TECHNOLOGY INVESTMENT ROADMAP

DISCUSSION PAPER

A framework to accelerate low emissions technologies

May 2020

Contents

List of figures

List of tables

List of boxes

To be added

Ministerial foreword

Practical action to reduce global emissions

Australia consistently meets and beats our climate change targets. We will do so for our Kyoto-era targets, and for our 2030 target.

We have done so while keeping our economy strong and goods exports (much of these energy-intensive) have more than tripled since 1990. Our emissions per person and per dollar of GDP are now at their lowest levels in 29 years.

As we recover from the COVID-19 pandemic, we must continue to prioritise investment in technologies that improve productivity and support a resilient economy.

The goal of this Roadmap is to bring a strategic and system-wide view to future investments in low emissions technologies.

At its core, this is about technology not taxes. It means reducing emissions, not reducing jobs and the economy. It is an approach based on rigour, discipline and optimism, not ideology.

As the nation's largest early-stage technology investor, regular articulation of the Government's investment priorities through annual Low Emissions Technology Statements will support a partnership with the private sector and the states and territories.

Our efforts to accelerate new and emerging technologies will focus on areas of comparative advantage in agriculture, industry, mining and energy-intensive exports.

To avoid crowding out private sector investment, our priorities will continue to evolve. We must support technologies that can succeed, but we must also be disciplined in recognising when technologies are struggling and in leaving deployment of technologies that have reached commercial viability to the private sector.

Recent Government initiatives – including the $1 billion Grid Reliability Fund, the development of a National Hydrogen Strategy and commitment of $500 million to support that industry, and the NSW state energy deal – are aligned with this forward-looking philosophy.

Australia's role in the global response to climate change can go beyond simply reducing our own emissions. We will seek out international partnerships to accelerate the development and commercialisation of new technologies and continue to support global efforts to reduce emissions, particularly among the fast-growing economies and populations of our Indo-Pacific region.

The Roadmap and first Low Emissions Technology Statement will be the cornerstone of Australia's long term emissions reduction strategy, to be delivered ahead of COP26. The long term strategy will consider how various technologies may reduce our emissions without damaging our economy.

The Government's approach to technology deployment will continue to be characterised by incentivising voluntary emissions reductions on a broad scale. The Climate Solutions Fund, Safeguard Mechanism and ClimateActive carbon neutral certification framework are calibrated accordingly.

This will position Australia to overachieve on our 2030 Paris target in a decade's time – while maintaining a strong economy.

The Government will publish the first Low Emissions Technology Statement in coming months. Stakeholders are invited to contribute to this process by providing feedback in response to the questions detailed in this discussion paper and through targeted consultation to be conducted by the Ministerial Reference Panel and my Department.

The Hon Angus Taylor MP

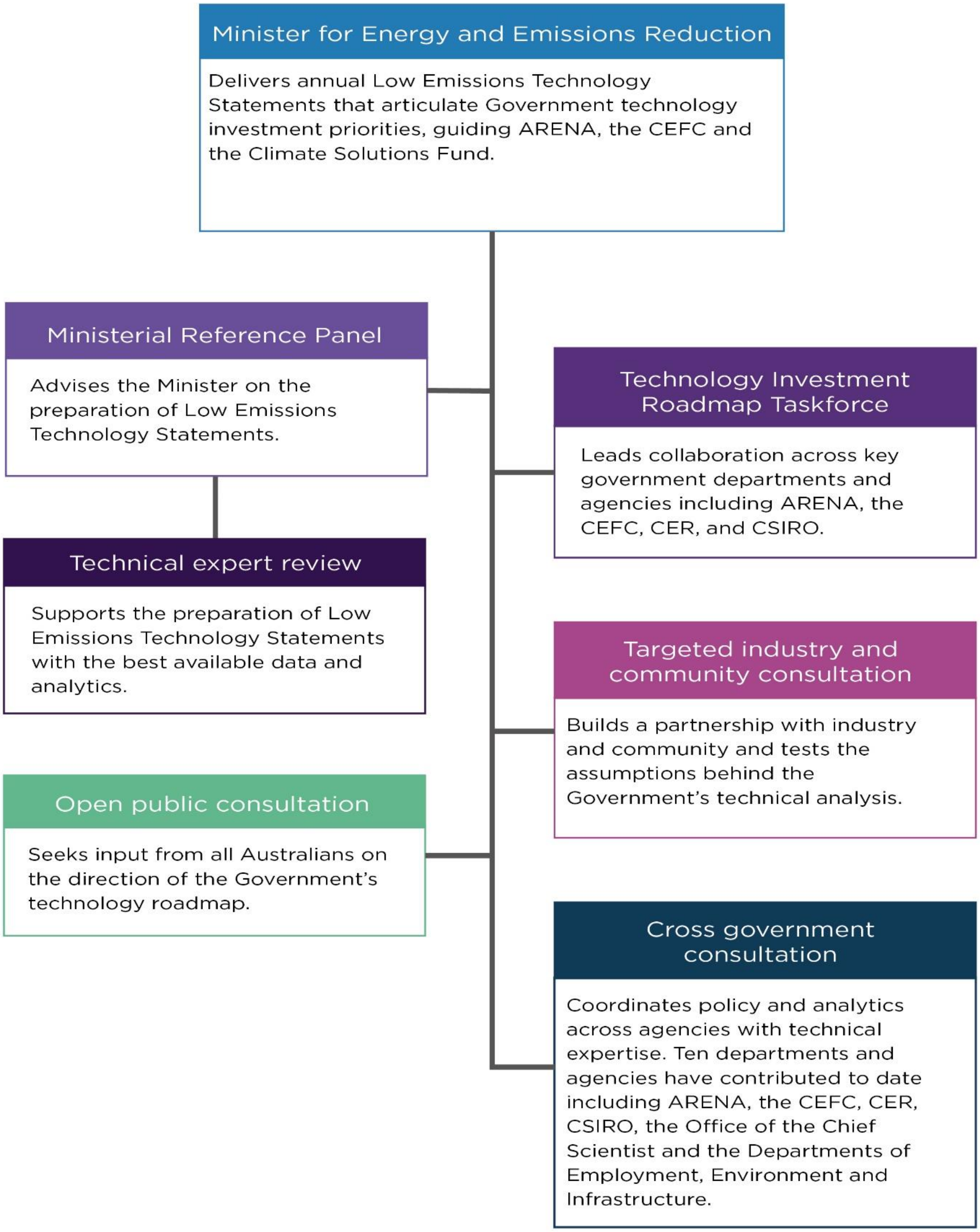
Minister for Energy and Emissions Reduction

Development of the Technology Investment Roadmap

- **AUGUST 2019:** The Minister for Energy and Emissions Reduction commissions the development of a technology investment roadmap.
- **SEPTEMBER 2019:** A collaboration of technology experts from key public service agencies led by the Department of Industry, Science, Energy and Resources and supported by CSIRO and ARENA meets to commence a survey of low emissions technologies to support the development of the Roadmap.
- **DECEMBER 2019:** At COP25 in Madrid, Australia joins the Leadership Group for Industry Transition, a public-private partnership led by India and Sweden aimed at using technology to reduce emissions in economically important industrial sectors like steel, aluminium and cement.
- **MARCH 2020:** The Minister for Energy and Emissions Reduction announces the Government is developing a Technology Investment Roadmap, confirms H2 under $2 as Government's first priority technology stretch goal and that the Government will articulate its technology priorities through annual Low Emissions Technology Statements.
- **MARCH 2020:** The Prime Ministers of Australia and Singapore commit to conclude an international cooperation agreement on low emissions technologies by the end of 2020. The agreement will focus on hydrogen, carbon capture, use and storage and renewable electricity trade.
- **APRIL 2020:** The Ministerial Reference Panel is established to advise the Minister on the preparation of annual Low Emissions Technology Statements. The panel is chaired by Australia's Chief Scientist, Dr Alan Finkel AO, with the following members: Drew Clarke, Grant King, Shemara Wikramanyake, Alison Watkins, Ben Wilson, and Jo Evans (*ex officio*).
- **MAY 2020:** The Government releases the King Review and Government response. The King Review's 26 recommendations are targeted at supporting an emerging trend of voluntary emissions reductions and maximising co-investment from the private sector and other levels of government alongside the $2 billion Climate Solutions Fund.

- **NOW:** The Technology Investment Roadmap discussion paper is released for public consultation.
- **JUNE-JULY 2020:** The Department of Industry, Science, Energy and Resources will lead targeted consultation processes with specific sectors.
- **Q3 2020:** The first annual Low Emissions Technology Statement to be delivered to Parliament. The statement will articulate the Government's technology investment priorities and progress towards them.
- **BEFORE COP26:** Australia's technology-focused Long Term Emissions Reduction Strategy to be released.

Roadmap governance and engagement structure



Stakeholder Input

The Technology Investment Roadmap will help inform Australia's first Low Emissions Technology Statement and will be a critical input to Australia's Long Term Emissions Reduction Strategy.

The Government welcomes stakeholders' views on the Roadmap, including with respect to:

a) The challenges, global trends and competitive advantages that should be considered in setting Australia's technology priorities.

b) The shortlist of technologies that Australia could prioritise for achieving scale in deployment through its technology investments (see Figure 7).

c) Goals for leveraging private investment.

d) What broader issues, including infrastructure, skills, regulation or planning, need to be worked through to enable priority technologies to be adopted at scale in Australia.

e) Where Australia is well-placed to take advantage of future demand for low emissions technologies, and support global emissions reductions by helping to deepen trade, markets and global supply chains.

In particular, the Government would welcome suggestions for economic stretch goals that could help establish pathways for the cost-effective deployment of priority technologies. As outlined in this Roadmap, these stretch goals would include producing hydrogen under $2 per kilogram, and could also cover carbon capture use and storage (CCUS), biological sequestration (in soil and vegetation), firmed renewables, and long-duration energy storage. The Government is interested in partnering with industry, research institutions and others with relevant commercial or technical expertise to develop these economic stretch goals, which should be ambitious but achievable.

