002	0	0
Generation Intensity (g CO_2 eq / kWh)[f]	**1 300**	**1 100**	**100**	**8**	**7**	**23**	**7**	**14**	**4**	**2**
	Losses									
Unallocated Energy (GWh)[o, p]	unk	unk	unk	20	33	20	22	10	20	20
SF_6 Emissions (kt CO_2 eq)[q]	0	0	–	0	0	0	0	0	0	0
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**	**	**	**	**	**	**	**	**	**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

unk Indicates unknown as appropriate data were unavailable

* For years where unallocated energy data was not available, values were interpolated

** Due to the high level of imports from New Brunswick, values for New Brunswick are more indicative of GHG consumption intensity.

Table A13–4 Electricity Generation and GHG Emission Details for Nova Scotia

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
	kt CO_2 equivalent									
Combustion	**6 900**	**9 600**	**10 700**	**7 590**	**7 210**	**6 990**	**6 390**	**6 680**	**6 990**	**6 690**
Coal	5 110	8 320	5 520	5 170	4 850	4 450	4 390	4 740	4 890	4 870
Natural Gas	–	–	x	x	760	690	640	730	780	770
Other Fuels[c]	1 790	1 280	x	x	1 610	1 860	1 360	1 210	1 320	1 050
Other Emissions[d]	–	–	–	–	–	–	–	–	–	–
Overall Total[e, f, g]	**6 900**	**9 600**	**10 700**	**7 590**	**7 210**	**6 990**	**6 390**	**6 680**	**6 990**	**6 690**
Electricity Generation[h, i]										
	GWh									
Combustion[j]	**8 440**	**10 500**	**11 100**	**8 770**	**8 560**	**8 220**	**7 820**	**7 700**	**7 890**	**7 400**
Coal	6 020	8 850	6 770	5 500	5 250	4 870	4 830	4 840	4 980	4 990
Natural Gas	–	–	181	1 370	1 470	1 300	1 240	1 440	1 420	1 360
Other Fuels	2 430	1 610	4 110	1 890	1 840	2 050	1 750	1 410	1 490	1 050
Nuclear	–	–	–	–	–	–	–	–	–	–
Hydro	**1 120**	**887**	**1 040**	**964**	**1 100**	**1 010**	**803**	**850**	**938**	**1 032**
Other Renewables[k]	**26.1**	**0**	**113**	**780**	**764**	**821**	**979**	**1 270**	**1 090**	**970**
Other Generation[l, m]	–	–	–	–	–	–	–	–	–	–
Overall Total[f]	**9 590**	**11 300**	**12 200**	**10 500**	**10 400**	**10 000**	**9 610**	**9 810**	**9 910**	**9 400**
Greenhouse Gas Intensity[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	720	840	880	720	690	690	660	680	700	710
CH_4 intensity (g CH_4 / kWh)	0.007	0.009	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
N_2O intensity (g N_2O / kWh)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Generation Intensity (g CO_2 eq / kWh)[f]	**720**	**850**	**880**	**720**	**690**	**700**	**670**	**680**	**710**	**710**
	Losses									
Unallocated Energy (GWh)[o, p]	580	830	770	570	680	570	630	640	420	610
SF_6 Emissions (kt CO_2 eq)[q]	23	23	29	39	33	33	28	40	25	25
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**770**	**920**	**940**	**770**	**740**	**740**	**720**	**730**	**740**	**760**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

