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

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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.

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Executive Summary

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Chapter 1: Introduction

Mahmoud Hammoud, Bénédicte Hurlet, Loretta MacDonald, Raphaëlle Pelland St-Pierre, Lindsay Pratt and Anne-Marie St-Laurent Thibault.

Chapter 2: Greenhouse Gas Emission Trends

Sean Angel, Alice Au, Warren Baker, Dominique Blain, Ana Blondel, Corey Flemming, Vanessa Gagnon-Chantereau, Brandon Greenlaw, Bénédicte Hurlet, Jordon Kay, Geneviève Leblanc-Power, Emil Laurin, Catherine Lee, Jonathan Lee, Doug MacDonald, Frank Neitzert, Kristen Obeda, Raphaëlle Pelland St-Pierre, Lindsay Pratt, Catherine Robert, Duane Smith, Steve Smyth, Anne-Marie St-Laurent Thibault, Brittany Sullivan, Brett Taylor, Arumugam Thiagarajan and Kristine Tracey.

Chapter 3: Energy (CRF Sector 1)

Warren Baker, Owen Barrigar, Brandon Greenlaw, Chia Ha, Jordon Kay, Frank Neitzert, Steve Smyth, Brett Taylor, Shawn Tobin and Kristine Tracey.

Chapter 4: Industrial Processes and Product Use (CRF Sector 2)

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Chapter 5: Agriculture (CRF Sector 3)

Corey Flemming, Chang Liang, Doug MacDonald and Arumugam Thiagarajan.

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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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.

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Readers' Comments

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TABLE OF CONTENTS

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

LIST OF TABLES

LIST OF FIGURES

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

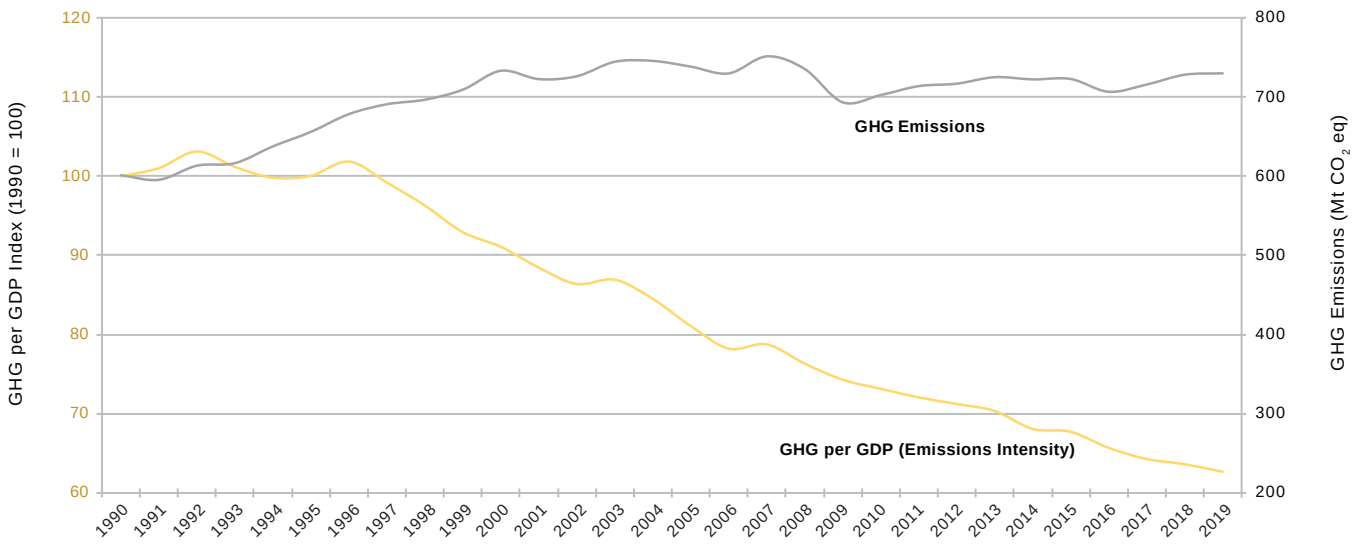
After fluctuations in recent years, in 2019 (the most recent dataset in this report) Canada's GHG emissions were 730 Mt CO_2 eq,[3] a net decrease of 9 Mt or 1.1% from 2005 emissions (Figure ES–1).[4] Emission trends since 2005 have remained consistent with previous editions of the NIR, with emission 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)**

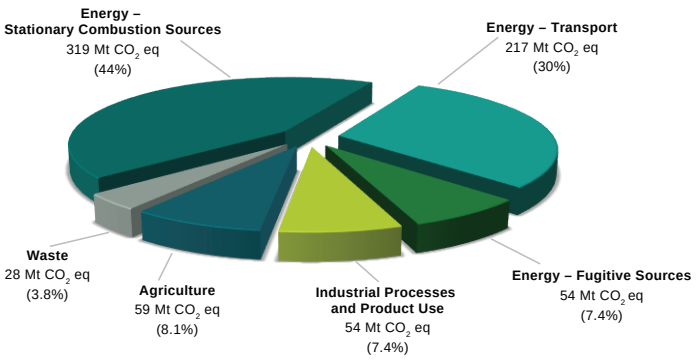
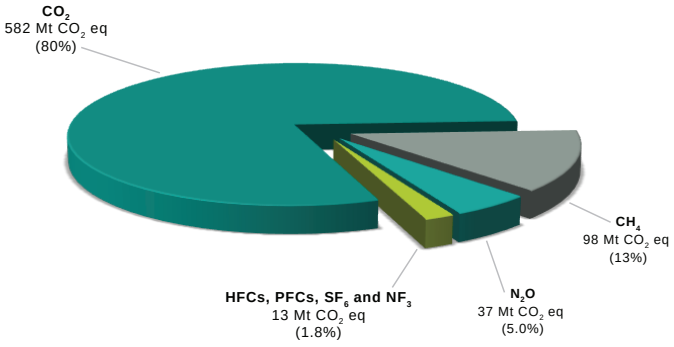


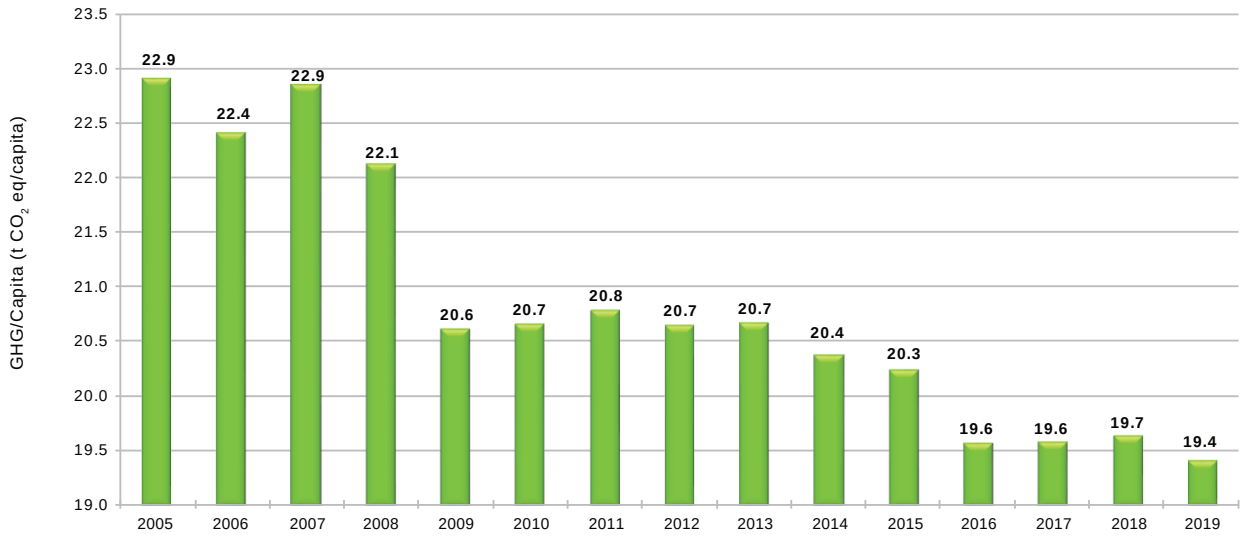
Figure ES–3 **Breakdown of Canada's Emissions by GHG (2019)**



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)**

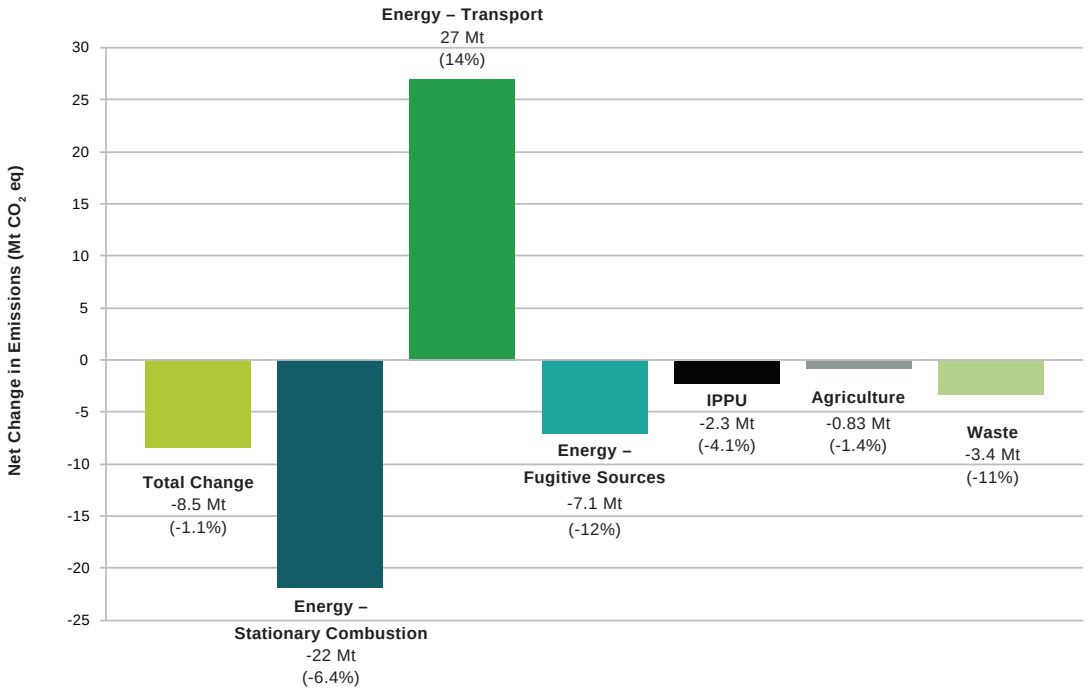


Table ES–2 **Canada's GHG Emissions by Intergovernmental Panel on Climate Change Sector, Selected Years**

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.

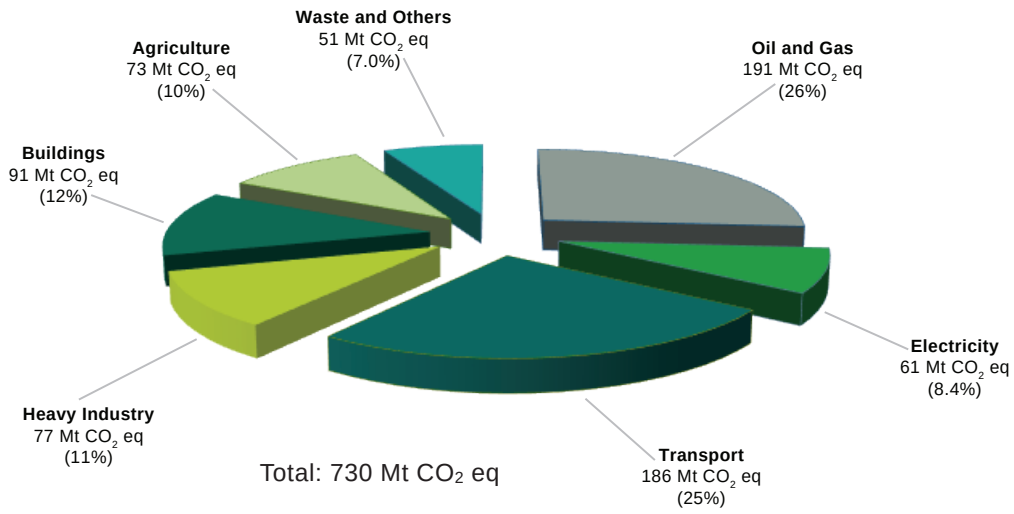
The conversion of forests[8] to other land uses is still a prevalent practice in Canada and is mainly due to resource extraction and cropland expansion. Emissions due to forest conversion in the years 2005 to 2019 have fluctuated around 16 Mt.

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**

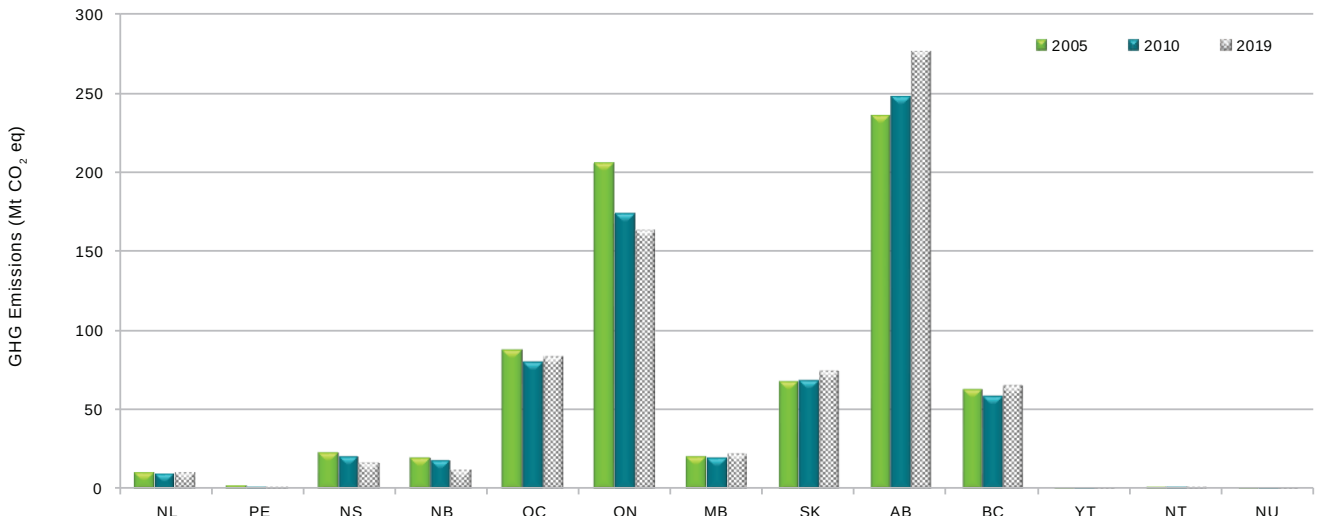


Table ES–4 **GHG Emissions by Province and Territory, Selected Years**

	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.