Written submissions should be provided at https://consult.industry.gov.au/ by 11:59pm (AEST) Sunday, 21 June 2020.

Executive summary

A technology roadmap to guide investments through to 2050

Technology will drive a successful shift to secure, more affordable energy and lower emissions. Deploying the right technology when and where it is needed will allow Australian industry to capture new opportunities from rising global demand for lower emissions products and services.

Australian technology is already making a significant contribution around the world. For example, Australian-developed solar technology is used in more than 60 per cent of commercial solar cells globally and achieves record efficiencies of up to 25 per cent compared with standard cells.[1]

A key goal of this Roadmap is to ensure Australia remains at the forefront of global low emissions technological innovation. Driving down the cost of deploying low emissions technologies to a point where they are competitive with existing alternatives will deliver meaningful reductions in global emissions.

This Roadmap will bring a strategic and system-wide view to future investments in low emissions technologies. Our approach will be hard-headed, recognising the economic and technical barriers to widespread deployment today, while remaining optimistic about future advances and the role different technologies may play in the global effort to reduce emissions.

Identifying the point where new technologies approach broad-based economic parity with more emissions-intensive alternatives is critical to understanding the role public investment should play in accelerating technology development and deployment. Part of this is understanding where smaller opportunities for commercial deployment emerge along the way to parity, and how to reduce barriers to adoption once the technology has reached parity with higher-emitting alternatives.

The Australian Government has already invested $10.4 billion into more than 670 clean energy projects with a total project value in excess of $35 billion. These projects include the largest pumped hydro scheme in the southern hemisphere (Snowy 2.0) hydrogen[2] demonstration

---

[1] Passivated Emitter and Rear Cell (PERC) Technology, see Box 5 below for details.

[2] Unless otherwise indicated, references to hydrogen in this report refer to clean hydrogen. Clean hydrogen is produced using renewable energy or using fossil fuels with substantial carbon capture and storage (CCS). This definition reflects a technology-neutral stance.

projects, electric vehicle charging networks, and biofuels production. These investments are stimulating innovation, supporting new jobs and improving the reliability of our energy supply while lowering emissions.

The Australian Government is also partnering with states and territories to improve energy reliability and affordability and reduce emissions. The recent state deal with New South Wales is an example, where both governments have committed to initiatives that will lower prices for consumers, reduce emissions and strengthen grid reliability.

Positioning Australia as a leader in low emissions technologies requires a partnership, with other levels of government, the private sector and researchers as well as close collaboration internationally. To build that partnership, this Roadmap will be supported by:

- **Low Emissions Technology Statements** published each year to communicate progress towards defined technology goals. Each statement will provide an update of global technological developments and fine-tune the Government's investment portfolio while retaining commitment to our long term vision.
- **Ministerial Reference Panel** composed of industry, private investment, government and research leaders to advise the Minister for Energy and Emissions Reduction in the preparation of Low Emissions Technology Statements. While the reference panel will advise generally on technology priorities, its primary role will be identifying pathways for efficient deployment of new technologies. Dr Alan Finkel, Australia's Chief Scientist, is the inaugural Chair of the reference panel.
- **Technical expert review** to ensure the Low Emissions Technology Statements are supported by the best available data and analytics.
- **Targeted industry and community consultation** to test the assumptions behind the Government's technical analysis and build partnerships with stakeholders.

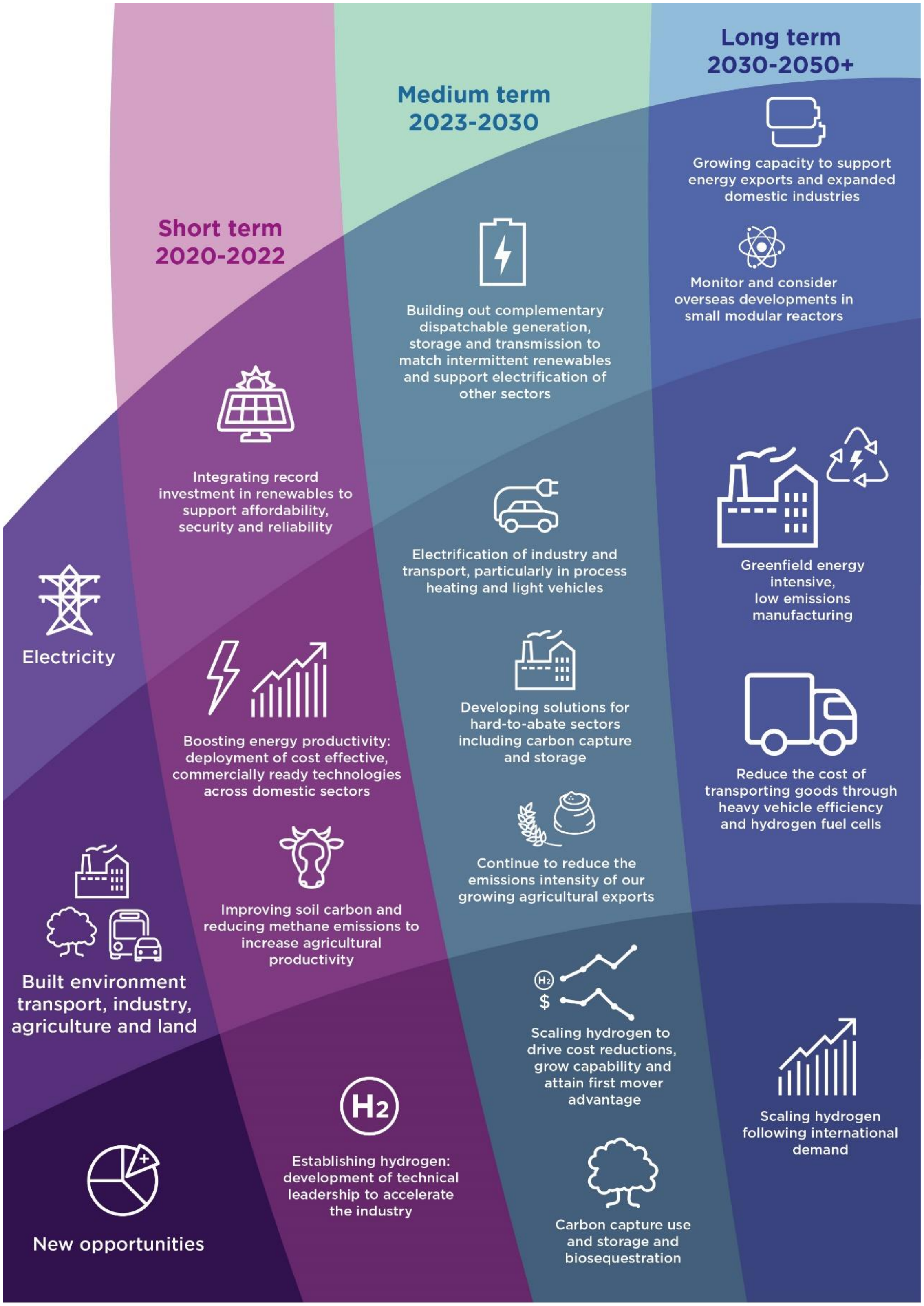
- **Open public consultation** through the Department of Industry, Science, Energy and Resources website. Consultation seeks input from all Australians on the direction of the Government's technology roadmap.

The first Low Emissions Technology Statement will be published later this year with input from the above. All Australians are invited to contribute to this important national conversation.

The Roadmap will allow us to work towards clear priorities over the short, medium and long term. In the short term, we want to support investment in the new generation, storage and transmission needed to balance record investment in renewable energy. We want to deploy technology that will boost the energy productivity of our industry and built environment, and make inroads towards addressing emissions from livestock. Over the medium term, we will support building storage and transmission infrastructure and the electrification of industry while scaling our domestic hydrogen industry. Over the long term, Australia's technology investments should build new export-facing industries in the global low emissions economy including those leveraging hydrogen and carbon capture and storage.

A summary of key technology challenges and opportunities is set out below and will be refined through consultation with stakeholders throughout 2020.

Figure: Key technology challenges and opportunities



An economy-wide survey of over 140 new and emerging technologies underpins this Roadmap. The survey found a range of technologies across all sectors of the Australian economy with the potential to improve productivity, lower costs, reduce emissions and support secure energy supply (see Appendix A for a list of technologies surveyed and Appendix B for a summary of results by sector). The Government will seek stakeholder views on the assumptions underpinning the technology survey.[3]

Stakeholder Input

The Technology Investment Roadmap will help inform Australia's first Low Emissions Technology Statement and will be a critical input to Australia's Long Term Emissions Reduction Strategy.

The Government welcomes stakeholders' views on the Roadmap, including with respect to:

a) The challenges, global trends and competitive advantages that should be considered in setting Australia's technology priorities.

b) The shortlist of technologies that Australia could prioritise for achieving scale in deployment through its technology investments (see Figure 7).

c) Goals for leveraging private investment.

d) What broader issues, including infrastructure, skills, regulation or planning, need to be worked through to enable priority technologies to be adopted at scale in Australia.

e) Where Australia is well-placed to take advantage of future demand for low emissions technologies, and support global emissions reductions by helping to deepen trade, markets and global supply chains.

In particular, the Government would welcome suggestions for economic stretch goals that could help establish pathways for the cost-effective deployment of priority technologies. As outlined in this Roadmap, these stretch goals would include producing hydrogen under $2 per kilogram, and could also cover carbon capture use and storage (CCUS), biological sequestration (in soil and vegetation), firmed renewables, and long duration energy storage. The Government is interested in partnering with industry, research institutions and others with relevant commercial or technical expertise to develop these economic stretch goals, which should be ambitious but achievable.