Table A13–5 **Electricity Generation and GHG Emission Details for New Brunswick**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
kt CO_2 equivalent										
Combustion	**6 020**	**8 970**	**8 060**	**4 190**	**3 760**	**3 780**	**4 000**	**3 340**	**3 670**	**3 300**
Coal	1 180	3 130	2 910	x	1 330	1 160	1 490	1 370	1 530	1 300
Natural Gas	–	–	x	x	1 040	1 040	1 000	580	650	640
Other Fuels[c]	4 840	5 840	x	1 150	1 390	1 590	1 500	1 390	1 480	1 360
Other Emissions[d]	–	–	–	–	–	–	–	–	–	–
Overall Total[e, f, g]	**6 020**	**8 970**	**8 060**	**4 190**	**3 760**	**3 780**	**4 000**	**3 340**	**3 670**	**3 300**
Electricity Generation[h, i]										
GWh										
Combustion[j]	**7 630**	**11 000**	**12 100**	**5 310**	**6 980**	**5 630**	**6 100**	**4 390**	**4 780**	**3 920**
Coal	1 270	3 820	2 920	2 250	2 560	1 650	2 160	2 090	2 330	1 820
Natural Gas	–	–	1 970	1 770	2 570	2 320	2 360	1 300	980	940
Other Fuels	6 360	7 210	7 210	1 290	1 850	1 650	1 580	1 000	1 480	1 150
Nuclear	**5 340**	**3 960**	**4 380**	**4 480**	**5 010**	**4 280**	**4 540**	**5 120**	**4 870**	**5 020**
Hydro	**3 460**	**3 220**	**3 820**	**3 400**	**2 960**	**2 620**	**3 260**	**2 600**	**2 530**	**2 990**
Other Renewables[k]	–	–	–	**737**	**786**	**792**	**766**	**781**	**825**	**888**
Other Generation[l, m]	–	–	–	–	–	–	–	–	–	–
Overall Total[f]	**16 400**	**18 200**	**20 300**	**14 500**	**15 700**	**13 300**	**14 700**	**12 900**	**13 000**	**12 800**
Greenhouse Gas Intensity[n]										
Generation Intensity (g GHG / kWh electricity generated)										
CO_2 intensity (g CO_2 / kWh)	360	490	390	290	240	280	270	260	280	260
CH_4 intensity (g CH_4 / kWh)	0.004	0.005	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
N_2O intensity (g N_2O / kWh)	0.007	0.009	0.007	0.004	0.004	0.005	0.005	0.004	0.005	0.004
Generation Intensity (g CO_2 eq / kWh)[f]	**370**	**490**	**400**	**290**	**240**	**280**	**270**	**260**	**280**	**260**
Losses										
Unallocated Energy (GWh)[o, p]	990	1 300	1 100	490	530	450	590	220	460	540
SF_6 Emissions (kt CO_2 eq)[q]	0.71	0.70	–	0.82	0.58	0.83	0.59	1.50	1.40	1.40
Consumption Intensity (g GHG / kWh electricity consumed)										
Consumption Intensity (g CO_2 eq / kWh)[r]	**390**	**530**	**420**	**300**	**250**	**290**	**280**	**260**	**290**	**270**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

Table A13–6 Electricity Generation and GHG Emission Details for Quebec

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**1 490**	**567**	**616**	**367**	**245**	**205**	**233**	**239**	**242**	**232**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	114	194	269	144	13	0	1.0	1.0	2.0	1.0
Other Fuels[c]	1 380	373	347	223	231	205	232	238	241	231
Other Emissions[d]	**–**	**2.5**	**4.6**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[e, f, g]	**1 490**	**569**	**621**	**367**	**245**	**205**	**233**	**239**	**242**	**232**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**1 980**	**1 150**	**1 390**	**1 140**	**1 010**	**960**	**1 290**	**1 310**	**1 340**	**1 230**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	191	212	14	14	0	0	0	0	0
Other Fuels	1 980	961	1 170	1 130	1 000	960	1 290	1 310	1 340	1 230
Nuclear	**4 070**	**4 890**	**4 480**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Hydro	**112 000**	**153 000**	**155 000**	**182 000**	**177 000**	**175 000**	**177 000**	**182 000**	**180 000**	**180 000**
Other Renewables[k]	**–**	**173**	**416**	**1 030**	**1 010**	**6 420**	**9 420**	**9 530**	**10 200**	**10 700**
Other Generation[l, m]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**118 000**	**160 000**	**161 000**	**184 000**	**179 000**	**182 000**	**188 000**	**193 000**	**191 000**	**191 000**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	13	3.5	3.7	2.0	1.4	1.1	1.2	1.2	1.3	1.2
CH_4 intensity (g CH_4 / kWh)	0.0004	0.0005	0.001	0.0002	0	0	0	0	0	0.0002
N_2O intensity (g N_2O / kWh)	0.0003	0.0002	0.0004	0	0	0	0	0	0	0.0001
Generation Intensity (g CO_2 eq / kWh)[f]	**13**	**3.6**	**3.9**	**2.0**	**1.4**	**1.1**	**1.2**	**1.2**	**1.3**	**1.2**
	Losses									
Unallocated Energy (GWh)[o, p]	7 300	13 000	9 100	12 000	13 000	2 600	9 000	12 000	9 000	2 000
SF_6 Emissions (kt CO_2 eq)[q]	37	36	30	67	17	74	81	22	58	58
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**14**	**4.1**	**4.3**	**2.5**	**1.6**	**1.6**	**1.8**	**1.4**	**1.6**	**1.5**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