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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.

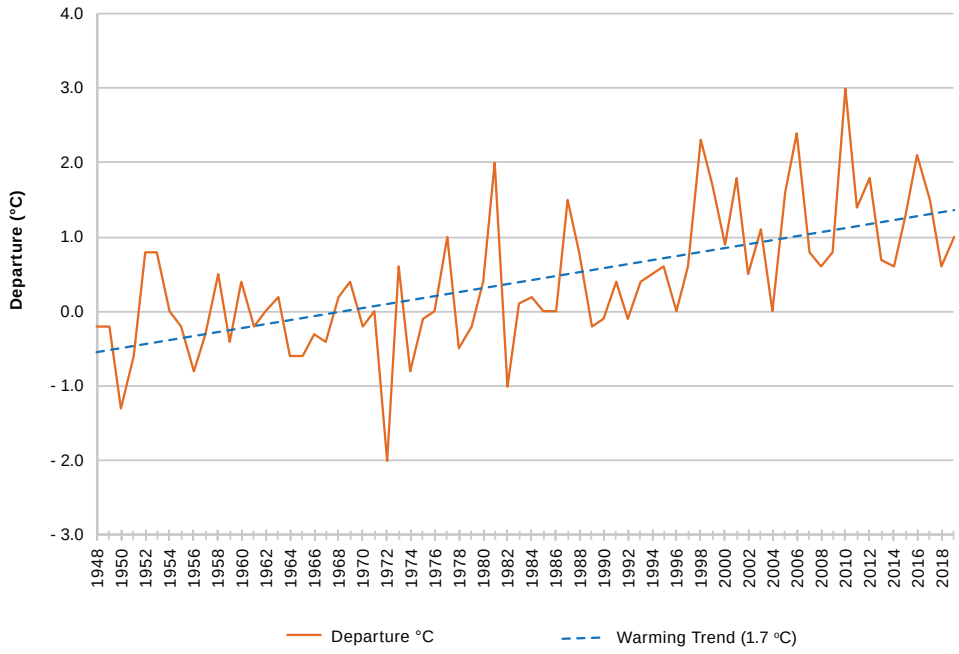
This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the period 1990−2018. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2020 submission to the UNFCCC. The NIR

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-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-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.

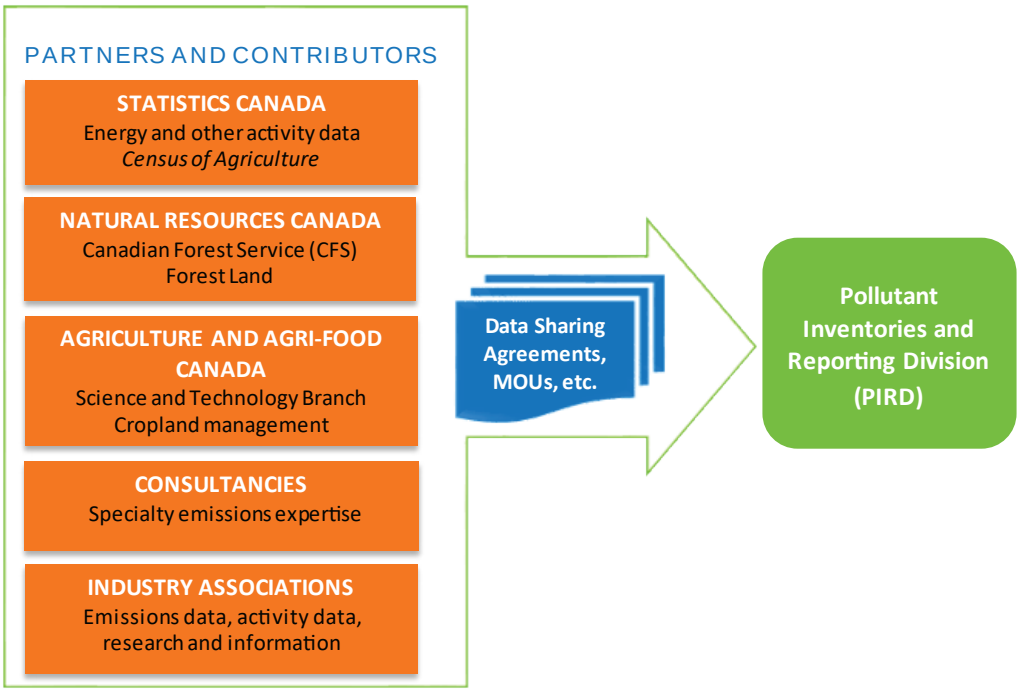
1.2.1.1. Statistics Canada

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

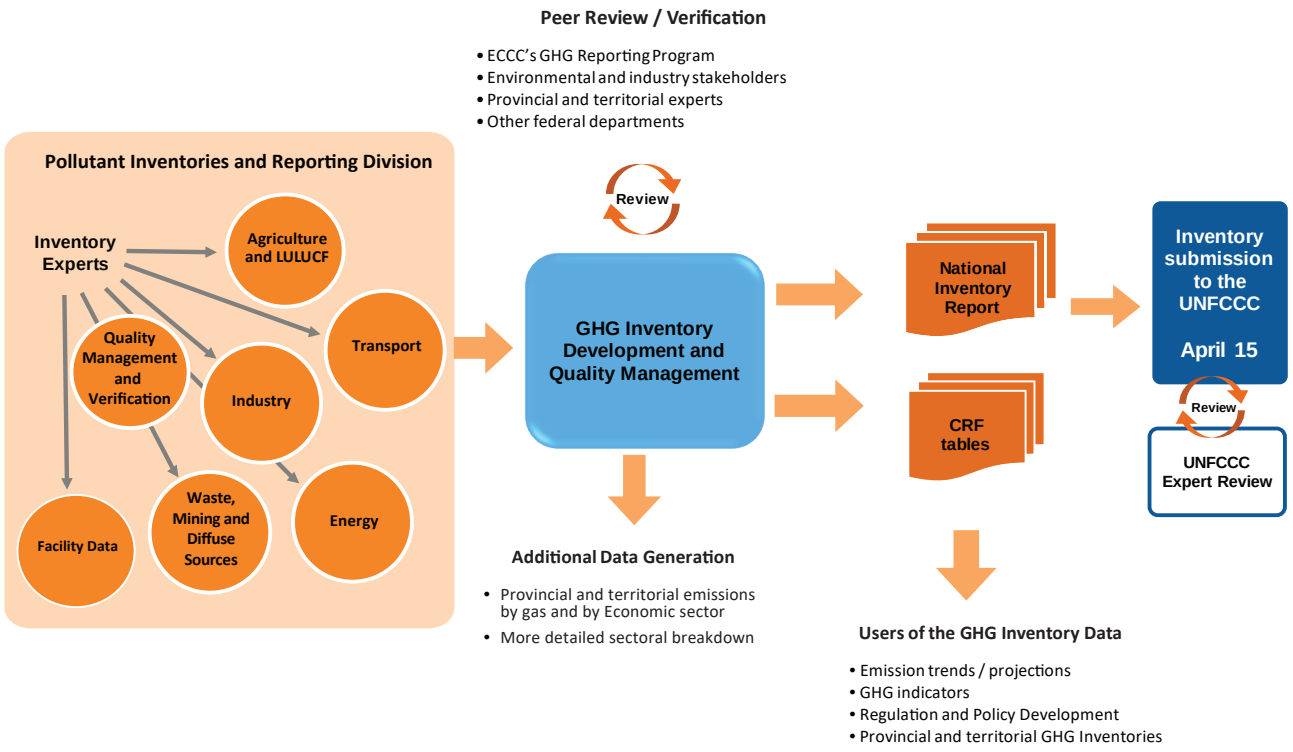
Canada's inventory is developed, compiled and reported annually by ECCC's Pollutant Inventories and Reporting Division, with input from numerous experts and scientists across Canada. Figure 1–3 identifies the various stages of the inventory preparation process.

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.

1.3.2.2. 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).

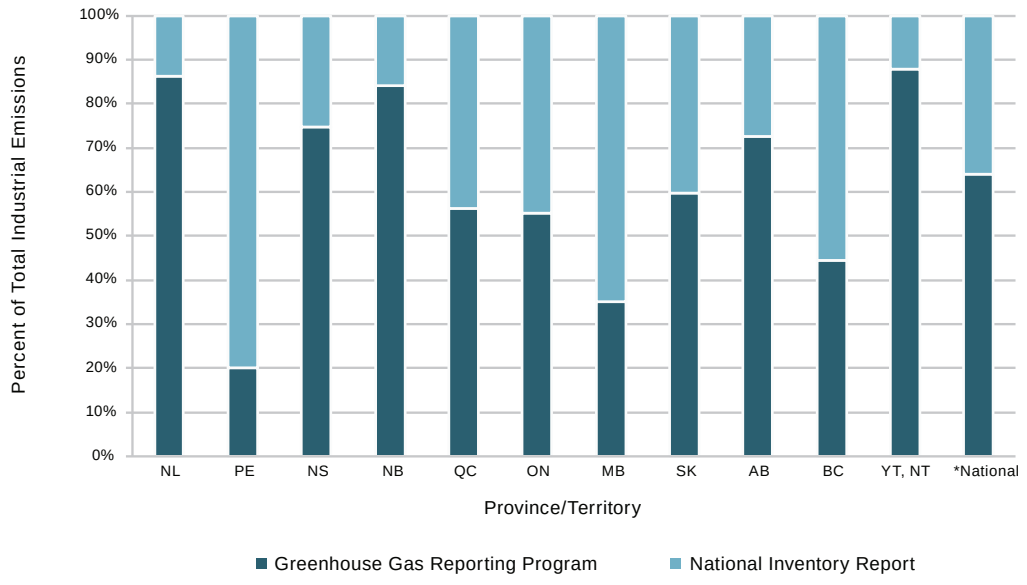
It is important to note that the GHGRP applies to specific emission sources that exist at facilities and does not cover all sources of GHG emissions (e.g., road transportation, combustion of fuels from residential sources, and agricultural sources), whereas the NIR is a complete accounting of all GHG 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

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).

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.

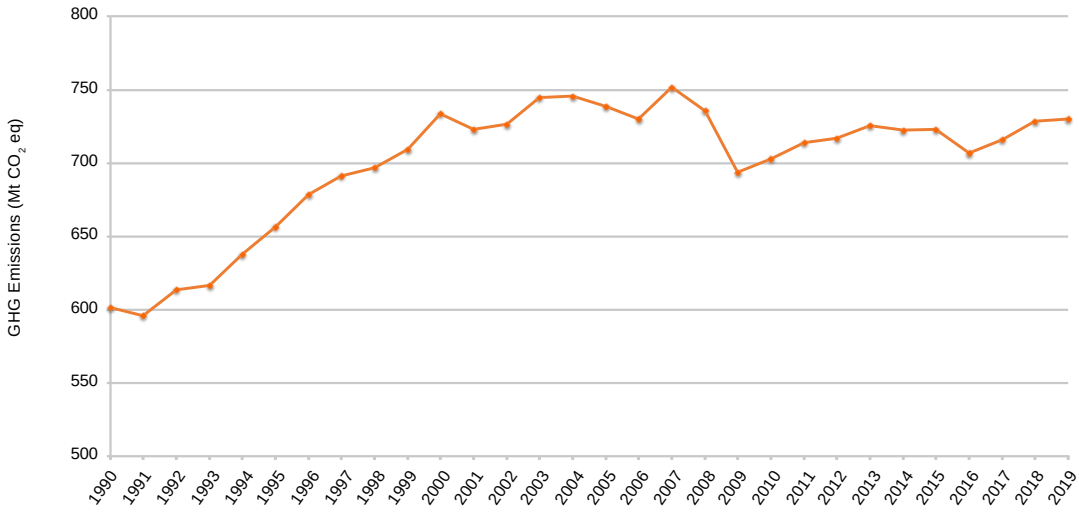
Over the long term, Canada's economy has grown more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (or GHGs per Gross Domestic Product [GDP]) has declined by 37% since 1990, and by 23% since 2005 (Table 2–1). The decline in emissions intensity since 1995 (Figure 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)**



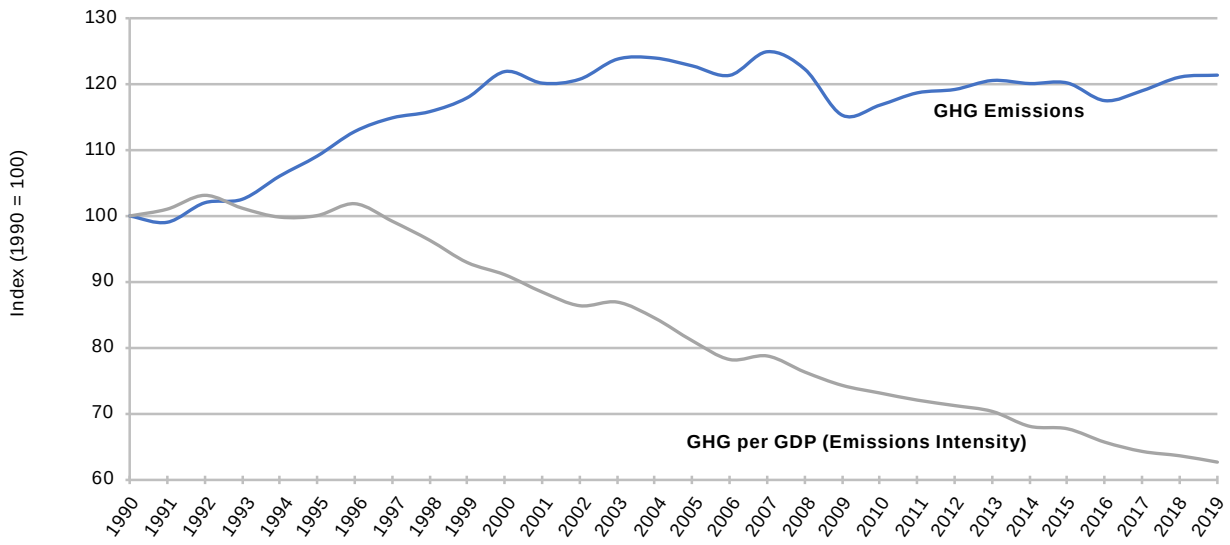
2.1.1. Provincial and Territorial GHG Emissions Trends