Written submissions should be provided to https://consult.industry.gov.au/ by 11:59pm (AEST) Sunday, 21 June 2020.

---

[3] In 2016 the Australian Government commissioned CSIRO to develop a *Low Emissions Technology Roadmap* (2017). CSIRO's Roadmap identified technology options in the energy sector for Australia to meet its emissions reduction targets while delivering economic opportunities. The technology survey of this Roadmap updates CSIRO's work within a lasting framework for technology investment decisions. Various other sources were used in compiling technical readiness and cost estimates. These are detailed in the technical Appendix B.

A technology investment roadmap

This Roadmap approaches the prioritisation of technology investments in eight stages (Figure 1). This stepwise approach will regularly survey new and emerging technology opportunities and challenges with stakeholders to arrive at economy-wide priorities for low emissions technology investments.

Global technology leaders including Germany,[4] the European Union,[5] the United States[6] and Japan[7] have set in place long term, strategic approaches to their technology innovation and deployment programs. Other major economies, such as the United Kingdom,[8] have recently implemented similar measures.

International experience demonstrates that clear articulation of national technology priorities has benefits beyond optimisation of the central government's investment. Over time this approach builds partnerships with key domestic and international stakeholders on technology innovation and investments of importance to national goals. Clear government technology priorities also allow private capital providers to take account of national goals in making their own investment decisions.

[4] German Federal Ministry for Economic Affairs and Energy, 2018.
[5] European Commission, 2017.
[6] US Department of Energy, 2017 and 2015.
[7] Japan Ministry of Economy, Trade and Industry, 2018.
[8] UK Department for Business, Energy and Industrial Strategy, 2017.

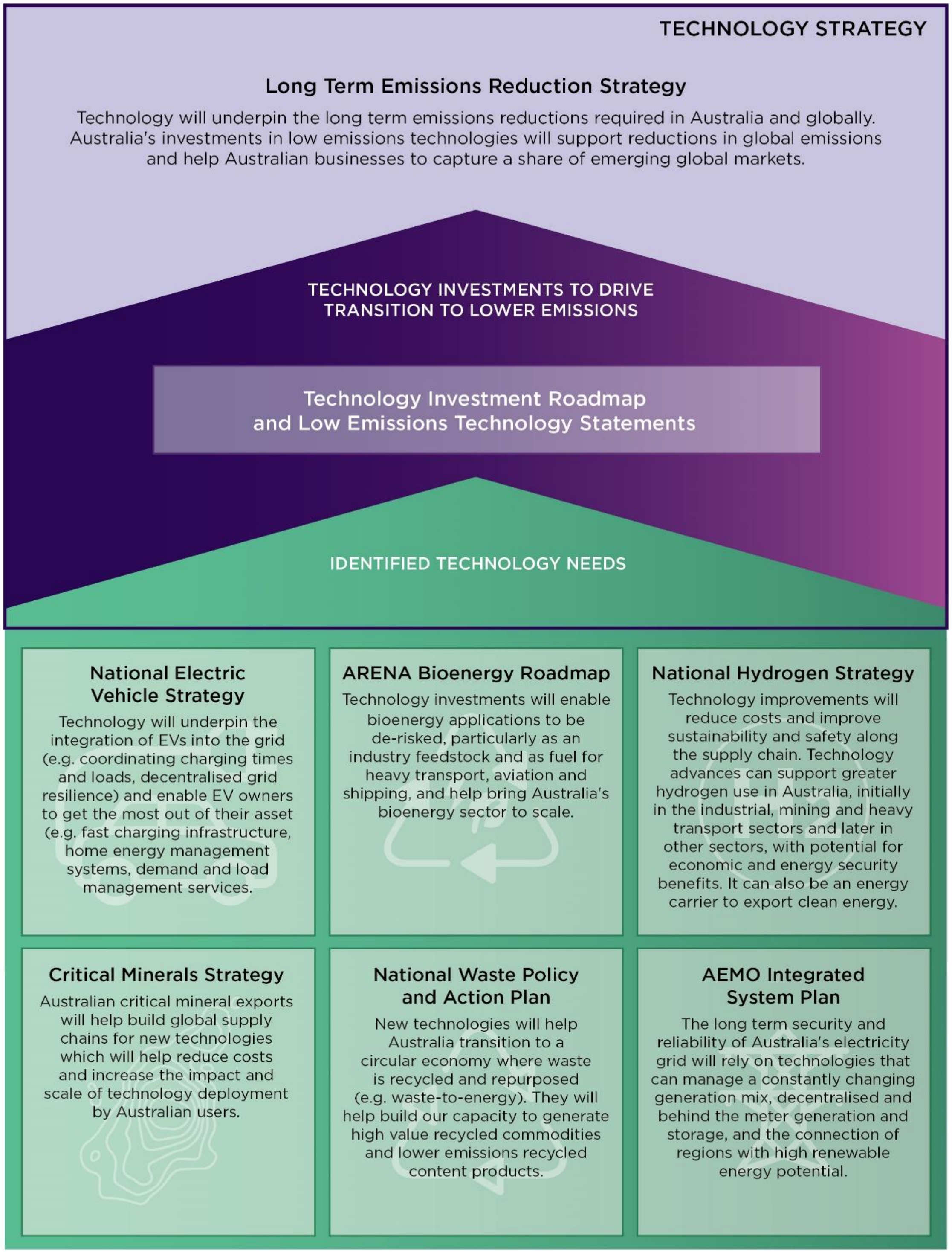
Figure 1: A roadmap for strategic and system-wide technology investment

The Roadmap covers technology in the broadest sense - that is, deployment of existing, new, and emerging scientific and engineering applications (methods, systems and devices) that reduce emissions or improve energy reliability, security and affordability.

The Roadmap will complement the Government's broader energy and emissions reduction policies.

Figure 2 shows how the Roadmap will form the cornerstone of Australia's Long Term Emissions Reduction Strategy and complement several other strategies across government, including the National Hydrogen Strategy (released in November 2019), the National Electric Vehicles Strategy (forthcoming), the Bioenergy Roadmap (forthcoming) and the Critical Minerals Strategy (released in March 2019).

Figure 2: Technology deployment to complement other strategies relevant to lowering long term emissions



Stage 1: Setting a clear vision

Our technology vision is for Australia to have reliable, secure and affordable energy to power the domestic economy, and economy-wide technologies deployed to maximise the employment and growth opportunities of the global shift towards lower emissions. In that vision, industry, investors, researchers, governments and the broader community will realise a lasting partnership that:

- Develops and deploys cutting-edge technologies consistently to boost productivity.
- Builds on Australia's comparative advantages to create new export-facing growth and employment opportunities in emerging lower emissions industries while being cognisant of where those opportunities can benefit regional communities.
- Secures our place as a global low emissions technology leader by attracting and retaining the best minds in priority low emissions technology research fields and disseminating that expertise through industry to create a globally competitive workforce.[9]

The Government's technology investments will drive the realisation of that vision by pursuing the following overarching goals:

- Improving **affordability** of energy for Australian households and businesses.
- Maintaining **security** and **reliability of** energy supply.
- Meeting, and where possible beating, **Australia's emissions reduction commitments** and **helping other countries** to lower their emissions through the export of low emissions technologies, products and services.
- **Seeking employment** and **growth** opportunities, particularly in regional areas, arising from increasing global demand for low emissions energy and products.

The Government will set measurable economic goals for specific priority technologies and track our progress towards them. The first specific goal will be producing hydrogen at below

[9] This vision is adapted from the outlook vision described by CSIRO's Australian National Outlook 2019.

$2 per kilogram. That is the point at which hydrogen will be competitive with alternatives in large-scale deployment across our energy system. This goal will allow us to track how hydrogen is progressing on its cost curve. Other goals will be developed in partnership with industry and stakeholders, including through consultation on this Roadmap. Our approach will be hard-headed, recognising today's economic and technical barriers to widespread deployment, while remaining optimistic about future advances and the role different technologies may play in the global effort to reduce emissions.

Cost-competitiveness of new technologies is what will ultimately unlock deployment and displace more emissions-intensive alternatives, not just in Australia but globally. Technology goals will provide a measurable pathway towards our vision and will be the basis for evaluating the impact of our investments.

Stage 2: Survey of new and emerging technologies

The Department of Industry, Science, Energy and Resources conducted an economy-wide survey of new and emerging technologies with the potential to contribute to our overarching goals. The survey was supported by key scientific and technical agencies across the government including ARENA, the CEFC, CSIRO, the Clean Energy Regulator, and the Office of the Chief Scientist. The survey covers over 140 new and emerging technologies, looking at their abatement potentials, technological and commercial readiness levels and cost-effectiveness (a full list of technologies is provided in Appendix A).[10] This survey will be a key

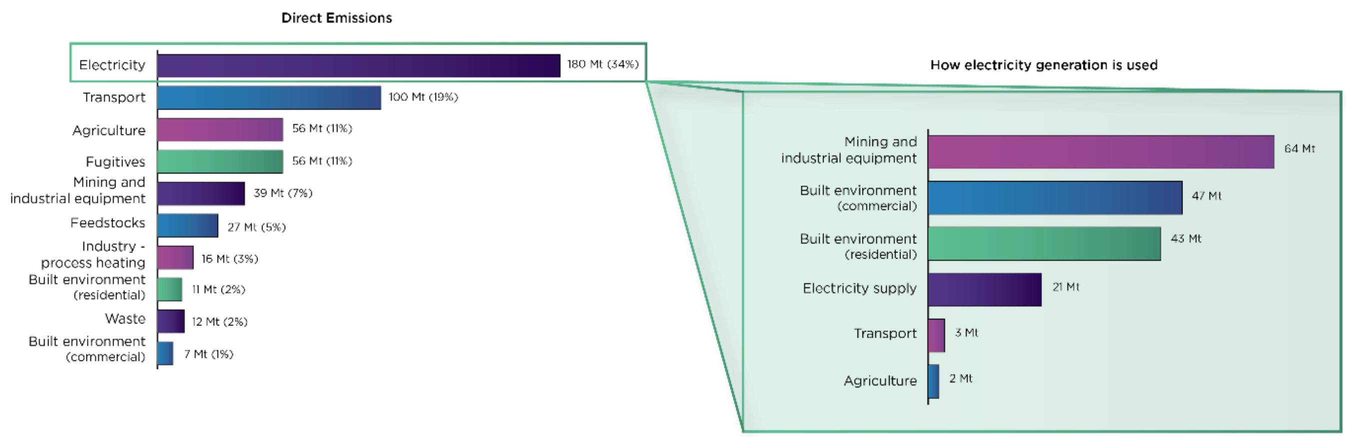
[10] Technology costs have been calculated by comparing the costs and savings of new technologies to the cost of practical replacement of existing, common-use technologies on a net present value (NPV) basis. A single discount rate of 7 per cent was applied. It is acknowledged that actual discount rates will vary across industries based on risk and return, and this analysis will be refined following industry consultation. For the electricity generation technologies, pumped hydro (solar and wind), nuclear, and batteries (solar and wind), abatement and cost were estimated on full replacement of the current grid within the time period. Where best available data has predicted cost changes over time for technologies, this information has been factored into estimates across time periods. Where no information on cost predictions has been available, costs have been held steady at today's costs.