Table A13–7 **Electricity Generation and GHG Emission Details for Ontario**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**25 900**	**44 200**	**35 400**	**10 300**	**6 030**	**6 250**	**5 540**	**2 560**	**4 090**	**3 880**
Coal	24 700	38 800	29 000	3 150	95	–	–	–	–	–
Natural Gas	8	4 930	6 210	7 040	5 810	6 170	5 420	2 420	3 970	3 820
Other Fuels[c]	1 160	477	185	60	120	80	120	140	120	60
Other Emissions[d]	**–**	**0.77**	**1.4**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[e, f, g]	**25 900**	**44 200**	**35 400**	**10 300**	**6 030**	**6 250**	**5 540**	**2 560**	**4 090**	**3 880**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**29 200**	**52 200**	**40 900**	**17 500**	**15 600**	**15 900**	**13 600**	**6 800**	**10 600**	**10 100**
Coal	27 800	40 800	29 400	2 900	100	0	0	0	0	0
Natural Gas	3	10200	10 000	13 900	14 700	15 300	12 700	5 900	9 800	9 400
Other Fuels	1 430	1 140	1 440	720	780	640	900	870	840	750
Nuclear	**59 400**	**59 800**	**78 000**	**93 100**	**96 200**	**91 800**	**91 100**	**90 400**	**90 200**	**90 500**
Hydro	**38 700**	**36 600**	**34 600**	**36 900**	**38 200**	**34 800**	**36 100**	**39 500**	**37 800**	**35 700**
Other Renewables[k]	**–**	**1**	**26**	**4 240**	**3 660**	**12 200**	**12 100**	**11 800**	**13 600**	**12 600**
Other Generation[l, m]	**–**	**–**	**–**	**3 340**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**127 000**	**149 000**	**153 000**	**155 000**	**154 000**	**155 000**	**153 000**	**149 000**	**152 000**	**149 000**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	200	300	230	70	40	40	40	20	30	30
CH_4 intensity (g CH_4 / kWh)	0.002	0.011	0.013	0.012	0.010	0.010	0.009	0.004	0.007	0.007
N_2O intensity (g N_2O / kWh)	0.003	0.005	0.004	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Generation Intensity (g CO_2 eq / kWh)[f]	**200**	**300**	**230**	**70**	**40**	**40**	**40**	**20**	**30**	**30**
	Losses									
Unallocated Energy (GWh)[o, p]	10 000	12 000	12 000	22 000	9 000	5 000	13 000	13 000	13 000	12 000
SF_6 Emissions (kt CO_2 eq)[q]	76	75	50	64	43	56	62	56	57	57
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**220**	**320**	**250**	**80**	**40**	**40**	**40**	**20**	**30**	**30**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