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%

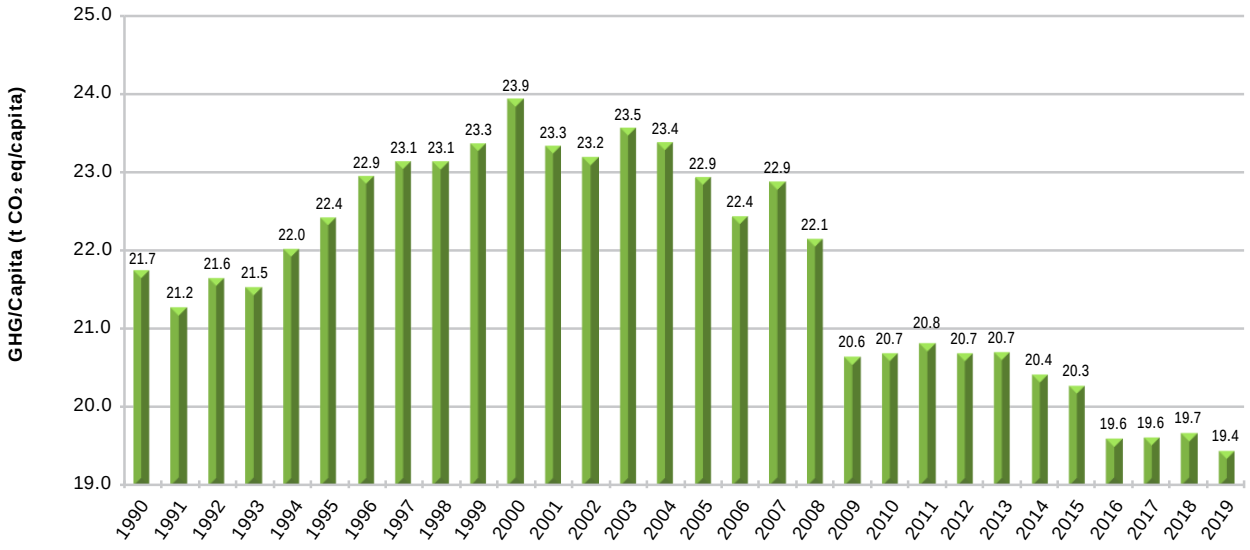
Notes:

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**

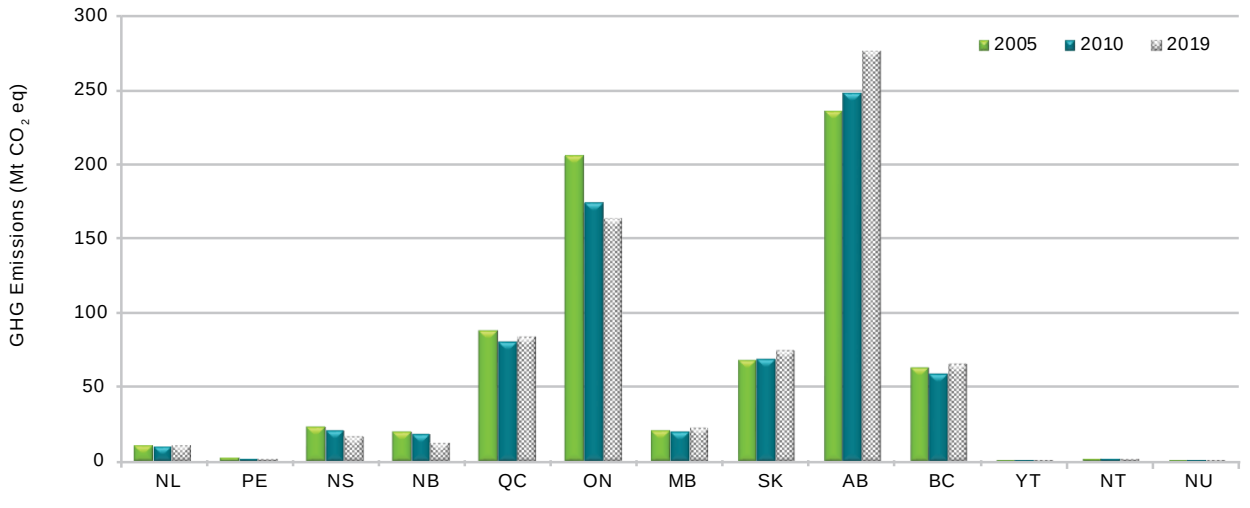


Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

	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

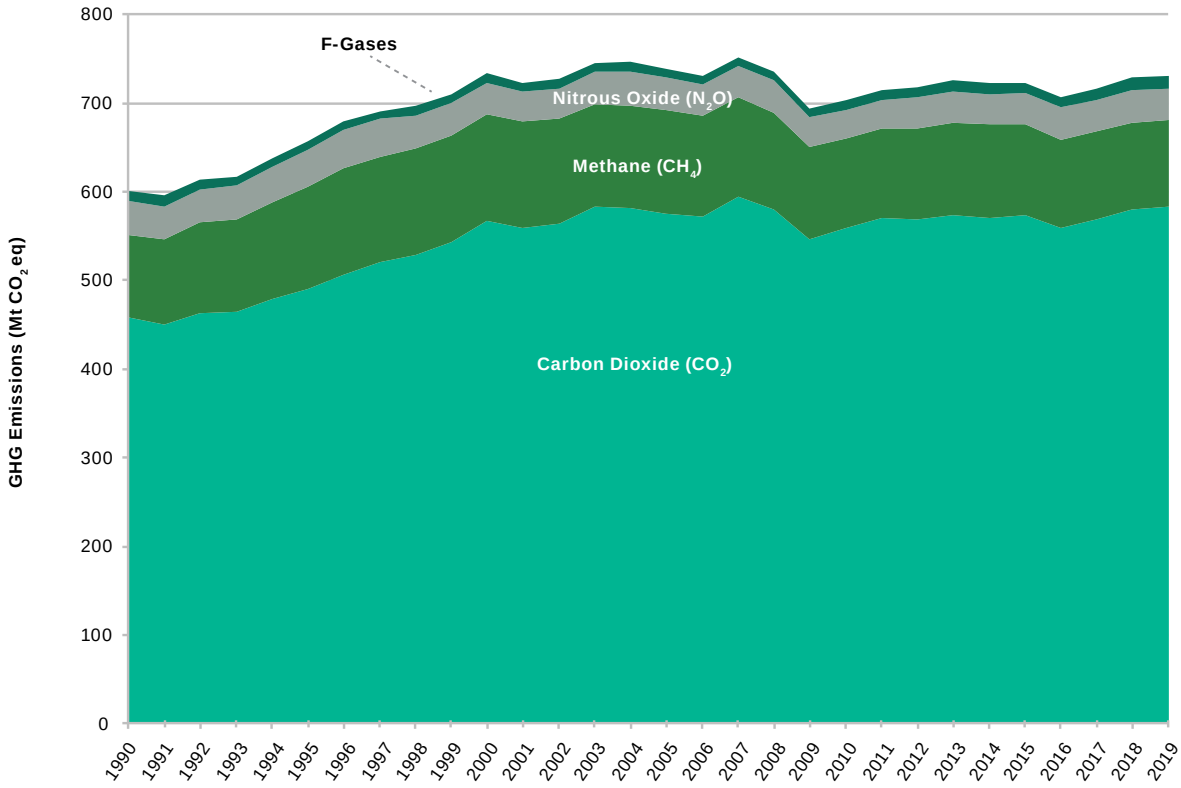
Canada's GHG emissions profile is similar to that of most industrialized countries in that carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions, accounting for 582 Mt (80% of total emissions) in 2019. As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions.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

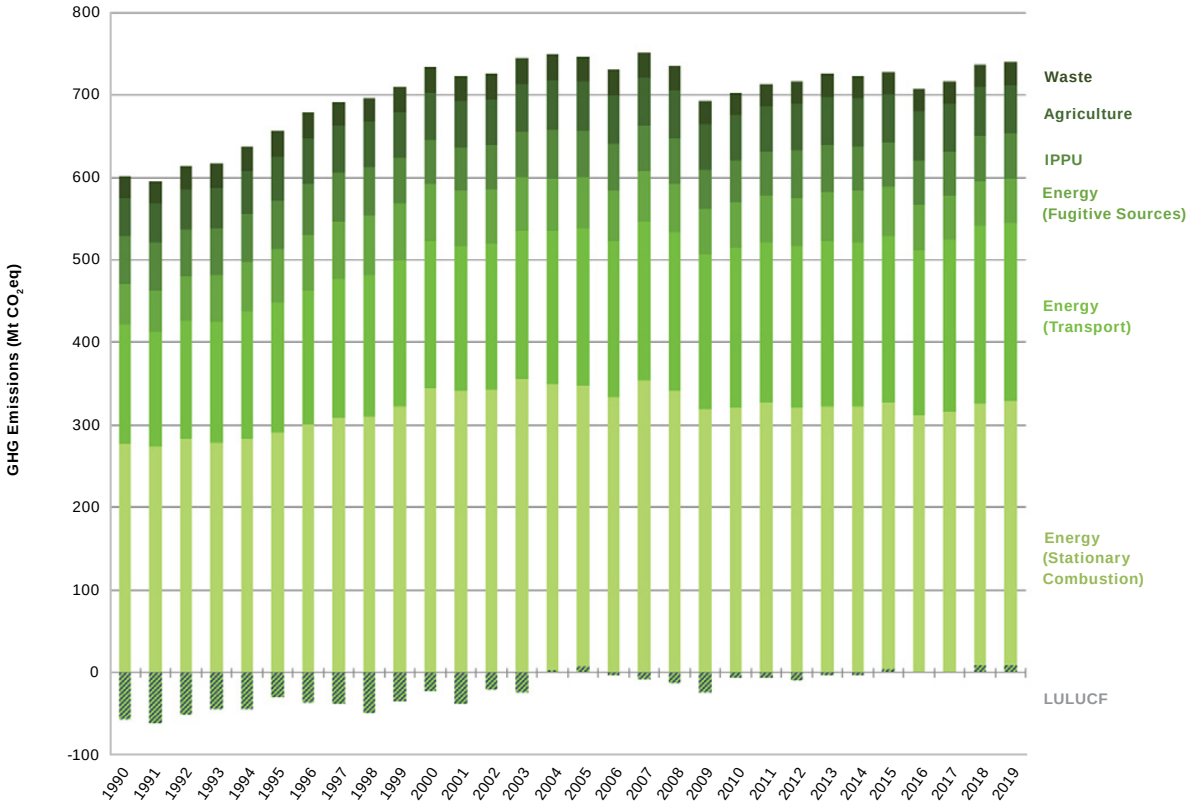
The Energy sector dominated the long-term trend over the 1990–2019 period, with increases of 72 Mt (50%) in Transport, 41 Mt (15%) in Stationary Combustion and 4.9 Mt (10%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 12 Mt (26%), while the IPPU sector saw 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)**

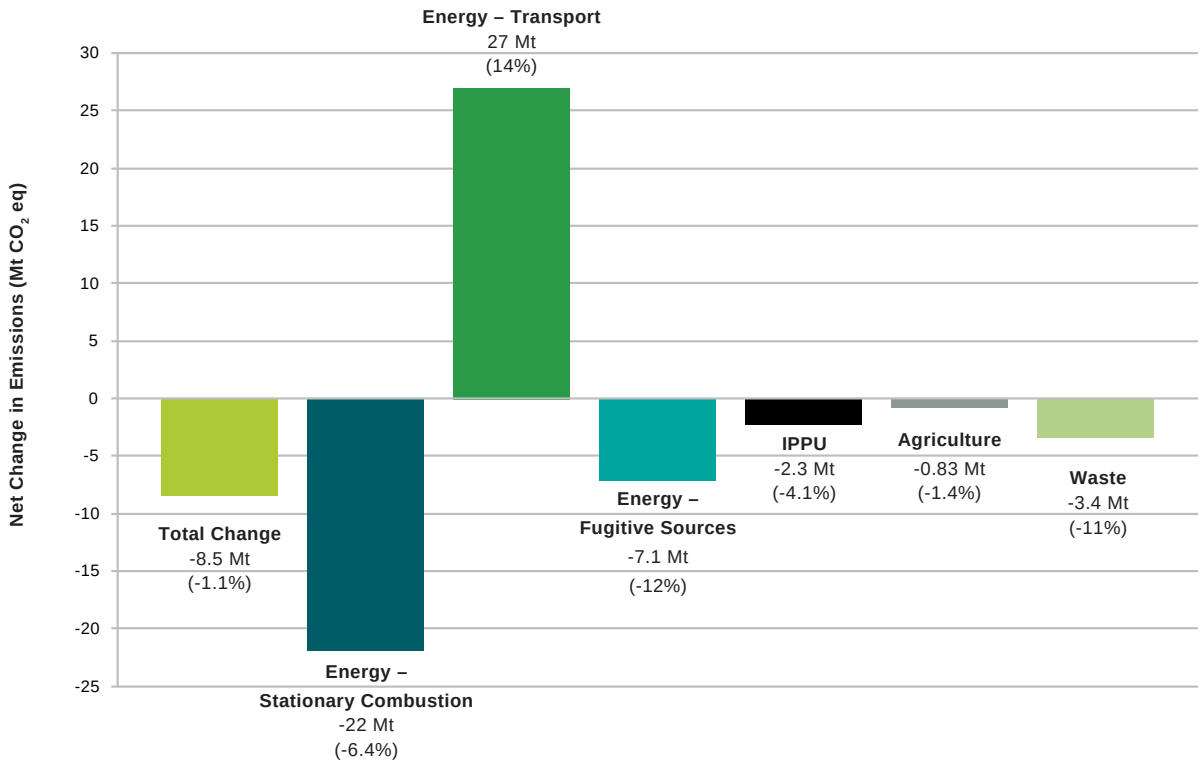
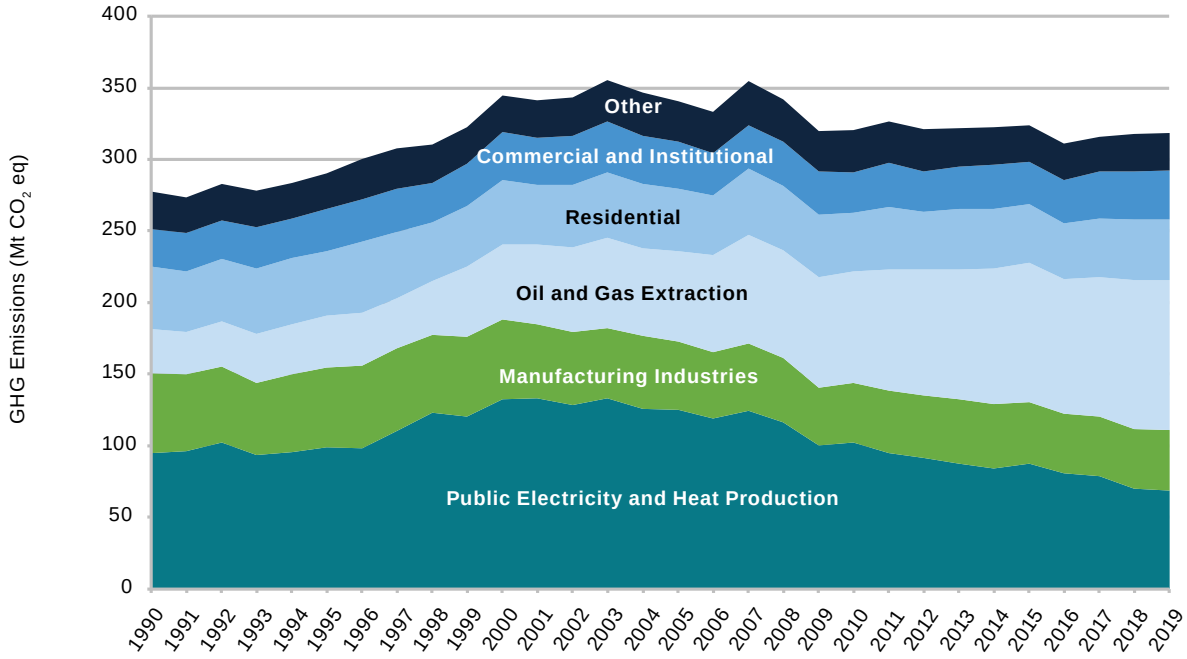