Technologies were evaluated based on the technology readiness level (TRL) globally, and the commercial readiness index (CRI) developed by ARENA. CRI relates to commercial deployment in Australia. Emerging technologies were measured from TRL 1 (concept) to TRL 9 (full technological development). For technologies with a TRL of 9, the CRI has been shown in each chart presented in Appendix B. The TRL and CRI levels reflect the business-as-usual trajectory for a technology that could be reached by the end of the relevant time period.

input towards establishing investment priorities through annual Low Emissions Technology Statements.

Technologies were considered in the following categories: electricity generation (including enabling technologies), industrial process heating, mining and industrial equipment, feedstocks, transport, built environment (residential and commercial), fugitives, agriculture, waste, and negative emissions. The glossary provides additional explanations for technical terms used in this section.

Figure 3: Sectors covered by the technology survey including their impact on national emissions



Notes: Feedstocks includes emissions from petroleum refining, chemicals, ammonia production, iron and steel production and cement; Direct (scope 1) emissions are displayed on the left. Agriculture includes emissions from combustion of fuels in agriculture, land use, land-use change and forestry.
Source: Commonwealth of Australia 2019

To test our initial findings and analysis, the Department's survey will be refined in consultation with stakeholders throughout 2020.

Summary results of the technology survey[11]

Electricity generation is a crucial sector with linkages across the economy. A range of technologies have the potential to improve reliability, security and affordability while lowering emissions. Maintaining Australia's world-leading rate of deployment of solar and wind generation will require corresponding investments in flexible generation and energy storage,

[11] Figure 4 summarises the economy-wide technology survey (note that circle areas represent relative abatement potential).

network augmentation, frequency and voltage control technology to ensure network security and reliability. Combining gas generation with renewables allows affordable, low emissions generation from solar and wind to be combined with the firming capability of gas generation (combined-cycle or aeroderivative turbines, or reciprocating generators). Deploying new and emerging technologies to continually improve the efficiency of our current and future fleet of gas, coal and hydro generators has been and will continue to be an important source of technology-driven emissions reduction.

Box 1: Pumped hydro and improved interconnection

Pumped hydro, through projects such as Snowy 2.0, Marinus Link and Battery of the Nation, will play an important role in managing the penetration of renewables by storing excess energy in high-altitude dams and flexibly generating electricity in periods of high demand.

The Government has invested more than $1.4 billion into these projects through the Climate Solutions Package. Economic modelling has found that Snowy 2.0 will provide market benefits of between $4.4 and $6.8 billion and reduce spot prices, leading to lower costs for consumers.

Snowy 2.0 will be the largest energy storage project in the Southern Hemisphere with its ability to provide 350 gigawatt hours of electricity, enough to power 500,000 homes for a week. Snowy 2.0 will add an extra 2,000 megawatts of generation capacity to the National Electricity Market and will increase the capacity of the Snowy Scheme by 50 per cent.

Batteries are up to 80 times more expensive than Snowy 2.0 (on a per unit of storage basis). Matching the bulk storage of Snowy 2.0 would require more than 1,800 South Australian Tesla batteries (the Hornsdale Power Reserve), costing hundreds of billions of dollars.

The Government is also partnering with the Tasmanian Government to deliver the Marinus Link transmission project and the Battery of the Nation initiatives, to provide additional dispatchable electricity and energy storage to the National Electricity Market.

Marinus Link is the proposed 1,500 megawatt second undersea electricity interconnector linking Tasmania's renewable energy zones to Victoria's Latrobe Valley. It is an essential part of the future National Electricity Market.

Battery of the Nation is a plan by Hydro Tasmania to construct up to 2,500 megawatts of pumped hydro across Tasmania to take advantage of its vast hydro and wind resources.

As the share of inverter-connected devices in the grid increases, more system security technologies (such as grid-forming inverters and synchronous condensers) will need to be deployed. Technologies such as virtual power plants (VPPs) for effectively integrating distributed energy resources (DER) like rooftop solar PV, and home batteries are promising but require further cost reductions to accelerate uptake. While these technologies mature, our existing thermal generation fleet will continue to play a critical role in providing the low-cost energy supply and firming services needed to keep the lights on and retain large industrial loads like aluminium smelters, which are themselves playing an increasingly important role in stabilising the grid.

A large proportion of direct industrial emissions arise from the combustion of fuels (primarily gas and coal). These emissions can be mitigated by deploying a combination of electrification, energy efficiency and carbon capture, use and storage technologies across a variety of applications. For example, eliminating emissions from production of cement is a difficult challenge even over the longer term, and carbon capture may provide a viable pathway towards lowering emissions. Geosequestration of carbon dioxide (CO_2) represents a significant opportunity for abatement in export gas. The carbon dioxide injection system at the Gorgon natural gas facility that commenced in August 2019 is expected to inject and store between 3.4 million and 4 million tonnes of greenhouse gas emissions each year once fully operational.

Box 2: Gorgon Carbon Dioxide (CO_2) Injection Project

The Gorgon Carbon Dioxide (CO_2) Injection Project in Western Australia is a commercial-scale demonstration of geologically sequestering CO_2 to reduce greenhouse gas emissions.

The project is operated by Chevron Australia and is supported by the Australian Government through a $60 million grant from the Low Emissions Technology Demonstration Fund.

Carbon dioxide is separated from natural gas streams when producing Liquefied Natural Gas (LNG). Chevron operates LNG facilities at the Gorgon and Io Jansz gas fields, and the Carbon Dioxide Injection Project enables capture of CO_2, prior to its entry into the atmosphere.

The project commenced CO_2 injection into the Dupuy Formation, 2 km below Barrow Island, on August 2019 and is set to be a world leader in this technology. It will be one of the world's largest commercial-scale CO_2 injection facilities, capable of capturing 3.4–4 million tonnes of CO_2 per annum (the equivalent of removing up to 1.25 million cars from the roads each year) and more than 100 million tonnes over the life of the project).

Barrow Island is a Class A Nature Reserve and the Commonwealth and Western Australia governments have worked closely with Chevron Australia to protect the island's ecology. Chevron implements a comprehensive quarantine management system to monitor its environmental impact, and an ongoing monitoring program to manage the Dupuy Formation injection site.

Emerging nuclear technologies (for example, small modular reactors) have potential but require R&D and identified deployment pathways. Engineering, cost and environmental challenges, alongside social acceptability of nuclear power in Australia, will be key determinants of any future deployment.

The progress of emerging technologies overseas will continue to be monitored to discover more about each technology's costs, benefits and any potential challenges. More will need to be known about these new technologies to identify any potential for application in Australia.

A variety of surveyed technologies could reduce costs for households and businesses. In the residential sector, heat pump dryers, hot water systems and pool heaters are proven technologies with high abatement potential that can deliver cost savings with payback periods of around five years. Further analysis is required to identify the most efficient deployment pathways for technologies that are cost-effective but have not yet seen strong uptake in

Australia. The Government's approach to technology deployment will continue to be characterised by incentivising voluntary emissions reductions on a broad scale.

In the transport sector, hybrids, alternative fuels and electric vehicles present opportunities to improve road transport efficiency and reduce emissions, although pre-2030 abatement potential is limited by the turnover of Australia's light vehicle fleet (average age of 10 years) and the readiness of these technologies to support emissions reduction in the heavy vehicle fleet.

Both battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) are predicted to experience increasing uptake. While sometimes seen as competing technologies, they each meet specific consumer and industry needs. For example, fuel cells are considered more readily scalable to bigger vehicles, heavier loads and longer distances such as in long-haul transport.[12] Current battery technology constraints suggest BEVs are more likely to be suited to personal use and light commercial vehicles, particularly back-to-base fleets.

Refuelling and broader transport infrastructure will continue to evolve with the changing composition of Australia's transport fleet. The Roadmap will complement other initiatives, such as the forthcoming National Electric Vehicle Strategy, to support consumer choice as new technologies come to market.

In the agriculture sector, there are opportunities to improve soil carbon levels and livestock productivity, as well as deploying technologies to enhance fertiliser use, carbon storage in vegetation and improve fire management. Further research and development is needed to fully understand the abatement and productivity opportunities for this sector. Improvements in remote sensing technology have the potential to build on the success of the Emissions Reduction Fund and catalyse further emissions reduction through the Climate Solutions Fund. There are also opportunities to improve fuel and energy consumption and the supply of inputs for energy production and building construction. The Government will work with stakeholders to support investments in technology that are likely to have the greatest impact.