Table A13–8 Electricity Generation and GHG Emission Details for Manitoba

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**519**	**1 070**	**349**	**104**	**110**	**103**	**54.0**	**53.9**	**25.1**	**24.3**
Coal	x	x	x	x	77.4	71.3	33.4	29.6	5.6	0
Natural Gas	x	x	x	x	31.0	31.8	7.5	11.7	7.1	12.4
Other Fuels[c]	48.6	11.8	15.1	1.7	1.7	–	13.2	12.6	12.4	11.8
Other Emissions[d]	**–**	**4.8**	**8.8**	**16**	**16**	**21**	**15**	**16**	**16**	**16**
Overall Total[e, f, g]	**519**	**1 070**	**358**	**120**	**127**	**124**	**69**	**69**	**41**	**40**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**399**	**881**	**447**	**91**	**96**	**107**	**56**	**62**	**30**	**32**
Coal	375	869	421	65.4	68.9	63.4	28.5	29.5	5.3	0
Natural Gas	0.904	–	10.6	24.0	25.2	29.4	11.7	17.0	9.7	16.6
Other Fuels	22.4	12.4	15.1	1.5	1.6	14.4	15.5	15.2	15.0	15.2
Nuclear	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hydro	**19 800**	**31 500**	**36 400**	**35 300**	**34 500**	**34 800**	**36 600**	**36 000**	**30 700**	**32 900**
Other Renewables[k]	**–**	**–**	**53.4**	**868**	**911**	**903**	**966**	**927**	**873**	**884**
Other Generation[l, m]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**20 200**	**32 400**	**36 900**	**36 300**	**35 500**	**35 800**	**37 600**	**37 000**	**31 600**	**33 900**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	26	33	9.6	3.3	3.5	3.4	1.8	1.9	1.3	1.2
CH_4 intensity (g CH_4 / kWh)	0.0004	0.0004	0.0002	0.0003	0.0003	0.0003	0.0001	0.0001	0.0001	0.0001
N_2O intensity (g N_2O / kWh)	0.001	0.001	0.0002	0.0001	0.0001	0.0001	0	0	0	0
Generation Intensity (g CO_2 eq / kWh)[f]	**26**	**33**	**9.7**	**3.3**	**3.6**	**3.5**	**1.8**	**1.9**	**1.3**	**1.2**
	Losses									
Unallocated Energy (GWh)[o, p]	2 100	3 750	1 900	3 800	3 900	3 700	2 500	450	370	190
SF_6 Emissions (kt CO_2 eq)[q]	4.3	4.2	4.0	1.2	0.9	1.0	2.4	1.1	2.4	2.4
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**29**	**38**	**10.3**	**3.7**	**4.0**	**3.9**	**2.0**	**1.9**	**1.4**	**1.3**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

Table A13–9 Electricity Generation and GHG Emission Details for Saskatchewan

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
	kt CO_2 equivalent									
Combustion	**11 100**	**14 500**	**15 200**	**15 100**	**15 200**	**16 100**	**16 000**	**16 500**	**16 100**	**15 800**
Coal	x	x	x	x	12 600	12 600	12 200	12 500	11 700	11 400
Natural Gas	x	x	x	x	2 580	3 520	3 780	4 030	4 400	4 380
Other Fuels[c]	6.47	10.4	4.30	0.27	6.36	9.12	9.40	9.40	9.40	5.80
Other Emissions[d]	**–**	**10**	**18**	**35**	**35**	**39**	**42**	**41**	**41**	**41**
Overall Total[e, f, g]	**11 100**	**14 500**	**15 300**	**15 100**	**15 200**	**16 100**	**16 000**	**16 600**	**16 100**	**15 800**
Electricity Generation[h, i]										
	GWh									
Combustion[j]	**9 660**	**14 100**	**14 800**	**15 300**	**14 800**	**19 100**	**20 300**	**20 700**	**19 400**	**19 300**
Coal	9 340	11 400	12 200	11 800	10 200	12 100	12 000	12 000	10 300	10 000
Natural Gas	310	2 660	2 610	3 510	4 530	6 990	8 220	8 660	9 020	9 270
Other Fuels	10	10	10	10	10	0	10	10	0	0
Nuclear	–	–	–	–	–	–	–	–	–	–
Hydro	**4 210**	**3 050**	**4 570**	**4 450**	**4 710**	**3 430**	**3 280**	**3 850**	**3 590**	**3 670**
Other Renewables[k]	**–**	**–**	**92**	**640**	**615**	**620**	**746**	**739**	**694**	**707**
Other Generation[l, m]	**–**	**–**	**–**	**878**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**13 900**	**17 100**	**19 500**	**21 300**	**20 100**	**23 100**	**24 300**	**25 200**	**23 800**	**23 800**
Greenhouse Gas Intensity[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	800	840	780	710	750	690	650	650	670	660
CH_4 intensity (g CH_4 / kWh)	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.06
N_2O intensity (g N_2O / kWh)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Generation Intensity (g CO_2 eq / kWh)[f]	**800**	**850**	**780**	**710**	**760**	**700**	**660**	**660**	**680**	**660**
	Losses									
Unallocated Energy (GWh)[o, p]	1 300	1 700	1 400	1 900	3 200	1 400	1 200	2 200	2 400	1 500
SF_6 Emissions (kt CO_2 eq)[q]	1.8	1.7	1.3	0.91	0.42	0.73	0.38	0.80	0.27	0.27
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**890**	**940**	**840**	**780**	**900**	**740**	**690**	**720**	**750**	**710**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