Table 2–4 **GHG Emissions from Stationary Combustion Sources, Selected Years**

	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)**

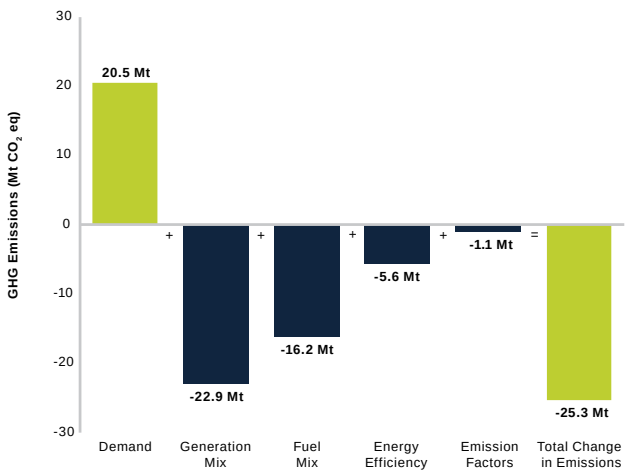
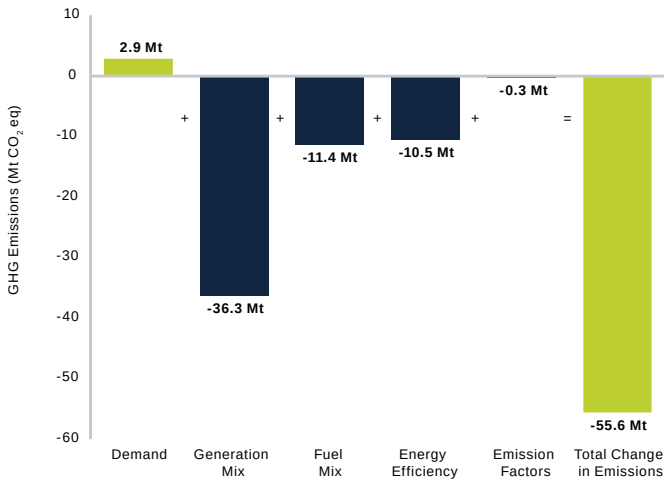


Figure 2–10 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2019 (Mt CO_2 eq)**



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**

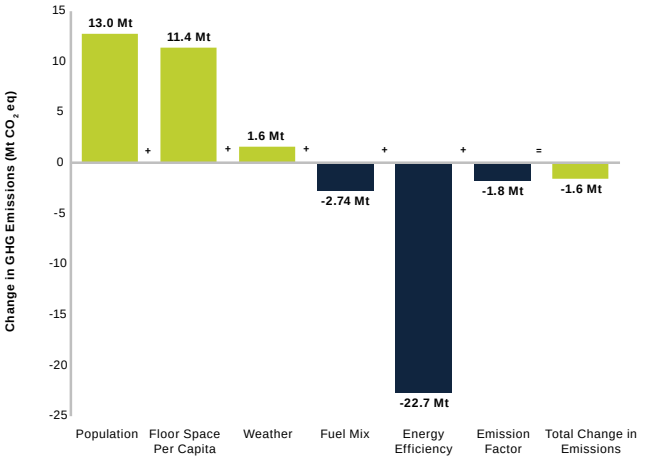
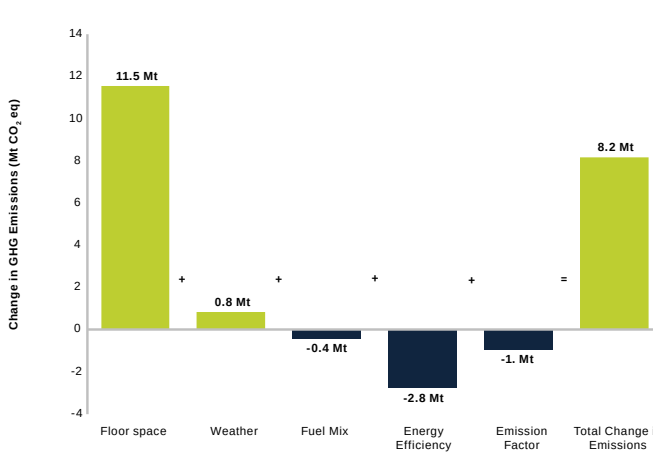


Figure 2–12 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Subcategory between 1990 and 2019**



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.

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.

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.

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**

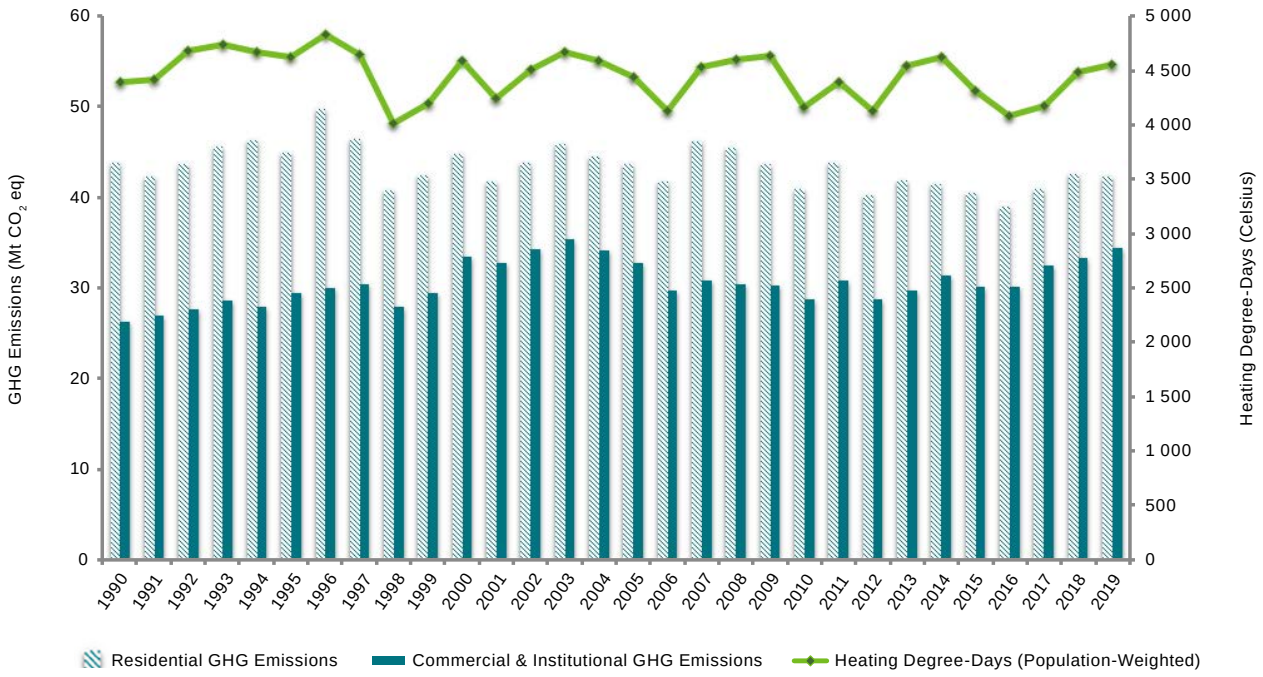
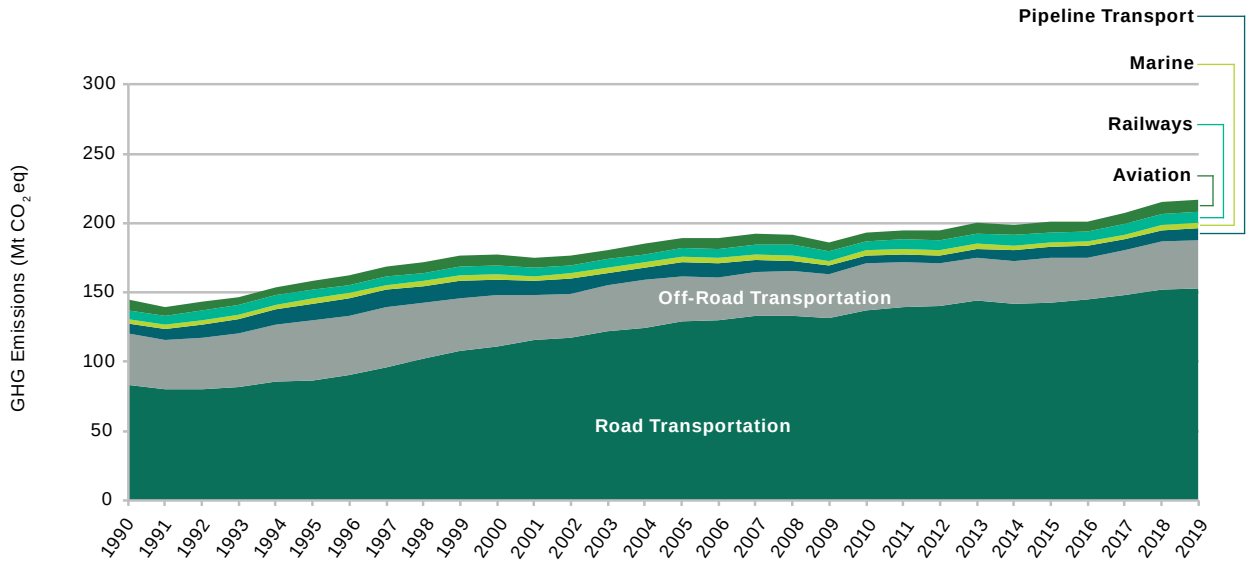


Figure 2–14 **Trends in Canadian GHG Emissions from Transport (1990–2019)**



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,

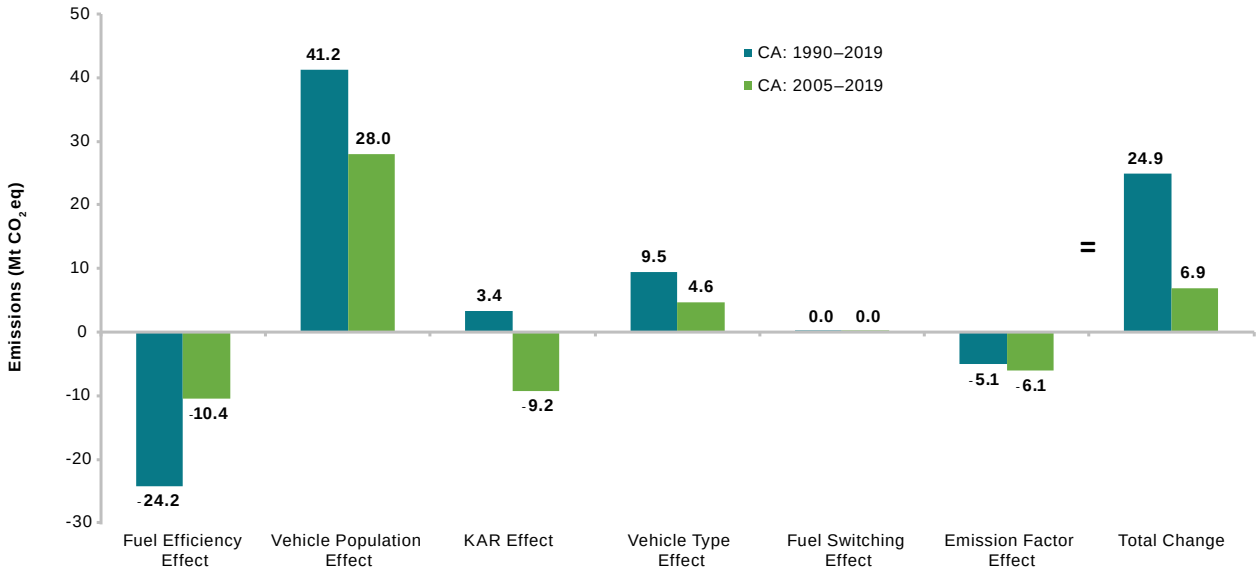
Table 2–6 **Trends in Vehicle Populations for Canada, 1990–2019**

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.