Reducing waste and associated emissions is a cross-cutting concern across the economy. Energy from Waste (EfW) technologies are proven and widely adopted across Europe, North America and Asia. Opportunities include deployment of proven technologies such as anaerobic

[12] COAG Energy Council Hydrogen Working Group, 2019, p. 17.

digestion (use of waste to produce biogas), combustion (used to produce high-pressure steam for generation) and gasification (to produce synthetic gas), as well as emerging technologies such as pyrolysis (separated waste streams to produce synthetic gas (syngas) or biochar).

Advanced waste-sorting technologies are also already proven in a commercial setting, and increasing deployment would deliver further benefits. Licella's Catalytic Hydrothermal Reactor is an example of plastic waste to biocrude oil technology, converting waste feedstocks into high-value products.

Box 3: Reducing emissions from organic waste

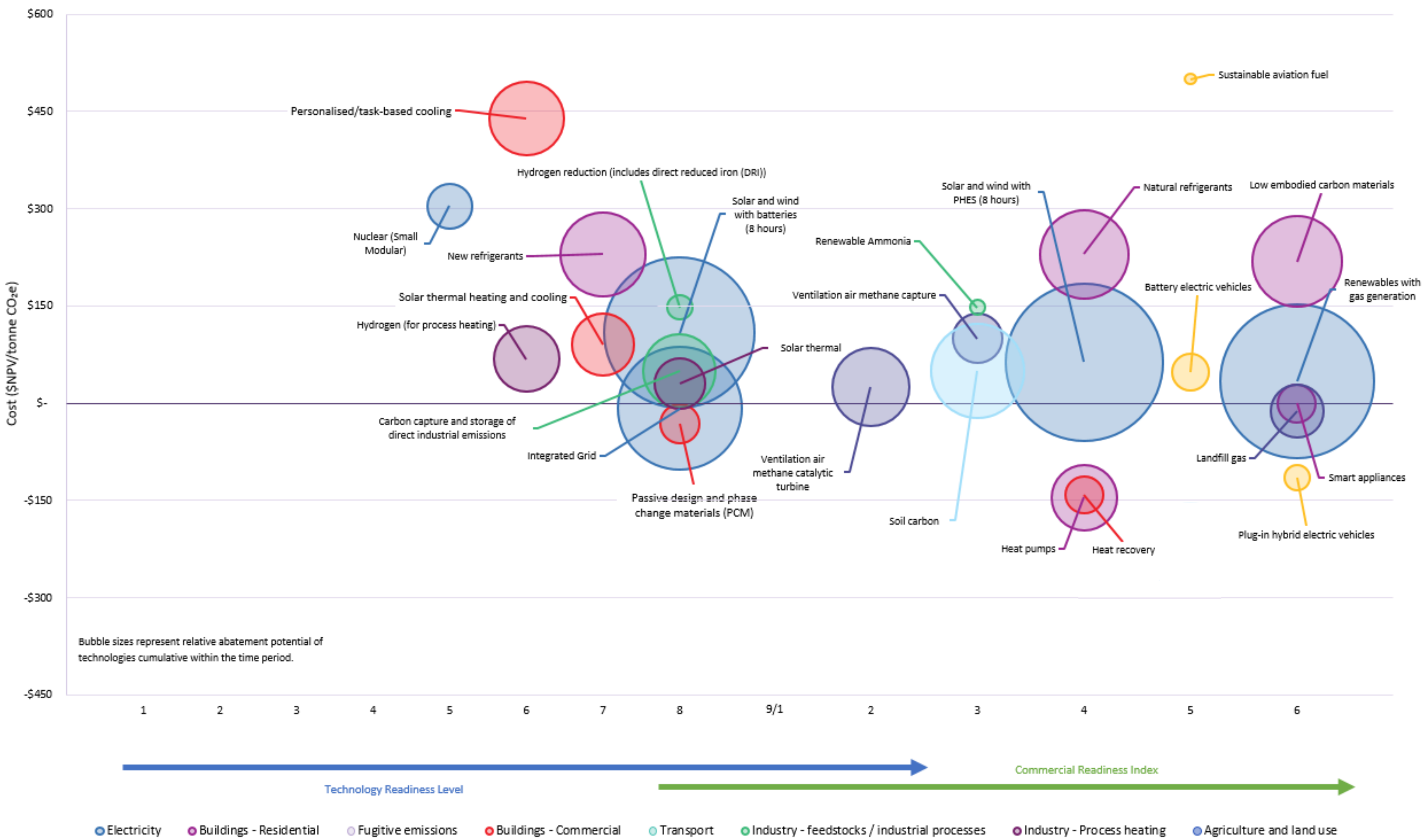
Organic waste decomposes in landfill to produce methane, which has a global warming potential 25-28 times greater than carbon dioxide. The Emissions Reduction Fund (ERF) has supported the reduction of methane emissions from landfills through both capture and flaring and through conversion of methane into renewable electricity. The Australian Government has invested more than $250 million into these projects through the ERF, reducing emissions by 23 million tonnes while encouraging better use of organic waste streams.

The ERF has supported the separation of organic waste from other waste streams at its source, and alternative treatment of waste that would otherwise go to landfill. Once the waste is in landfill, the ERF supports the capturing and combustion of the methane, including for electricity generation. As Australia's population grows, better management of waste in landfills will continue to reduce emissions, while providing dispatchable renewable electricity. Renewable electricity generation from landfill gas can also earn revenue from large-scale generation certificates under the Large-scale Renewable Energy Target (LRET).

The ERF also encourages reductions in emissions beyond landfills by supporting electricity generation from methane derived from anaerobic digestion of industrial wastewater, and production of process engineered fuel from mixed waste.

The ERF's waste methods are complemented by the implementation by Australian Governments of the National Waste Policy, which provides a framework for collective action by businesses, governments, communities and individuals until 2030 based on circular economy principles.

Figure 4: Summary of selected technologies with the potential to reduce emissions across the economy, 2023–2030



Notes: Refer to Footnote 10 for assumptions. Figure 4 shows a selection of the over 140 technologies surveyed for this Roadmap for the 2023–30 time period. The area of bubbles shows relative abatement potential of technologies over the given time period. Technology and commercial readiness are as projected to the end of the end of the time period (that is 2030). Details of the Technology Readiness Level and Commercial Readiness Index scales are given in Appendix C. The cost of abatement relating to a particular technology is indicated by the centre point of each bubble.

Stage 3: Australia’s technological needs and comparative advantage

The technological challenges and opportunities Australia pursues will be guided by the unique challenges we face, our comparative advantages and our existing R&D strengths as well as global trends. CSIRO’s *Low Emissions Technology Roadmap* (2017) provided a detailed survey of our comparative advantages, strengths and needs that has been used in developing the analysis below.

Australia’s unique challenges

Australia’s large landmass creates challenges for transmission of electricity over large distances from centralised generators. While Australia’s geographic and population distribution provides unique challenges, it also presents opportunities for innovation.

Electricity customers at the end of long distribution networks are subject to some of the lowest reliability levels in Australia. These networks are more prone to impact from bushfires and extreme weather events. The distances can also make it difficult, time-consuming and expensive to locate and fix faults and provide general maintenance.

The Government has supported innovative deployment of new technologies that increase affordability and reliability while reducing emissions in remote areas through, for example, ARENA in partnership with the Northern Territory Power and Water Corporation (NT Power and Water) SETuP program (Box 4).

The Government is also supporting a national expansion of clean energy technologies to improve reliability and affordability in regional communities, through the $50 million Regional and Remote Communities Reliability Fund (Box 5).

Box 4: Case study – Deploying renewable energy in remote communities

With support from the ARENA-funded SETuP project, NT Power and Water has deployed 10 MW of PV generation across 26 remote NT communities. PV energy has partially displaced diesel generation and is delivering 15 per cent fuel savings on average. At the Nauiyu community (Daly River), a popular NT barramundi fishing location, battery storage was added to 1 MW of PV, allowing the diesel engines to be turned off during daylight hours. Net fuel savings exceed 50 per cent.

NT Power and Water has developed new approaches to determining ‘least cost’ power system design, with the following benefits:

- A systematic framework for modelling ‘least cost’ power systems to demonstrate the optimum or ‘least cost’ designs. The optimum mix of technologies is determined by their respective costs including capital.
- PV and battery storage technology are ‘bolt on’ and complementary to existing diesel generation investments.
- Paired together, these technologies reduce the run hours for diesel engines, deferring capital replacement and resulting in large non-diesel operational savings on labour, material and service costs.
- A common control system platform at each site allows a ‘cookie cutter’ approach, reducing the engineering required at each site.
- The IP and lessons learned in small power systems—how to minimise power system costs while maintaining reliability—are transferable to larger power systems.
- New prefabricated PV array technology developed by Australian companies expedites remote project delivery.

Source: ARENA, 2019c

Box 5: Expansion of microgrids

The Regional and Remote Communities Fund is providing $50.4 million for feasibility studies looking at microgrid technologies to replace, upgrade or supplement existing electricity supply arrangements in off-grid and fringe-of-grid communities in regional and remote areas.

Microgrids can represent more reliable, secure and cost-effective energy supply options for regional and remote communities in Australia.

The intended outcomes of the program are:

- Viable projects attract funding to support scale-up and implementation of microgrid systems in regional and remote communities.
- Increased human capital (skills and knowledge) in the design and deployment of microgrids.
- Demonstrated commerciality and/or reliability and security benefits of deploying and upgrading microgrids.
- Reduced barriers to microgrid uptake in remote and regional communities.
- Increased dissemination of technology and/or project knowledge regarding the deployment and upgrading of microgrids.

Australia's comparative advantages

Australia has some of the world's most abundant and diverse energy and mineral resources. We have the world's highest per capita solar resource in the G20 and the second highest in the world, the world's largest known uranium resource, the world's fourth largest coal reserves and substantial gas reserves. Our energy resources are complemented by vast supplies of bulk commodities and minerals including iron ore, copper, zinc, gold, silver and nickel as well as critical minerals like lithium and rare earths.