Table A13–10 Electricity Generation and GHG Emission Details for Alberta

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
	kt CO_2 equivalent									
Combustion	**39 800**	**50 300**	**52 000**	**48 200**	**49 200**	**51 400**	**45 800**	**46 700**	**36 500**	**36 300**
Coal	38 000	44 200	46 800	40 700	41 400	44 100	39 000	38 600	26 000	24 900
Natural Gas	1 700	5 740	5 170	7 520	7 820	7 360	6 810	8 030	10 500	11 300
Other Fuels[c]	11.4	300	68.5	18.6	16.9	17.6	1.7	0	0	21.2
Other Emissions[d]	–	**5.7**	**10**	**6**	**14**	**19**	**17**	**16**	**15**	**16**
Overall Total[e, f, g]	**39 800**	**50 300**	**52 000**	**48 200**	**49 200**	**51 500**	**45 800**	**46 700**	**36 500**	**36 300**
Electricity Generation[h, i]										
	GWh									
Combustion[j]	**39 900**	**51 300**	**54 200**	**53 200**	**59 700**	**54 100**	**53 200**	**54 800**	**51 400**	**52 000**
Coal	37 300	40 700	42 200	38 500	43 400	39 100	38 900	37 000	29 400	27 700
Natural Gas	2 510	10 200	11 600	14 100	15 700	14 500	13 900	17 300	21 400	23 600
Other Fuels	21.6	443	424	630	550	517	448	576	647	670
Nuclear	–	–	–	–	–	–	–	–	–	–
Hydro	**2 060**	**1 760**	**2 240**	**1 990**	**1 820**	**1 980**	**1 970**	**2 060**	**1 990**	**2 040**
Other Renewables[k]	–	**88.9**	**837**	**2 260**	**3 520**	**4 090**	**4 590**	**4 630**	**4 140**	**4 220**
Other Generation[l, m]	–	–	–	–	–	–	–	–	–	–
Overall Total[f]	**41 900**	**53 200**	**57 300**	**59 700**	**65 200**	**60 300**	**59 900**	**61 700**	**57 700**	**58 300**
Greenhouse Gas Intensity[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	940	940	900	800	750	850	760	750	630	620
CH_4 intensity (g CH_4 / kWh)	0.02	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05
N_2O intensity (g N_2O / kWh)	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01
Generation Intensity (g CO_2 eq / kWh)[f]	**950**	**950**	**910**	**810**	**760**	**850**	**760**	**750**	**630**	**620**
	Losses									
Unallocated Energy (GWh)[o, p]	3 400	4 100	4 900	4 600	5 000	2 300	4 700	3 100	4 500	4 500
SF_6 Emissions (kt CO_2 eq)[q]	1.6	1.6	0.43	2.4	3.1	3.2	2.7	1.4	2.4	2.4
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**1 000**	**1 000**	**990**	**880**	**820**	**890**	**830**	**790**	**690**	**670**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

Table A13–11 Electricity Generation and GHG Emission Details for British Columbia

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**804**	**1 930**	**1 330**	**590**	**571**	**496**	**671**	**567**	**690**	**963**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	x	x	x	x	517	447	628	516	631	890
Other Fuels[c]	x	x	x	x	53	49	43	51	59	73
Other Emissions[d]	**–**	**2.4**	**4.6**	**6.7**	**7.4**	**7.2**	**6.5**	**6.5**	**6.9**	**7.4**
Overall Total[e, f, g]	**804**	**1 940**	**1 340**	**596**	**578**	**503**	**677**	**574**	**697**	**971**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**1 390**	**3 930**	**3 820**	**1 820**	**1 780**	**1 610**	**1 560**	**1 410**	**1 670**	**2 360**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	1 310	3 350	3 140	892	936	788	603	457	543	1 420
Other Fuels	79.4	585	689	926	846	818	956	950	1 130	950
Nuclear	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hydro	**46 400**	**50 800**	**50 300**	**50 500**	**49 000**	**52 400**	**54 500**	**57 100**	**52 900**	**48 000**
Other Renewables[k]	**–**	**–**	**–**	**152**	**849**	**868**	**1 220**	**1 590**	**1 690**	**1 650**
Other Generation[l, m]	**–**	**–**	**–**	**2 520**	**2 240**	**0**	**0**	**0**	**0**	**0**
Overall Total[f]	**47 800**	**54 700**	**54 100**	**55 000**	**53 900**	**54 800**	**57 300**	**60 100**	**56 300**	**52 100**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	17	35	24	10.5	10.4	8.9	11.5	9.3	12.1	18.3
CH_4 intensity (g CH_4 / kWh)	0.004	0.009	0.007	0.003	0.003	0.003	0.003	0.003	0.003	0.005
N_2O intensity (g N_2O / kWh)	0.0004	0.001	0.0016	0.0008	0.0008	0.0007	0.0008	0.0007	0.0007	0.0008
Generation Intensity (g CO_2 eq / kWh)[f]	**17**	**35**	**25**	**11**	**11**	**9.2**	**12**	**9.5**	**12.4**	**18.6**
	Losses									
Unallocated Energy (GWh)[o, p]	2 200	2 300	2 100	2200	3 900	2 100	2 200	2 400	2 100	1 600
SF_6 Emissions (kt CO_2 eq)[q]	57	56	48	42	26	20	14	19	12	21
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**19**	**38**	**27**	**12**	**12**	**9.9**	**13**	**10.3**	**13.1**	**19.7**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