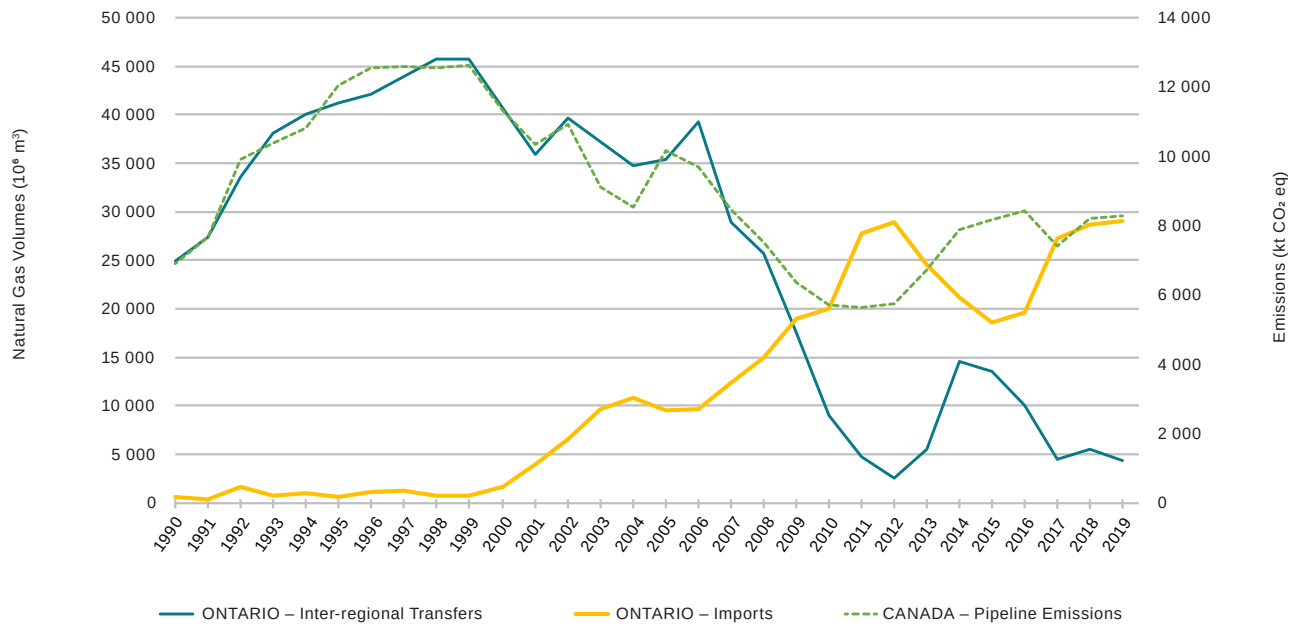
mining and logging industries; agricultural tractors and combines; recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment such as lawnmowers and trimmers. In 2019, off-road manufacturing, mining and construction and off-road agriculture and forestry account 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.

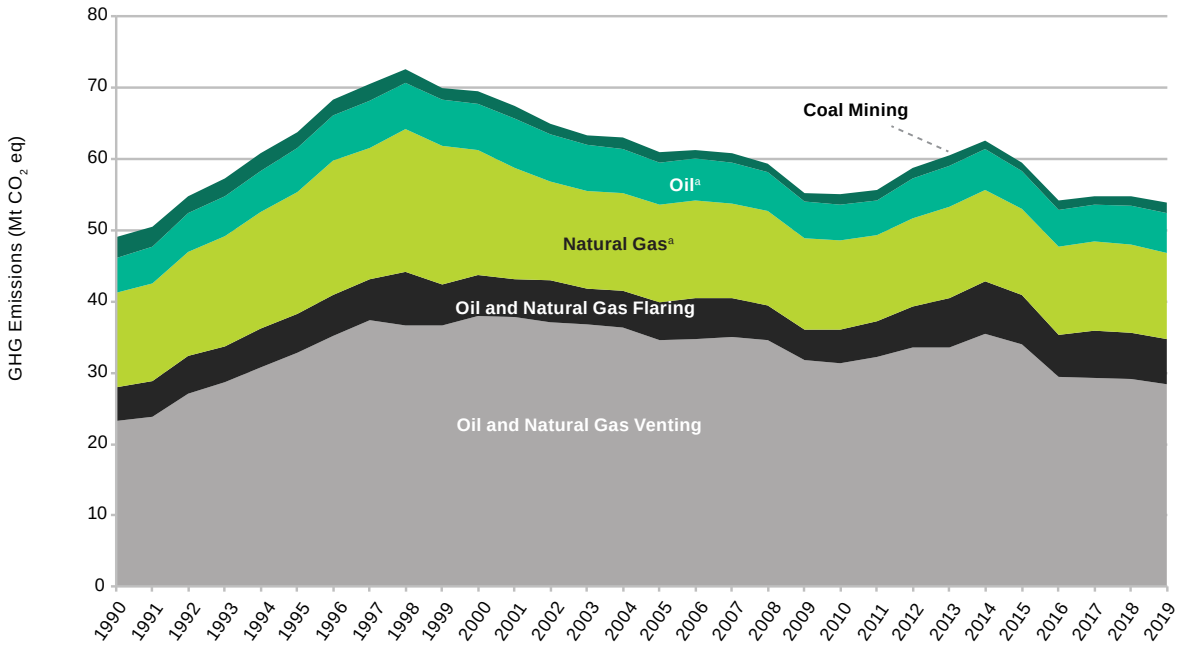
The 14% growth in Oil and Natural Gas fugitive emissions since 1990 (Figure 2–17) is a result of increased activity in the Oil and Gas sector. Since 1990, over 408,000 oil and gas wells have been drilled, and the number of producing oil and gas wells has increased by 180% (CAPP, 2020). As the number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

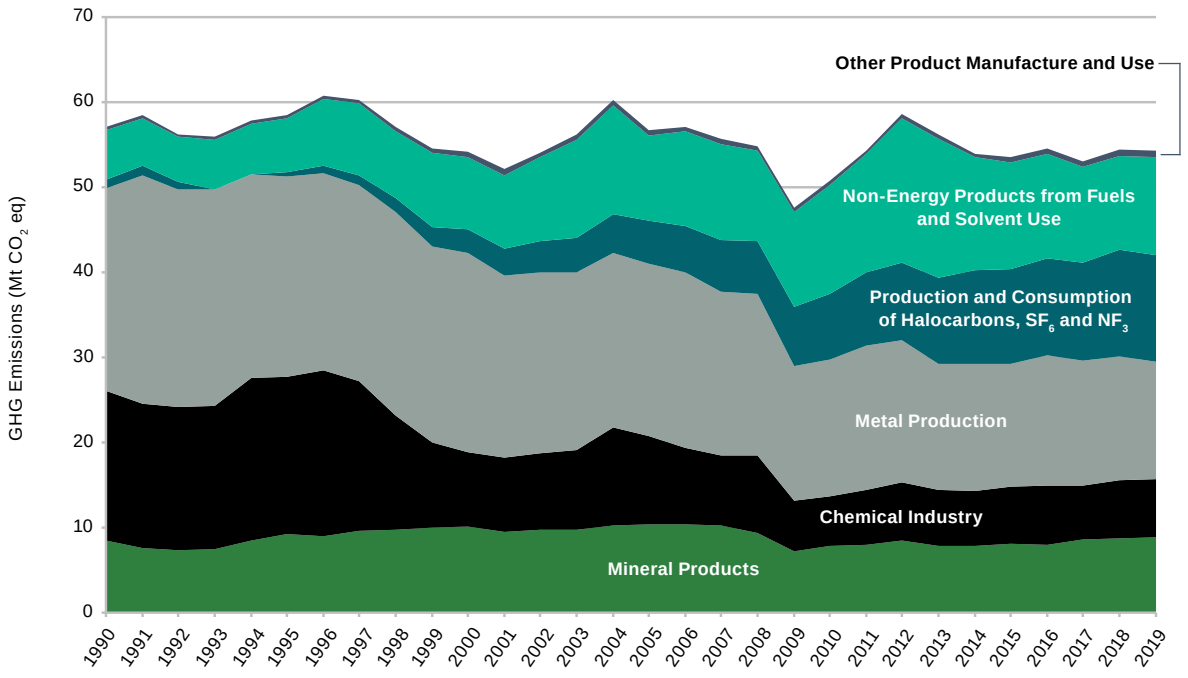


Table 2–8 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**

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.

2.3.2.5. 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)**

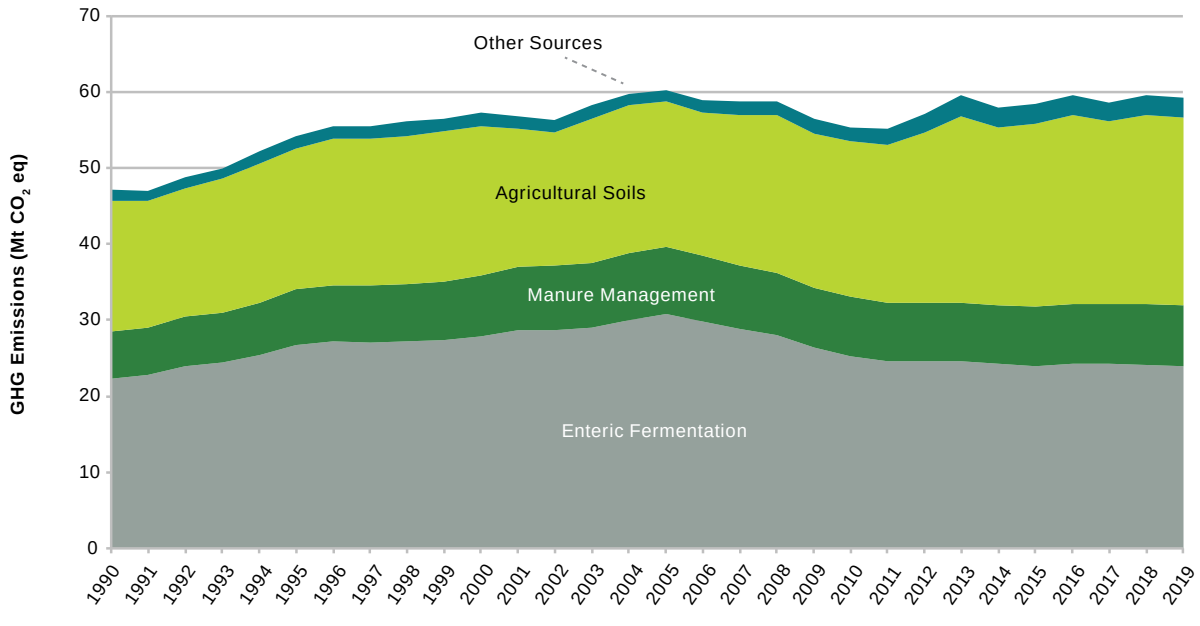


Table 2–9 **GHG Emissions from Agriculture, Selected Years**

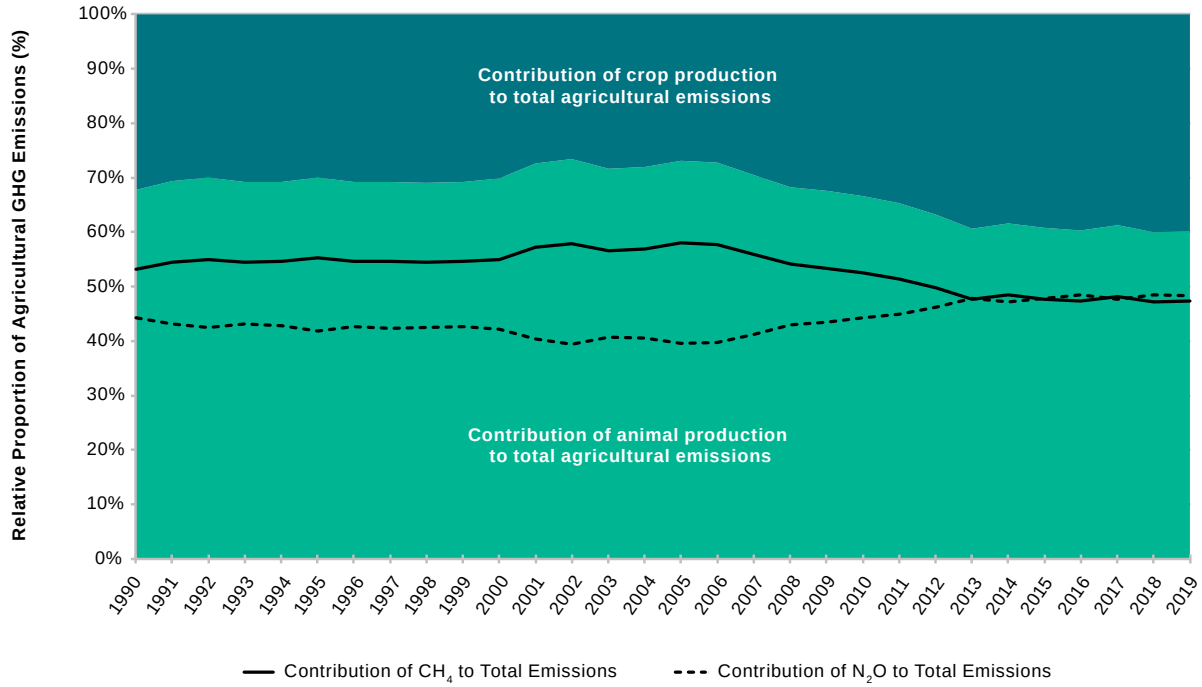
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2014	2015	2016	2017	2018	2019	1990–2019	2005–2019
Agriculture	**47**	**60**	**58**	**58**	**59**	**58**	**59**	**59**	**26%**	**-1%**
Enteric Fermentation	22	31	24	24	24	24	24	24	7%	-22%
Manure Management	6.1	8.8	7.7	7.8	7.9	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)