Australia is a net exporter of energy. Our resources and energy exports reached $297 billion in 2019. We are the world's largest exporter of liquefied natural gas, iron ore and metallurgical coal. The technical and project delivery leadership of Australian companies in the resources and energy sector is recognised and highly sought after. This leadership is complemented by a skilled and motivated workforce that supports a hard-won reputation for reliable production and supply to market. We are well served by world-class science and engineering capabilities in our leading scientific institutions, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and our universities.

These inherent strengths provide a basis for reducing emissions and helping our overseas partners to lower their emissions through our energy exports (particularly Japan, South Korea and China). To realise the opportunities before us, we need to ensure we leverage these strengths to ensure we remain at the forefront of knowledge creation and technical problem-solving.

As global demand for energy increases and countries seek to reduce emissions, demand for lower emissions energy sources (gas, hydrogen or renewable electricity via high voltage direct current (HVDC) cable) will grow.[13] Australia is well positioned to meet changing demand for direct exports of lower emissions energy.

On a pure energy collection and generation basis, solar and wind costs are projected to be cheaper than new thermal generation over all time horizons to 2050,[14] but the cost of firming is still a major issue, and will require much more work. For instance, renewables are not yet broadly deployed as a power generation source for large, always-on industrial loads that demand stable power supply. Energy storage – which can take many forms, including a coal stockpile, gas pipeline, dam or large-scale battery – is critical to maintaining affordability and reliability in any electricity grid. South Australia provides a real-world example of the feasibility and challenges associated with combining high levels of renewable energy with flexible gas generation to provide reliable, low emissions electricity supply.[15]

[13] IEA, 2019d

[14] Graham et al, 2018. As noted above, GenCost projects storage costs for wind and solar on the basis of scenarios 2 hours battery or 6 hours pumped hydro. Fully firmed wind and solar generation may require more storage than this and would further increase the costs of stored wind and solar.

[15] AEMO, 2019, pp. 32–33.

Box 6: Large-scale solar

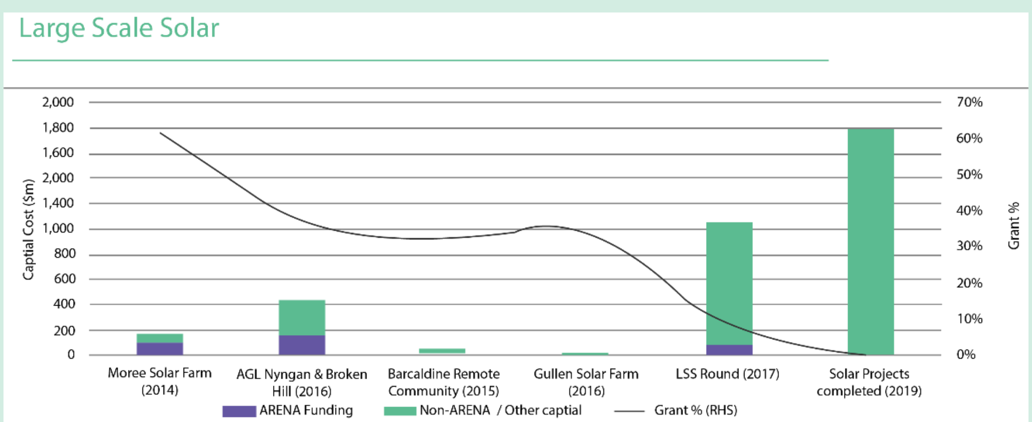
In the past decade, large-scale solar (LSS) has undergone a dramatic transformation in Australia – from an emerging technology far from commercial viability to one of the cheapest forms of new, un-firmed electricity generation available. Hundreds of solar power plants are now either already connected or under construction.

In 2012, there was less than 10 MW of LSS in Australia's electricity grid. Five years later, by December 2018, more than 3,000 MW of LSS had been connected to the grid. According to AEMO, there is more than 10 GW in the pipeline.

Between 2012 and 2018, ARENA contributed funding to 18 LSS projects across Australia, with the grant funds totalling close to $400 million. Over those five years, the total grant required per project from ARENA decreased dramatically as the gap to commerciality narrowed (refer chart below). The amount of ARENA funding required reduced from $1.60 per watt in 2014 to $0.19 per watt in 2016. In addition, total project costs decreased. Projects funded through ARENA's LSS Round cost around $2 per watt of capacity, one-third cheaper than AGL's plants in Nyngan and Broken Hill, which cost $2.80 per watt in 2014 and were competitive at the time.

Under its LSS competitive funding round, ARENA committed $92 million to 12 large-scale solar farms that are now all up and running, connected to the grid and generating electricity. Eight of the projects also received a total of $320 million in debt finance from the Clean Energy Finance Corporation which unlocked nearly $1 billion in private investment. Located across Queensland, NSW and Western Australia, the solar farms have a combined capacity of 492.5 MW, enough to power more than 150,000 homes.

The experience gained through ARENA's funding round helped reduce the costs of engineering, procurement and construction and drove innovation in solar panel technology, such as single axis sun tracking and high-voltage inverter technology.



Sources: *ARENA data, Clean Energy Council Project Tracker (publically available data only)*
Note: *Years in brackets refers to year of Financial Close*

Beyond cleaner energy, new technologies will need to be deployed at scale across energy and carbon-intensive products including processed foods, chemicals, iron, steel, nonferrous metals (aluminium) and non-metallic minerals (cement). As the world's fourth-largest minerals producer and a leading exporter of iron ore, metallurgical coal, aluminium, lead, zinc and nickel, Australia has a strong interest in future developments in these sectors.[16]

If significant cost reductions in energy storage are realised, careful and systematic deployment of low-cost renewable generation could re-establish our advantage in energy-intensive manufacturing and enable more onshore processing of our mineral wealth. However, Australia will not be able to capitalise on these opportunities if we compromise energy security, reliability or affordability in an effort to reduce emissions. The deployment of technology to firm variable supply and maintain grid stability should therefore be a priority.

Australia's stable banking and regulatory systems could position us as a technology financial centre for low emissions technologies where global projects are brokered and financed. The challenge is to attract the right mix of enabling services (legal, financial, project development and engineering) around a critical mass of venture capital, private investments and traditional banks active in the low carbon and renewables space.

Australia's RD&D strengths

In its 2017 analysis, CSIRO identified areas where Australia could provide global technological leadership and others where it is more likely to be a 'technology taker'.

Australian research institutions, including CSIRO and our universities, have established leadership in a range of low emissions technologies. The Government's future technology investments will leverage those strengths to meet Australia's own technology needs and maximise our role in the global shift to lower emissions. Understanding our competitive strengths and weaknesses is an important factor in achieving a balanced investment portfolio.

Australia's low emissions technology research strengths include bioenergy, smart grid technologies, grid integration of renewables, solar PV, concentrated solar thermal, hydrogen,

[16] Export.gov, 2018.

ventilation air methane (VAM) abatement technologies, and carbon capture and storage (CCS). Australia can continue to make important contributions to global efforts in these areas.

Australia could play an important role in driving the global shift to lower emissions, particularly with our neighbours in the Asia-Pacific, through:

- Leveraging our expertise in consulting services to deploy technologies domestically—for example, in the built environment or moving remote communities to reliable renewable energy (see Box 4) and exporting that service expertise overseas, particularly in the Pacific.
- Contributing IP to global low emissions supply chains, including for wind and solar, as we have successfully done in the past (see Box 5*).*
- Deploying technological innovation in, for example, concentrated solar thermal and hydrogen research and development.
- Linking into battery and storage supply chains through our lithium and other rare earth mineral exports, with a view to entering other parts of the supply chain in the future.
- Demonstrating carbon capture use and storage technology and assisting neighbours in the Asia-Pacific to do the same.

Australia is more likely to be a 'technology taker' in other areas. For example, wind and solar modules (including offshore wind) will mostly be manufactured at large scale overseas, but Australian research and development will contribute to these global value chains, particularly for solar PV.

Similarly, despite some domestic RD&D capability, cost reductions from manufacturing storage at scale will likely emerge overseas and then be imported. However, Australia's manufacturing capability could be expanded to take greater advantage of our mineral resources involved in battery production. Concentrated solar thermal with thermal storage is an important technology with firming potential in which Australia is making important contributions to global RD&D.

Electric vehicles are another key technology where Australia is likely to be a technology taker, with some local capabilities to supply components for global supply chains (for example, Australian businesses are recognised world-leading designers and manufacturers of electric vehicle technology such as fast chargers and vehicle retrofits).

Deploying overseas technology will not be a passive process; effective local deployment will often require tailoring overseas technology to domestic circumstances and changing local regulations to knock down barriers to deployment.

Box 7: Case study – Deploying concentrated solar thermal for high-temperature process heating

Concentrated solar thermal (CST) uses mirrors or lenses to concentrate sunlight onto a fixed point, resulting in high temperature heating. The heat can be used to create steam to produce electrical power or can be used as industrial process heat. It is possible to reach temperatures in excess of 1000ºC using CST.

The University of Adelaide, through a project part-funded by ARENA, is investigating ways to use CST technology to reduce emissions across various stages of the Bayer alumina refining process. This includes integrating low-temperature CST to produce steam, storing CST heat through solar reforming of natural gas, and using CST as a replacement for natural gas in the high-temperature calcination stage. The latter application of CST has the potential to significantly reduce emissions—natural gas combustion in high temperature calcination typically produces over 20 per cent of the refining process’s total emissions.

Box 8: Case study – Australian research is bringing down the cost of solar PV process heating

ARENA has supported the development of new technologies to reduce the installed cost of PV systems, improve system reliability and develop materials for new market applications.