Table A13–12 **Electricity Generation and GHG Emission Details for Yukon**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
	Greenhouse Gas Emissions[b]									
	kt CO_2 equivalent									
Combustion	**90.2**	**21.3**	**22.0**	**16.9**	**16.4**	**18.2**	**19.2**	**23.6**	**32.8**	**47.2**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	0.77	1.74	3.66	11.6	28.9
Other Fuels[c]	90.2	21.3	22.0	16.9	16.4	17.5	17.5	19.9	21.2	18.3
Other Emissions[d]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[e, f, g]	**90.2**	**21.3**	**22.0**	**16.9**	**16.4**	**18.2**	**19.2**	**23.6**	**32.8**	**47.2**
	Electricity Generation[h, i]									
	GWh									
Combustion[j]	**62.1**	**36.7**	**22.4**	**23.3**	**22.7**	**25.5**	**27.0**	**36.6**	**59.3**	**91.7**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	–	–	–	–	1.30	3.25	9.86	30.1	66.1
Other Fuels	62.1	36.7	22.4	23.3	22.7	24.2	23.8	26.8	29.2	25.6
Nuclear	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hydro	**423**	**261**	**320**	**425**	**411**	**422**	**419**	**448**	**419**	**376**
Other Renewables[k]	**–**	**0.388**	**0.890**	**0.277**	**0.334**	**0.650**	**0.509**	**0.033**	**0**	**0**
Other Generation[l, m]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**485**	**298**	**344**	**449**	**434**	**448**	**447**	**485**	**478**	**467**
	Greenhouse Gas Intensity[n]									
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	190	71	64	38	38	41	43	48	68	100
CH_4 intensity (g CH_4 / kWh)	0.005	0.002	0.002	0.001	0.001	0.002	0.002	0.003	0.007	0.017
N_2O intensity (g N_2O / kWh)	0.002	0.001	0.001	0	0	0	0	0.001	0.001	0.002
Generation Intensity (g CO_2 eq / kWh)[f]	**190**	**71**	**64**	**38**	**38**	**41**	**43**	**49**	**69**	**101**
	Losses									
Unallocated Energy (GWh)[o, p]	47	24	45	55	17	54	47	55	56	44
SF_6 Emissions (kt CO_2 eq)[q]	–	–	–	–	–	–	–	–	–	–
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**210**	**78**	**74**	**43**	**39**	**46**	**48**	**56**	**79**	**113**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