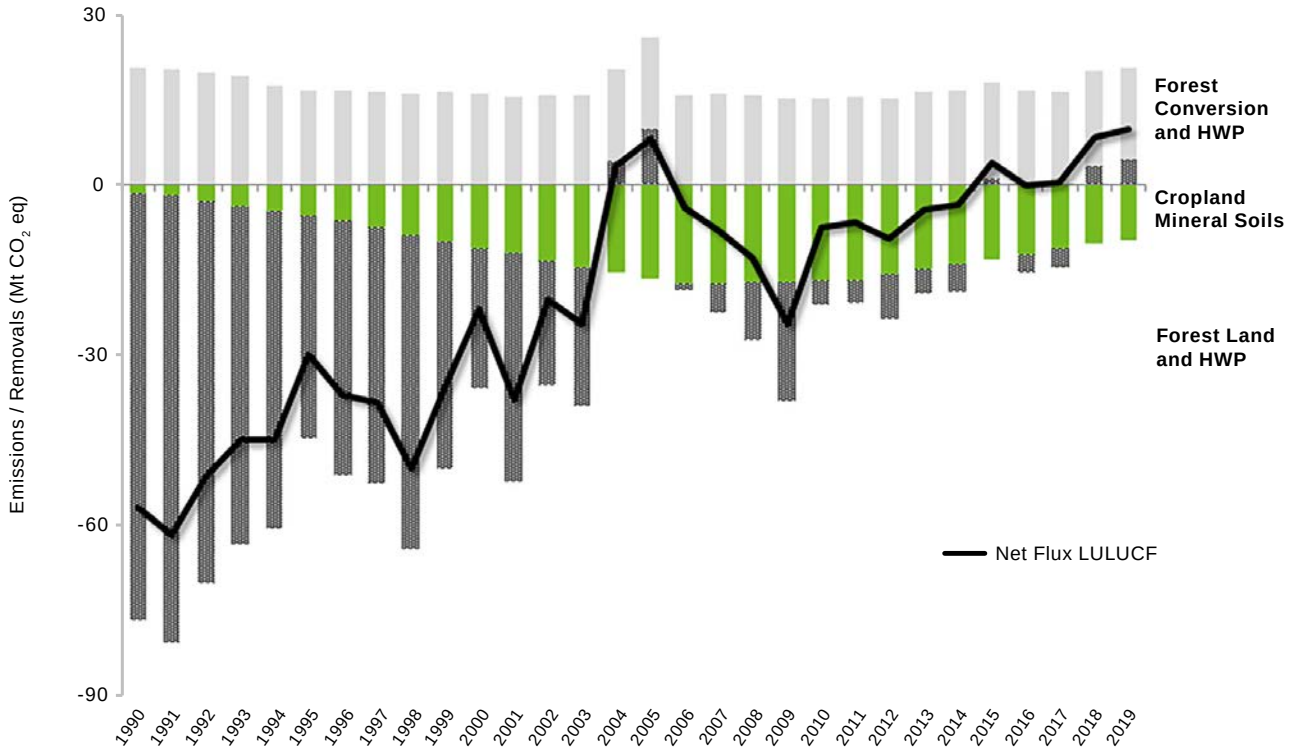
The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products (HWP) originating from domestic harvest. The total net flux from managed forests and resulting HWP amounted to an estimated 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.

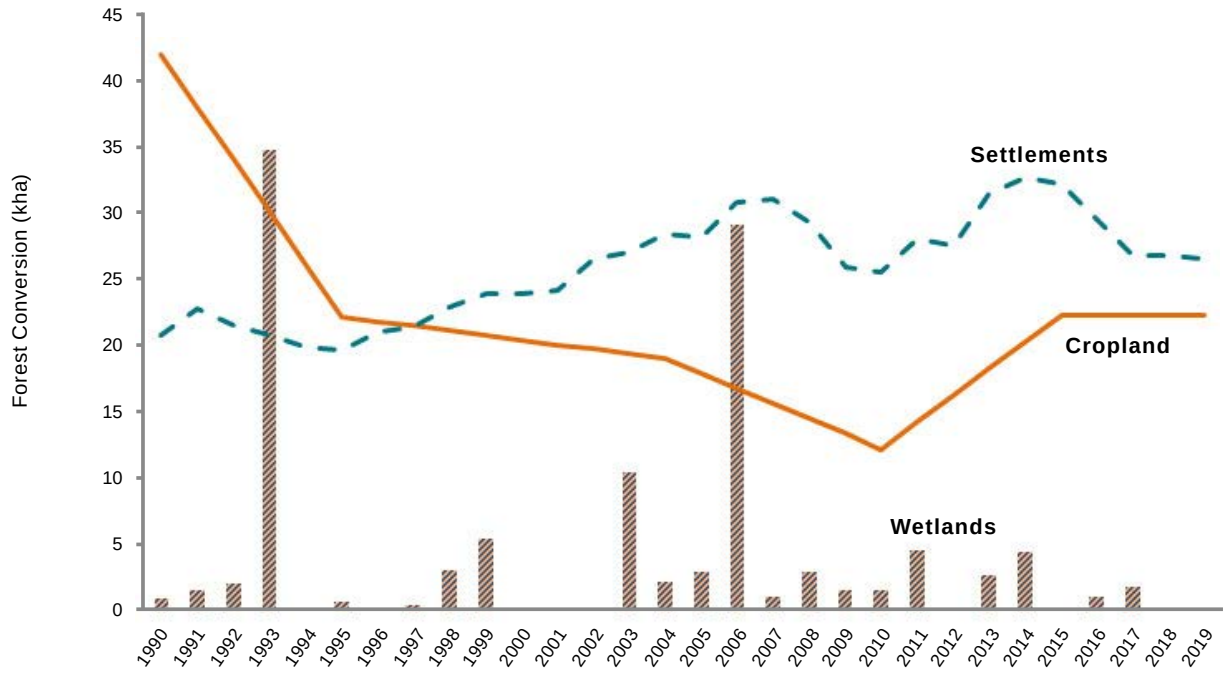
The conversion of forests to other land use is still a prevalent practice in Canada; it is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. Since 1990, 1.5 million hectares of forest have been converted to other 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)**

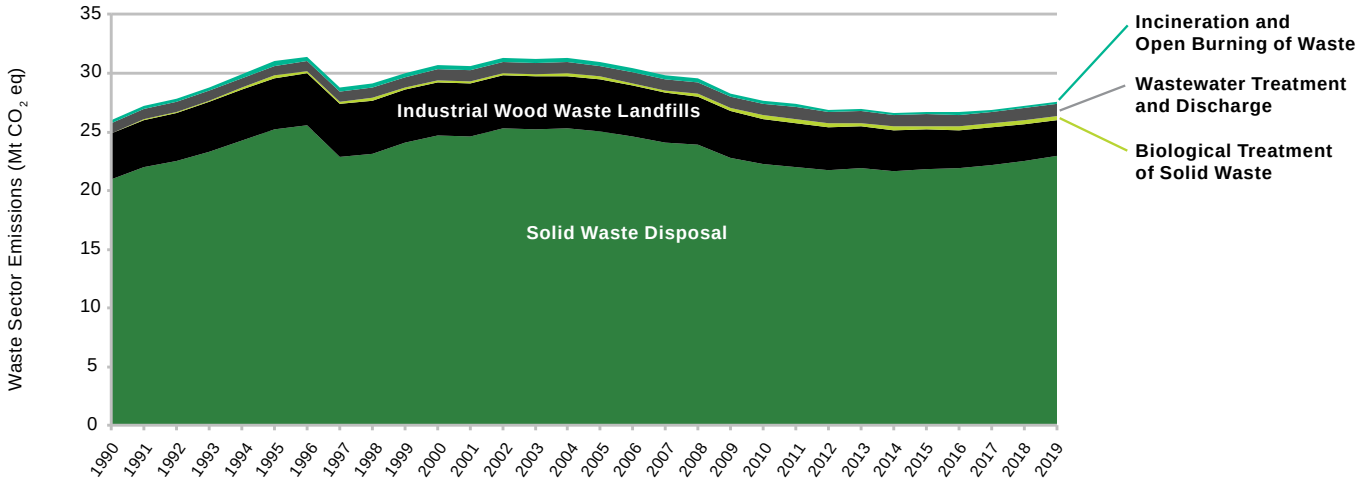
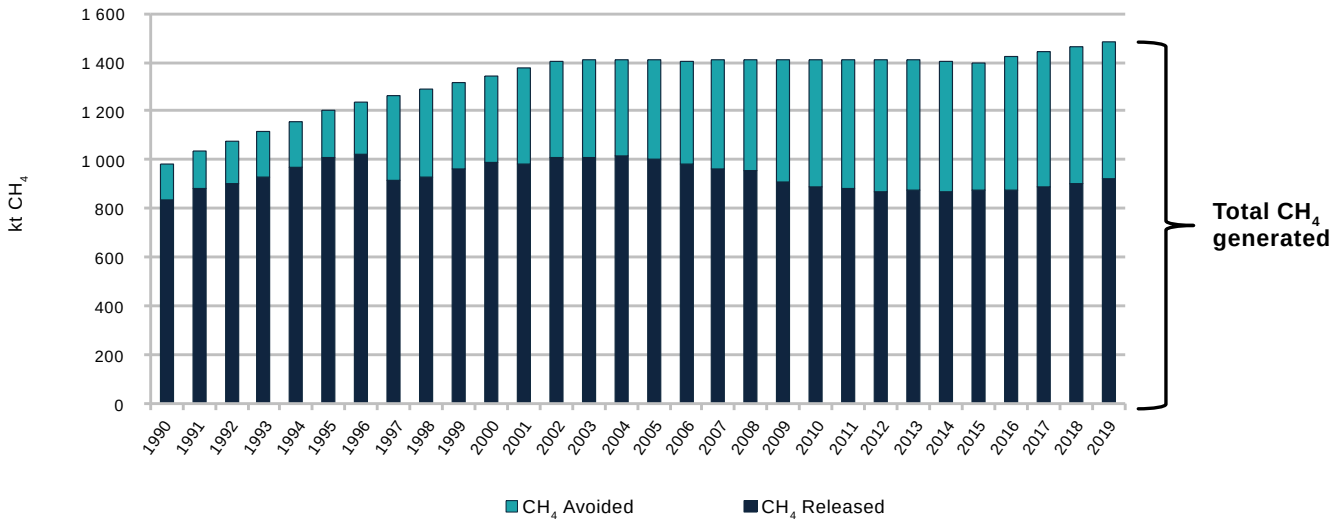


Table 2–11 **GHG Emissions from Waste, Selected Years**

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

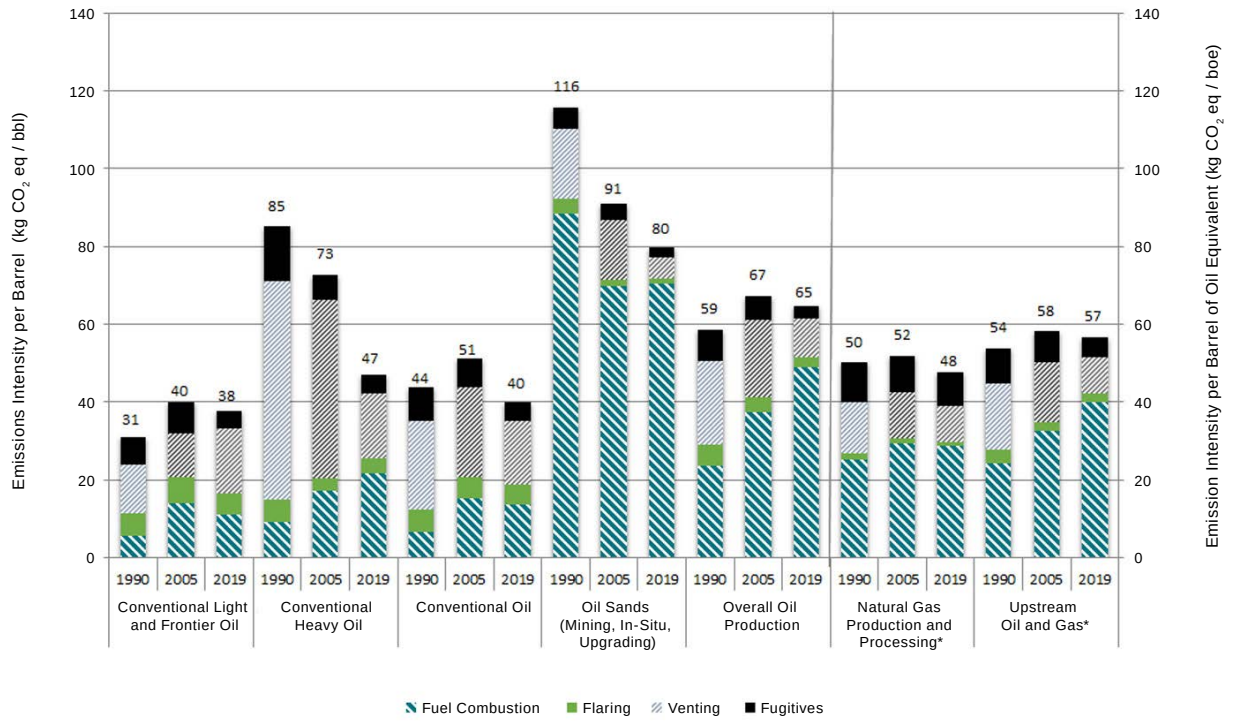
From 1990 to 2019, the production of total crude oil increased by 174% (StatCan, n.d.[c], n.d.[d]). The increase was driven almost entirely by Canada's oil sands operations, which accounted for 96% of total production growth. Total oil sands output (non-upgraded bitumen and synthetic crude oil production) 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%.

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.

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

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

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.
- 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.

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.

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.

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

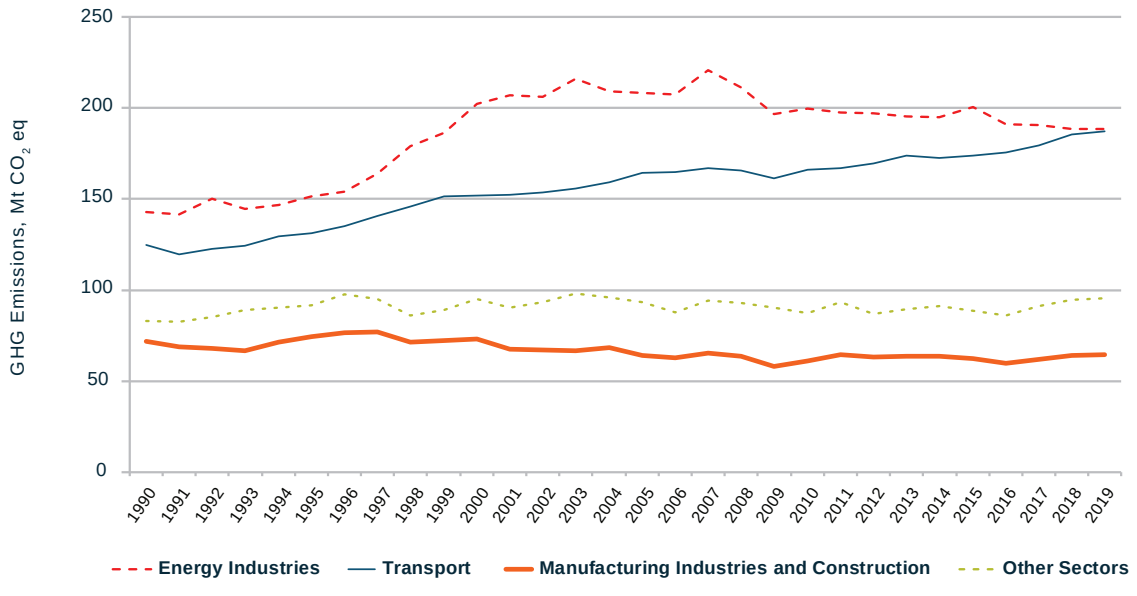
Emissions from fuels used for international navigation and international aviation are reported separately under the memo item International Bunkers, following 2006 IPCC Guidelines and UNFCCC reporting guidance.