Every one percentage point efficiency improvement in module performance (e.g. from 20 per cent to 21 per cent), reduces the cost of the module by approximately five per cent. Higher solar cell efficiencies also mean that the same electricity output can be achieved from a smaller number of modules, which also reduces balance of system costs and land costs.

Australian technology is expected to dominate the PV market over the next decade:

- The University of New South Wales (UNSW) developed the Passivated Emitter and Rear Cell (PERC), currently used in more than 60 per cent of commercial PV cells available in the global market, achieving world record efficiencies of up to 25 per cent (compared with approximately 20 per cent in standard solar cells). An estimate made by the Australian National University (ANU) of the potential benefits of the PERC solar cell technology indicates potential savings of $750 million. This is based on a five per cent relative efficiency improvement on 50 per cent of Australian PV systems installed over the ten-year period 2018 to 2028, with average annual installation rates of two gigawatts per year and average area-related costs of $1,500 per kilowatt. Worldwide, the savings could be 50 times larger, or more than $37 billion.
- New hydrogenation technology developed by UNSW and expanded by ANU has been demonstrated to increase the performance of low-quality/low-cost solar-grade silicon wafers. This technology can be incorporated into current standard cell manufacturing lines with minimal equipment change and has 22 industry partners interested in further development prior to commercial adoption. Its deployment over the coming decade could result in global savings of some US$7.5 billion each year, with Australia to directly benefit through lower module costs and royalties feeding back into the economy.

Global trends and drivers

Australia’s technology investments should be responsive to emerging trends. Investment decisions need not be based on predictions about an uncertain future; they can be based on identification and tracking of key drivers influencing technological innovation. Despite the inherent uncertainties, there are some trends we know will shape the global energy landscape and technology development. The Roadmap will track these trends to shape the technology investment portfolio. Some key drivers are considered below.

Global shift towards lower emissions

Parties to the Paris Agreement, including Australia, have collectively committed to the goal of reaching global peak greenhouse gas emissions as soon as possible and balancing anthropogenic emissions sources and sinks (‘net zero’ emissions) in the second half of this century. As countries move towards lower emissions economic activity, demand will rise for low emissions energy and products. This will not only continue to drive interest and investment in renewable energy generation, but also technologies to improve efficiencies in, and reduce emissions from, traditional energy sources including coal, gas and nuclear power.

Continuing deployment of variable, distributed and digitised electricity supply

Government policy and cost reductions are driving rapid uptake of renewable generation (primarily wind and solar PV) around the world. These global trends are continually shifting the economics of renewables as compared with fossil fuels.

Solar and wind are already the cheapest forms of generation on a pure energy collection and generation basis although there is still some way to go before new low emissions technologies (for example, hydrogen) are cost-competitive with gas and coal generation when the full cost of storage and backup of electricity are built in. Uptake of distributed energy resources is growing, and consumer preferences are increasing the complexity of the electricity system. Electricity generation is becoming increasingly interlinked with transport and industrial sectors (also called sectoral coupling) and becoming more digitised. Network augmentation, storage and grid integration technologies will enhance our capacity to optimise energy systems as these trends continue.

In the future (expected to be mostly after 2030), growth in hydrogen production and use could further drive sector coupling, by more closely linking electricity grid, gas distribution network and vehicle fuel infrastructure operations. Hydrogen production through electrolysis will use substantial quantities of electricity and could provide grid firming and stabilisation services.

Beyond firming services, additional hydrogen produced could also be used to refuel fuel cell vehicles, add to gas supply, provide chemical feedstocks or heat, or be exported overseas.

Hydrogen—capturing the opportunity

The world is increasingly looking to clean, flexible, storable and safe fuels. Hydrogen has all of these characteristics. When used as a fuel, it produces no carbon emissions, only water. It can be safely used in a broad range of applications.

Australia is well placed to develop a major hydrogen export sector. We have all the natural resources needed to produce it, a track record in building large-scale energy industries and a reputation as a proven partner to Asia's biggest energy importers.

But the size and timing of Australia's hydrogen opportunity could play out in many ways.

The National Hydrogen Strategy sets out an adaptive approach to industry development, to build on our comparative advantage without risking over-commitment. This approach allows Australia to build and demonstrate hydrogen capability and be ready to move quickly to scale up as signs of large-scale markets emerge. Some early actions to streamline regulation, open international markets and catalyse commercial investment are low-risk steps we can take now. A 'review-revise-adapt' feedback loop will refine actions as technology and markets change.

The National Hydrogen Strategy estimates that, in a cautiously optimistic scenario, the Australian hydrogen industry could generate around 7,600 jobs and add about $11 billion a year in additional GDP by 2050.[17] This is one example of the growth and employment opportunities that exist through investment in new and emerging clean energy technologies.

While the National Hydrogen Strategy takes a measured approach to building a new industry, some argue for Australia taking a much more aggressive approach. There is potential for renewable energy generation to exceed domestic demand, with surplus electricity generated by solar PV and wind absorbed through hydrogen production for domestic use and export.

[17] COAG Energy Council Hydrogen Working Group, 2019.

Significant investment in energy grid infrastructure such as storage and additional interconnectors would be needed to support this approach.

Secure and sustainable water supplies will be critical to attracting investment in hydrogen. Water resource development will need to be economically viable, optimise resource use, provide for environmental needs and consider local community input. Alternative sources such as desalination and waste water will need to be found if water resource planning and water entitlement regimes do not provide supply.

The increasing importance of liquefied natural gas (LNG)

According to the International Energy Agency (IEA), switching from coal to gas can provide ‘quick wins’ for global emissions reductions and has the potential to reduce electricity sector emissions by 10 per cent.[18] Recent modelling by the CSIRO has Australia’s domestic gas increasing by at least 20 per cent by 2060 under all scenarios, while gas production increases by at least 90 per cent (up to 250 per cent depending on the scenario).[19]

The role of natural gas will vary by country and region depending on their specific circumstances. In the IEA’s Sustainable Development Scenario, which is consistent with achieving the Paris Agreement temperature goals, gas demand in the Asia Pacific increases to 2040, and a significant share of this increase is met by growth in production in the region.[20]

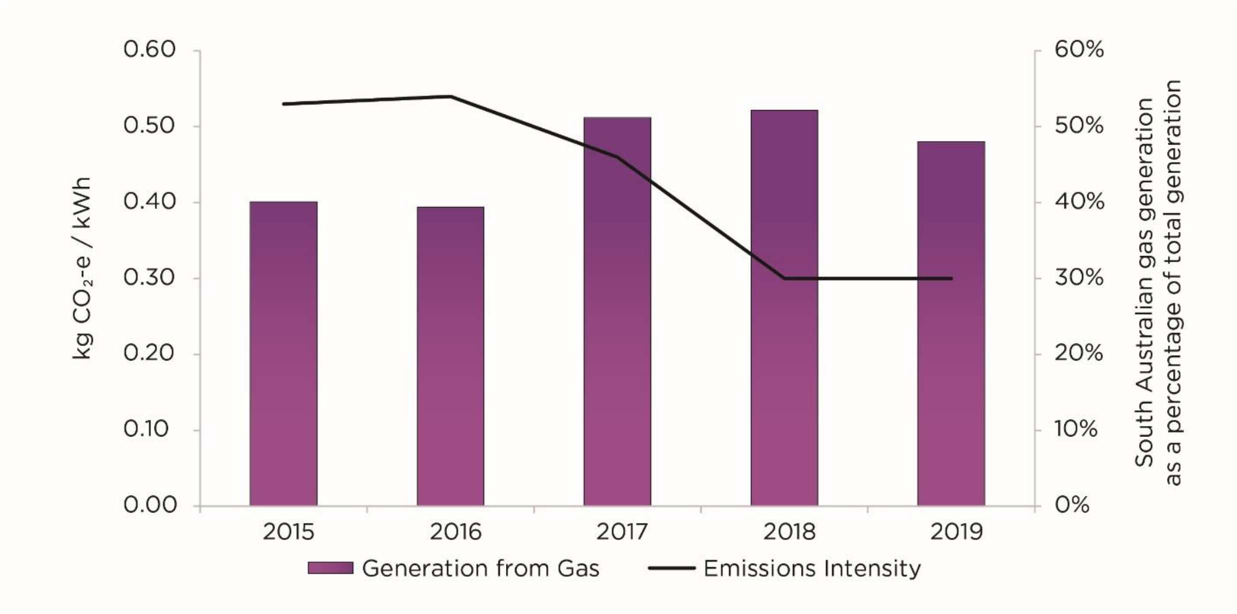
As the world’s largest exporter of LNG, Australia will continue to capitalise on this important low emissions export opportunity. Some of our key trading partners, including Japan and South Korea, have indicated that LNG will play an important role in decarbonising their electricity systems. LNG represents a continuing export opportunity for Australia.

Domestically gas will play an important role in balancing renewable energy, ramping up and down to match supply and demand. Gas is already playing an increasingly important role in South Australia to balance intermittent renewable electricity, with the share of gas generation increasing significantly even as the emissions intensity of the South Australian grid continues to decline to very low levels (Figure 5).

---

[18] IEA, 2019d.
[19] CSIRO 2019, p. 173.
[20] IEA, 2019d.

Figure 5: South Australia's decreasing emissions with increasing gas consumption for generation



Electrification presents an opportunity to reduce emissions; however, some energy uses will not suit electrification and will need other technology developments and alternative fuels to reduce emissions. Low or zero emissions gases, such as hydrogen or biomethane, could gradually replace natural gas for some uses, while utilising aspects of existing gas infrastructure. However, these will likely require substantial investments to develop industries and the technology.

Flexible gas capacity will continue to play a crucial role in supporting variable renewable energy, alongside continuing growth in energy storage, demand management and innovative grid technologies as alternatives.

As the world's largest LNG exporter, all of these factors will have implications for Australia's domestic gas market and export opportunities over the long term.