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Table A13–13 **Electricity Generation and GHG Emission Details for the Northwest Territories**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
kt CO_2 equivalent										
Combustion	**156**	**105**	**91**	**64**	**83**	**118**	**68**	**62**	**67**	**73**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	x	x	x	x	4.82	6.17	7.71	7.71	3.86	3.47
Other Fuels[c]	x	x	x	x	78	112	61	54	63	70
Other Emissions[d]	**0**	**2**	**5**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[e, f, g]	**156**	**106**	**96**	**64**	**83**	**118**	**68**	**62**	**67**	**73**
Electricity Generation[h, i]										
GWh										
Combustion[j]	**227**	**195**	**78**	**84**	**109**	**161**	**147**	**142**	**107**	**98**
Coal	–	–	–	–	–	–	–	–	–	–
Natural Gas	–	15.8	23.3	5.77	7.53	10.7	15.6	15.6	6.6	8.2
Other Fuels	227	179	54	79	102	150	131	127	100	90
Nuclear	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hydro	**226**	**247**	**259**	**263**	**234**	**164**	**243**	**249**	**253**	**267**
Other Renewables[k]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Other Generation[l, m]	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Overall Total[f]	**453**	**442**	**337**	**347**	**343**	**325**	**391**	**392**	**360**	**365**
Greenhouse Gas Intensity[n]										
Generation Intensity (g GHG / kWh electricity generated)										
CO_2 intensity (g CO_2 / kWh)	340	240	280	180	240	360	170	150	160	200
CH_4 intensity (g CH_4 / kWh)	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
N_2O intensity (g N_2O / kWh)	0	0	0	0	0	0	0	0	0	0
Generation Intensity (g CO_2 eq / kWh)[f]	**350**	**240**	**280**	**180**	**240**	**360**	**170**	**150**	**160**	**200**
Losses										
Unallocated Energy (GWh)[o, p]	21	21	19	17	58	9	36	23	7	7
SF_6 Emissions (kt CO_2 eq)[q]	–	–	–	–	–	–	–	–	–	–
Consumption Intensity (g GHG / kWh electricity consumed)										
Consumption Intensity (g CO_2 eq / kWh)[r]	**360**	**250**	**300**	**190**	**290**	**370**	**180**	**160**	**160**	**200**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

Table A13–14 **Electricity Generation and GHG Emission Details for Nunavut**

	1990	2000	2005	2013	2014	2015	2016	2017	2018	2019[a]
Greenhouse Gas Emissions[b]										
	kt CO_2 equivalent									
Combustion	**	**	**x**	**x**	**118**	**113**	**135**	**137**	**164**	**162**
Coal	**	**	–	–	–	–	–	–	–	–
Natural Gas	**	**	x	x	–	–	–	–	–	–
Other Fuels[c]	**	**	x	x	118	113	135	137	164	162
Other Emissions[d]	**	**	–	–	–	–	–	–	–	–
Overall Total[e, f, g]	**	**	**x**	**x**	**118**	**113**	**135**	**137**	**164**	**162**
Electricity Generation[h, i]										
	GWh									
Combustion[j]	**	**	**142**	**98**	**158**	**157**	**189**	**190**	**194**	**191**
Coal	**	**	–	–	–	–	–	–	–	–
Natural Gas	**	**	–	–	–	–	–	–	–	–
Other Fuels	**	**	142	98	158	157	189	190	194	191
Nuclear	**	**	–	–	–	–	–	–	–	–
Hydro	**	**	–	–	–	–	–	–	–	–
Other Renewables[k]	**	**	–	–	–	–	–	–	–	–
Other Generation[l, m]	**	**	–	–	–	–	–	–	–	–
Overall Total[f]	**	**	**142**	**98**	**158**	**157**	**189**	**190**	**194**	**191**
Greenhouse Gas Intensity[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	**	**	x	700	740	720	710	720	840	840
CH_4 intensity (g CH_4 / kWh)	**	**	x	0	0	0	0	0	0	0
N_2O intensity (g N_2O / kWh)	**	**	x	0	0	0	0	0	0	0
Generation Intensity (g CO_2 eq / kWh)[f]	**	**	**x**	**700**	**750**	**720**	**710**	**720**	**840**	**850**
	Losses									
Unallocated Energy (GWh)[o, p]	**	**	7	2	6	6	6	9	10	9
SF_6 Emissions (kt CO_2 eq)[q]	**	**	–	–	–	–	–	–	–	–
	Consumption Intensity (g GHG / kWh electricity consumed)									
Consumption Intensity (g CO_2 eq / kWh)[r]	**	**	**880**	**710**	**770**	**750**	**740**	**760**	**890**	**890**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total
h. Taken from StatCan Data Tables 25-10-0019-01 and 25-10-0020-01 (2005–2019).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded so as to present the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005–2019) or Cat. No. 57-202-XIB (1990–2004).
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRF Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

0 Indicates emissions or electricity generation value less than 0.1

x Indicates data not shown due to statistical limitations

* For years where unallocated energy data was not available, values were interpolated

** Data is only available aggregated with Northwest Territories. Please refer to Table A13–13 for values.

Annex 8, Rounding Protocol

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