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.

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.

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.

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

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)

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**

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.

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

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

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

$$CO_2 \text{ emissions} = EF_{cl} \times M_{cl} \times CF_{ckd} + EF_{toc} \times M_{cl}$$

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.

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),

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).

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.

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_i) 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/

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 predominance 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

$$\textit{Total Emissions } (t) = \textit{N}_2\textit{O Emissions } (t) \textit{ with abator} + \textit{N}_2\textit{O Emissions } (t) \textit{ without abator}$$

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.

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

$$\text{Total } CH_4 \text{ emissions (t)} = \sum^{y} [(\boldsymbol{SiC\ capacity} \times \boldsymbol{capacity\ utilization} \times \boldsymbol{Emission\ Factor\_SiC}) + (\boldsymbol{CaC_2\ capacity} \times \boldsymbol{capacity\ Emission\ Factor\_CaC_2})]$$

$\boldsymbol{y}$	=	companies
$\boldsymbol{SiC\ or\ CaC_2\ capacity}$	=	data collected from the industry, kt
$\boldsymbol{Capacity\ utilization}$	=	based on Cheminfo Services' knowledge of the industry, %
$\boldsymbol{Emission\ Factor\_SiC}$	=	see Annex 6
$\boldsymbol{Emission\ Factor\_CaC_2}$	=	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.

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.

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

$$E_{SC,PFC} = E_{FC} + E_{CF4} + E_{C2F6}$$

$E_{SC,PFC}$	=	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.

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.

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.

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.

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).

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.

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.

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.

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.

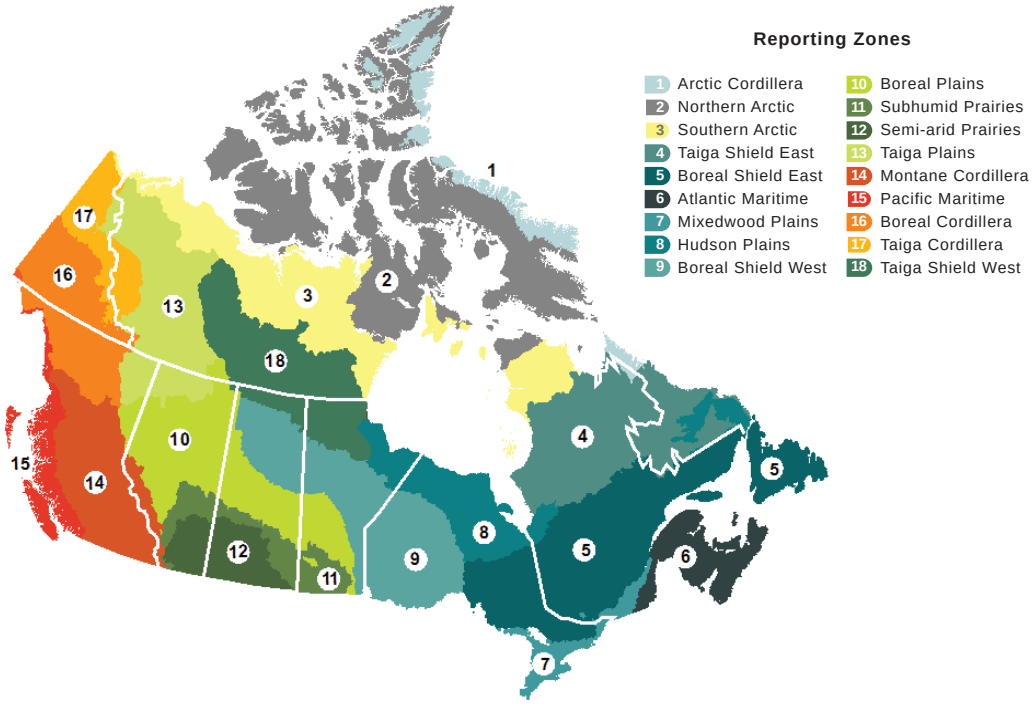
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRF Tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

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**



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.

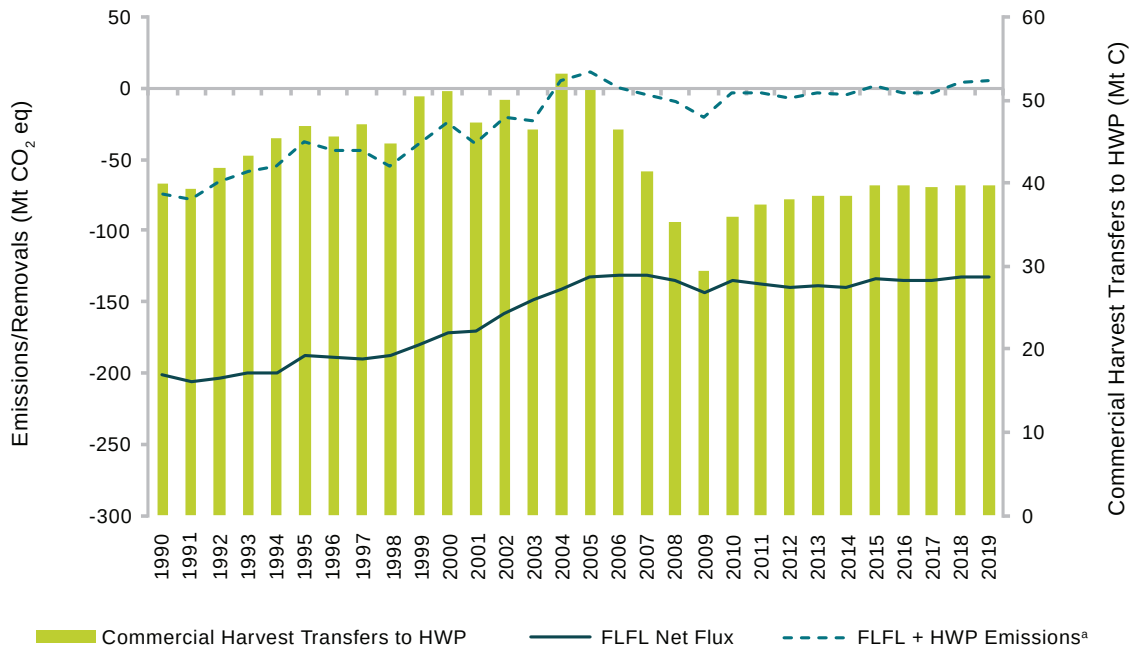
e. Immediate emissions include direct and indirect CO_2 and direct non-CO_2 emissions resulting from the immediate impact of wildfires. Post-wildfire CO_2 emissions are associated with the long-term effect of wildfires on dead and soil organic matter; they include small emissions associated with insect 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

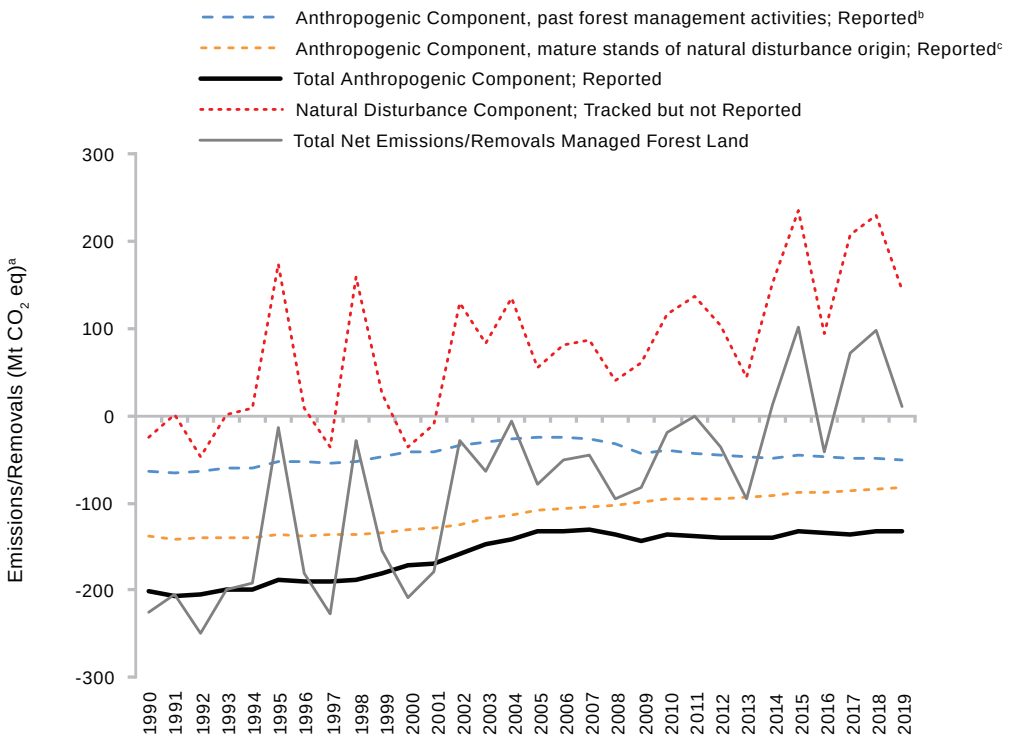
Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, or CBM-CFS3) (Kull et al., 2019; Kurz et al., 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

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.

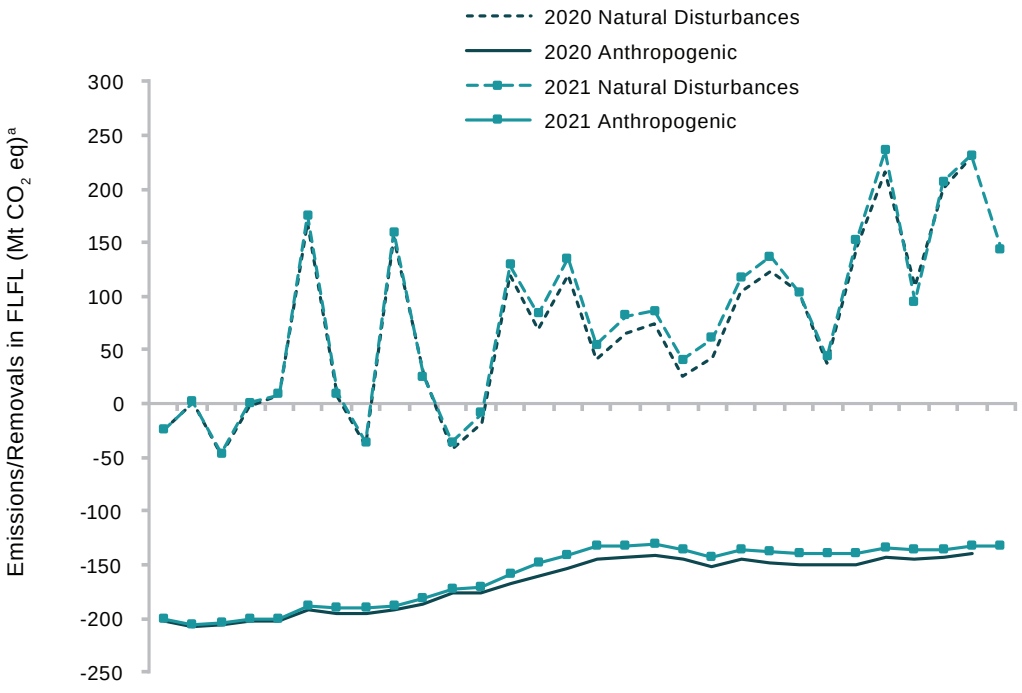
Other less significant recalculations were due to corrections to volume-to-biomass conversion parameters for areas of Western Canada following an external quality control review, implementation of a new measurement period for forest conversion activities from 2013 to 2018, and a revision to forest drainage 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

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/

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.

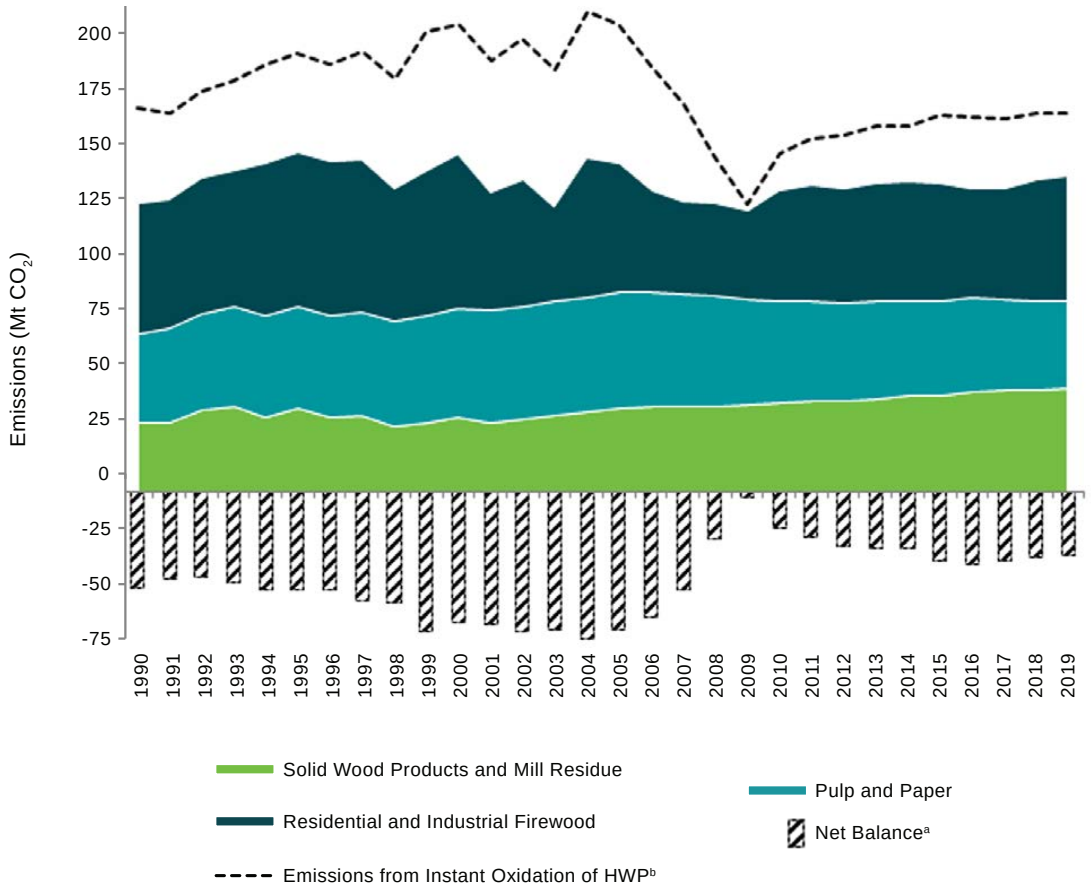
b. Carbon estimated by the CBM-CFS3 model in the form of wood biomass that results from forest harvest (including salvage logging after natural disturbances on Forest Land) and forest conversion activities in Canada and that would be reported as C losses in CRF table 4.A under Forest Land Remaining Forest 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.

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.

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.

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

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.

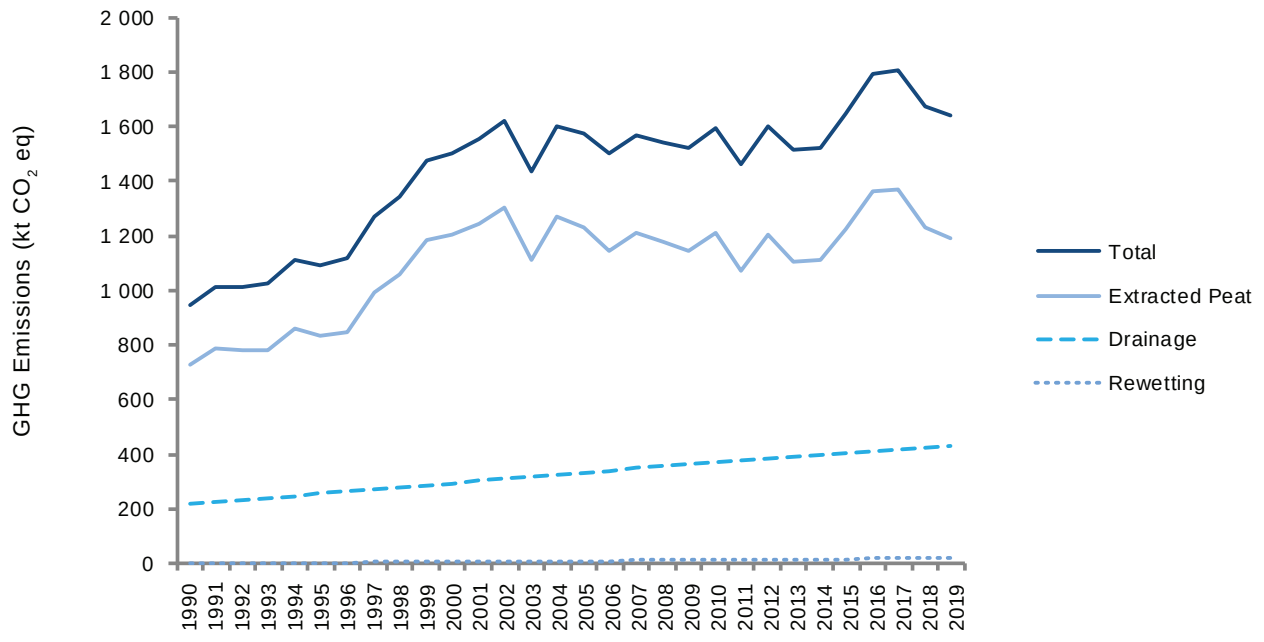
6.7.1.5. Recalculations

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.

6.8.2. 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

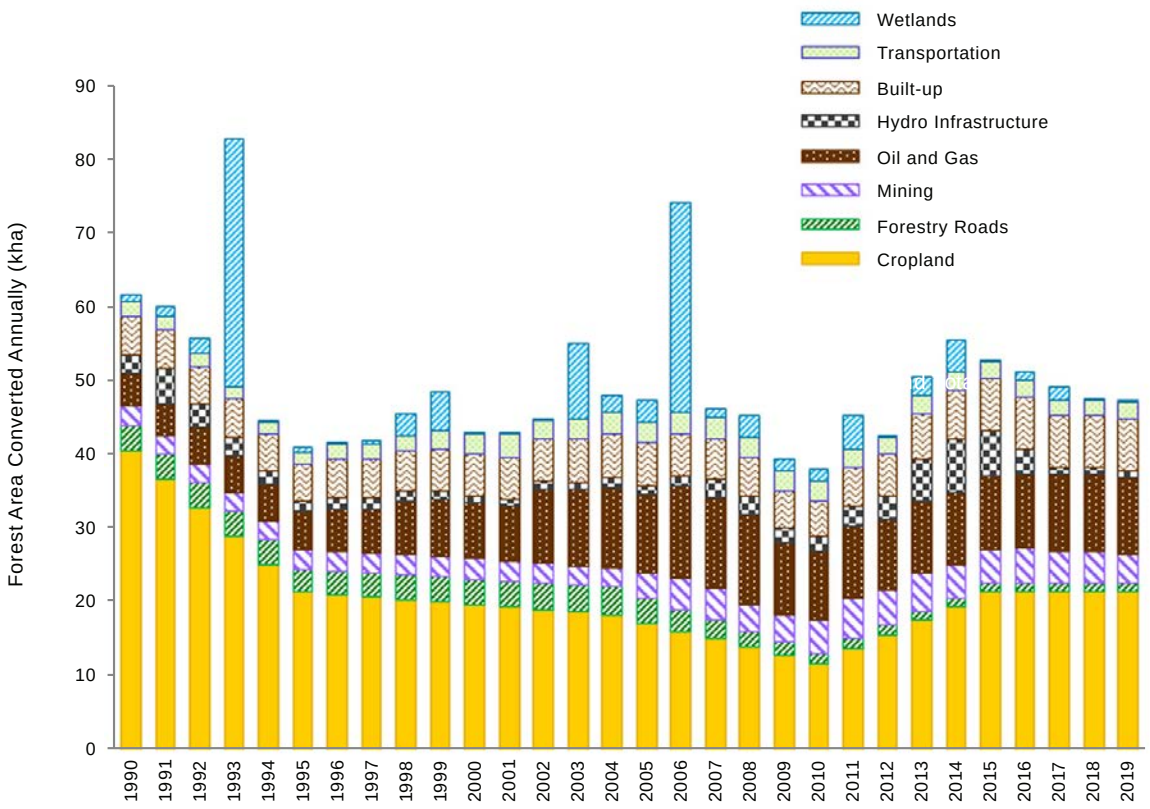
Future efforts to improve estimates for this category will focus on gathering data and compiling domestic science to estimate emissions from the soil pool as well as improving estimates of the pre-conversion above-ground biomass by adjusting the biomass factors used for each reporting zone with image-based 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.

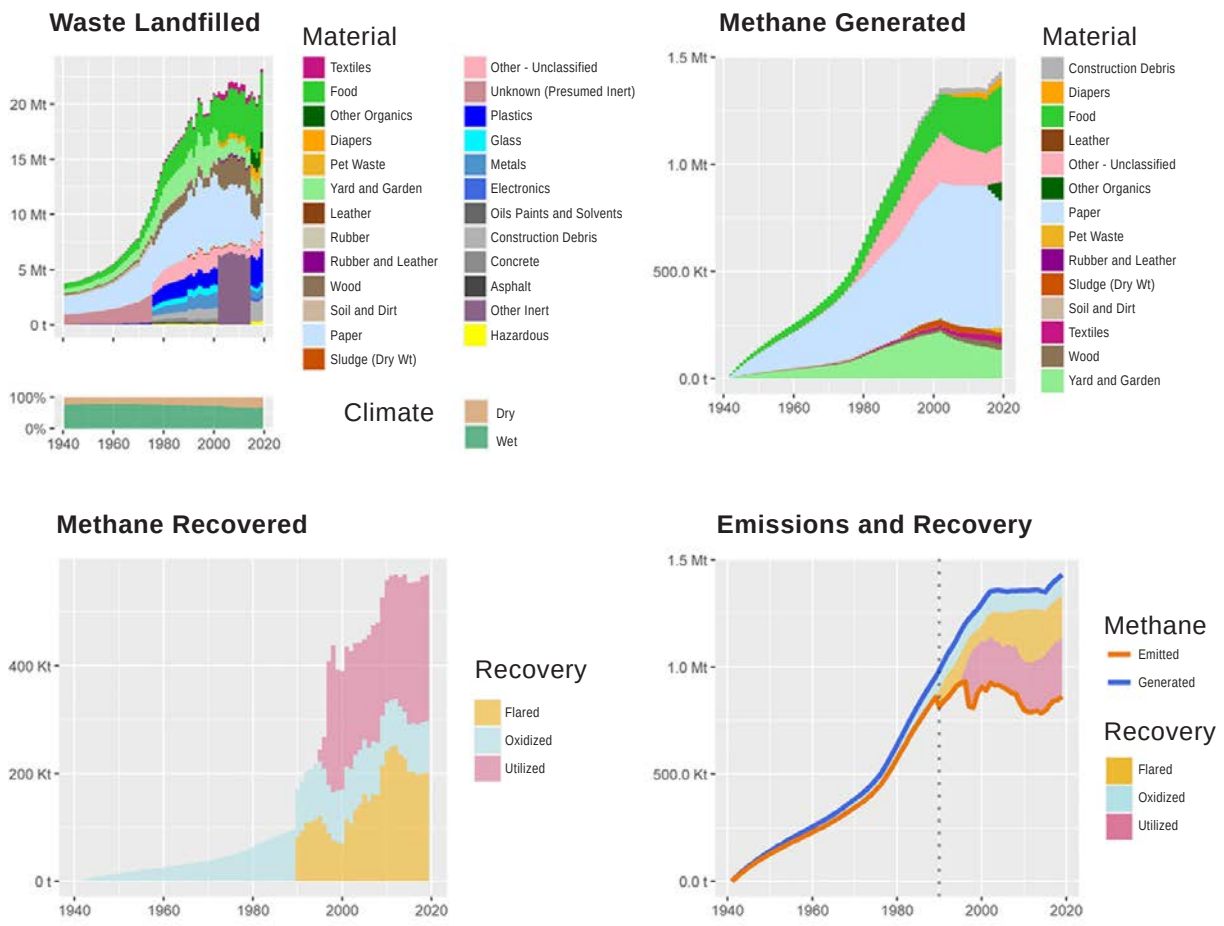
MSW disposal is the dominant contributor of emissions from the Waste sector. This category accounted for 81% of the Waste sector emissions in 1990, 81% in 2005 and 83% of Waste sector emissions in 2019 (Table 7–1).

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).

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)**

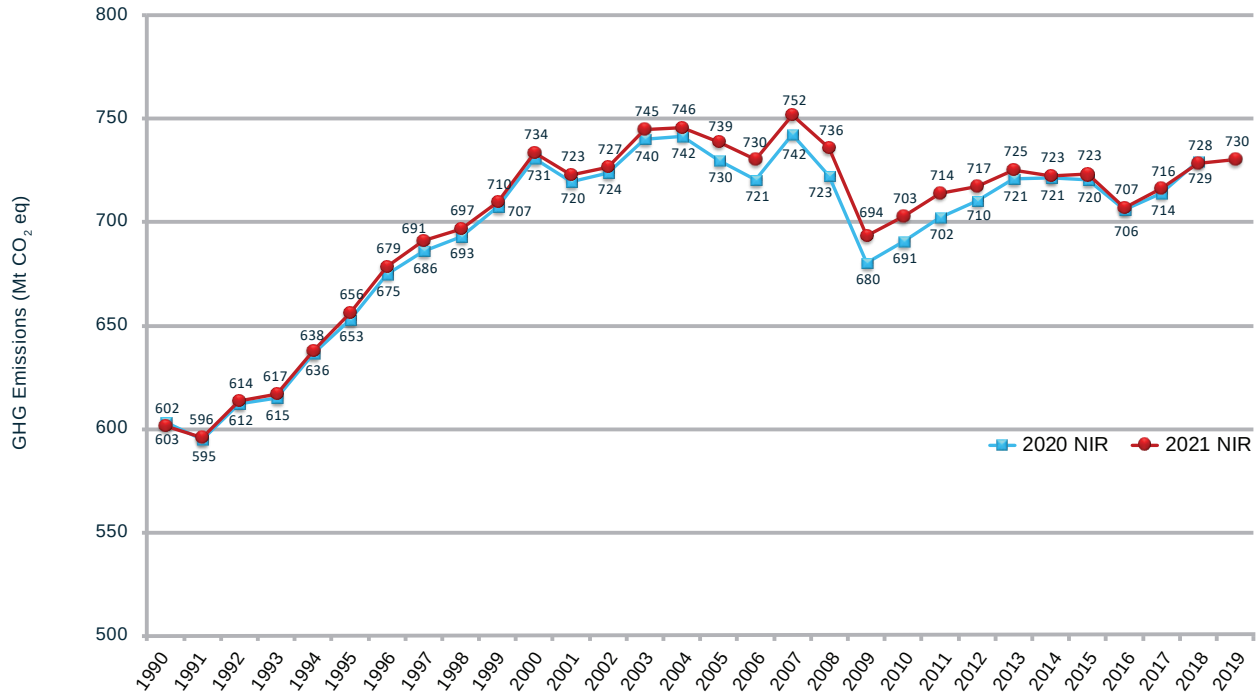


Table 8–1 **Summary of Recalculations in the 2021 National Inventory (excluding Land Use, Land-Use Change and Forestry)**

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 (excluing 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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