Key technology challenges and opportunities

Building on our comparative advantages, the roadmap identifies key technological challenges and opportunities for discussion with stakeholders. The Government's technology investments will target these outcomes over the timeframes considered below and summarised in Figure 6.

Short term challenges and opportunities (to 2022)

Electricity: Instantaneous shares of inverter-connected devices (wind and solar PV) continue to grow in the electricity sector, requiring new techniques to manage system security. Limits in distribution networks are also impacting on the expansion of rooftop PV. So an immediate priority (to 2022) for the electricity generation sector is to deploy technology that will allow orderly management of increased variable supply to maintain security and reliability, particularly energy storage and backup. Another challenge, or opportunity, is to deploy technology that will allow the electricity system as a whole to benefit from users investing in rooftop solar PV and other distributed energy resources. Technologies that increase the efficiency of existing thermal generators and reduce emissions also merit consideration, especially given the high utilisation and long lifespans of these types of facilities; a small increase in efficiency can result in a substantial reduction in emissions over many years.

Built environment, transport, industry, agriculture: The Department's survey identified several technologies that are cost-neutral or cost-negative with potential to boost productivity and lower emissions. Addressing challenges to deployment of cost-saving technologies across the built environment, transport, industry and agriculture is accordingly a priority.

Hydrogen: Establishing hydrogen expertise and technical leadership in the short term will help us accelerate the industry in the future if conditions allow. Australia's ability to capture a market share of future growth will be limited without this expertise and leadership. Investing in skills and expertise is an adaptive pathway that is beneficial irrespective of future outcomes. The National Hydrogen Strategy (released in November 2019) has identified short and medium term priorities for skills and RD&D investment.

Key medium term challenges and opportunities (to 2030)

Electricity: In the medium term the challenge will be fully realising the potential benefits of distributed energy resources and continuing to build the flexible capacity and transmission needed to maintain security, reliability and affordability. Government investments in driving down the costs of storage technologies such as large-scale batteries and pumped hydro will realise benefits beyond 2030. Overseas developments in emerging technologies (for example, small modular reactors) will continue to be monitored for potential domestic application.

Built environment: In the built environment, ‘zero energy’ buildings featuring technologies like hot water heat pumps, reverse-cycle air conditioners and variable-speed pool pumps represent a significant opportunity in the medium term to improve energy affordability. Digitalisation of the building services industry and advances in building automation will increase energy productivity and enable buildings to participate in electricity markets as distributed energy resources.

Transport, industry and agriculture: Electrification of industrial processes and transport presents a key opportunity to deliver both affordability and emissions benefits as the electricity grid becomes less emissions intensive and electric vehicle costs decline. Deployment of higher readiness technologies for process heating such as heat pumps, solar thermal and bioenergy, as well as technologies that could boost agricultural productivity, will be important over this time horizon for meeting or exceeding emissions reduction targets by 2030.

Hydrogen: Scaling hydrogen production to drive cost reductions will be a key technological challenge in the medium term. The National Hydrogen Strategy has suggested approaches governments could use to meet this medium term objective. The volume of hydrogen production through different methods (electrolysis, gasification or steam methane reforming) will ultimately be determined by the level of domestic and international demand as well as advances in technology. Australia’s potential for large-scale CCS is already of interest to some potential overseas markets looking to produce low emissions hydrogen from coal and gas.

Long term challenges and opportunities (2030 to 2050 and beyond)

Electricity: By 2030, many of the technical challenges involved in increasing shares of renewables and distributed energy are likely to have been resolved. A key remaining challenge will be providing enough long-duration flexible capacity to maintain reliability during periods of low wind and sun. While gas could fill this role, other options such as concentrated solar thermal and small modular reactors have lower emissions and may improve affordability. If increased electricity demand for electrifying industry and exports eventuates, a key challenge will be to continue growing grid capacity, including generation, storage and transmission.

Built environment: By 2030, comfortable, affordable zero energy buildings could be the norm for new construction, and the challenge will be to bring these benefits to Australia's remaining building stock.

Transport and industry: With electrification of light vehicles expected to be rapidly increasing by 2030, the challenge will shift to ensuring that low emissions options are available for heavy vehicles, including road freight, rail, shipping and aviation.

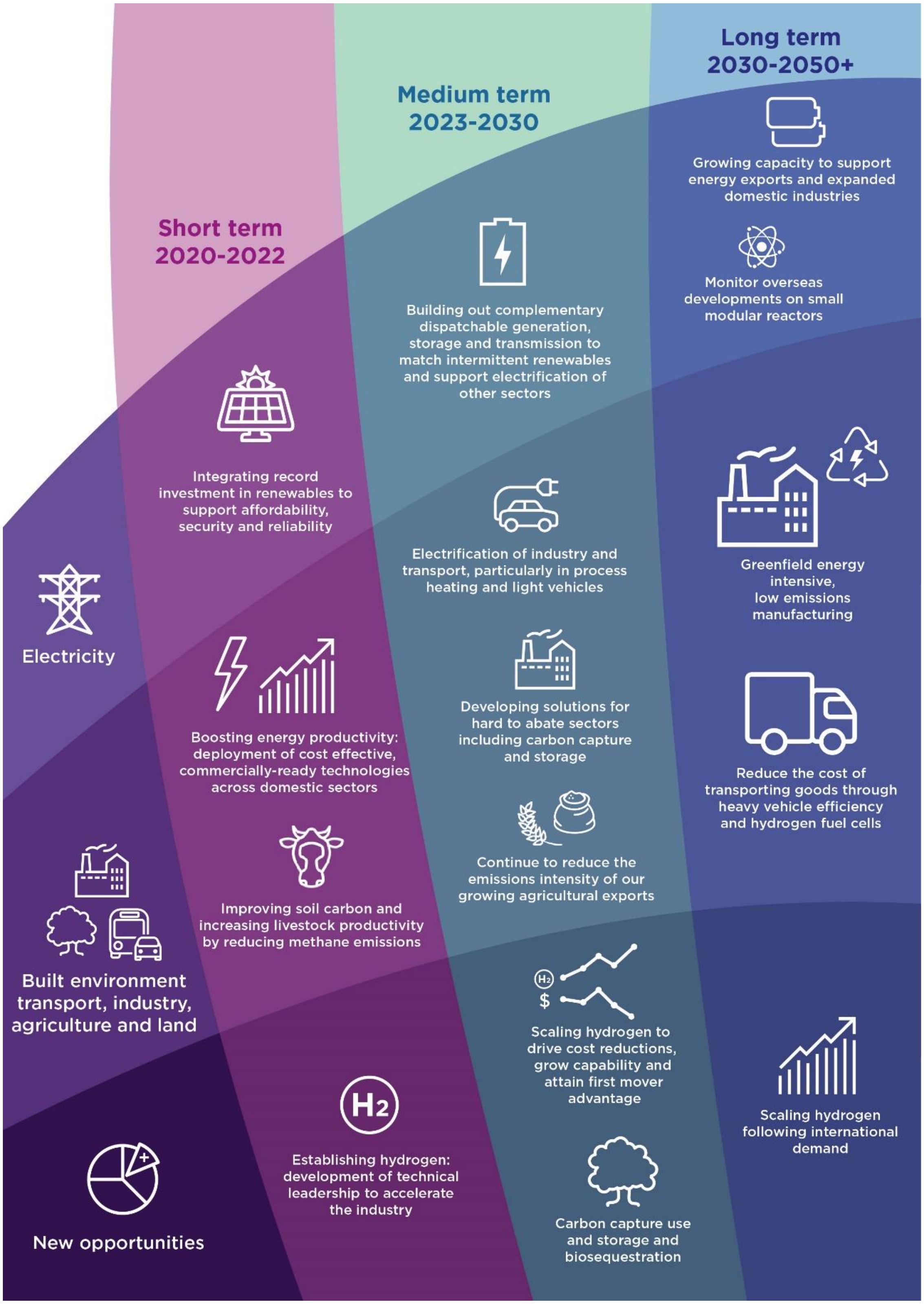
Manufacturing: By the 2030s, Australia may have realised a competitive advantage in energy intensive manufacturing by capitalising on its low-cost renewable capacity and harnessing carbon capture, use and storage (CCUS). This will be achieved by having low-cost renewable capacity matching industrial energy demand by 2030. Testing technological solutions for utilising renewable energy in high-temperature manufacturing will be a sound investment in the long term.

Negative emissions technologies (NETs): Even with strong global action to reduce emissions, deployment of NETs is likely to be necessary if the global goal of limiting warming to well below 2°C is to be met. For these technologies to be viable at scale, Government will need to make strategic investments in R&D and demonstration activities now to see results beyond 2030, including in carbon capture and biosequestration at scale.

Box 9: Battery energy storage system to increase efficiency and reduce emissions from offshore gas operations

In 2019, Woodside Energy Ltd installed a lithium-ion battery energy storage system (BESS) on its Goodwyn Alpha offshore production platform North West Shelf project, which supplies natural gas for Australia and export. The 1 MW / 1 MWh battery provides the back-up capacity for the platform, allowing the platform to run on three gas turbine generators instead of four. Gas turbine generators are significantly more efficient at higher loads, so running fewer generators means less fuel gas is needed to generate the same amount of power. The fuel gas demand is reduced by about eight tonnes per day, reducing the platform's CO_2-e emissions by about 4 per cent.

Figure 6: Key technology challenges and opportunities



Stage 4: Identifying priority technologies

The first Low Emissions Technology Statement will distil priority technologies for short, medium and long term impact. The survey of new and emerging technologies (Stage 2) will need to be refined to support this analysis by identifying interdependencies and cross-cutting technologies across sectors including where cost reductions could accelerate uptake. For example, pathways where the deployment of one technology facilitates another include:

- Deploying electrolysers for producing hydrogen is expected to offer benefits for integrating renewables, through the availability of a large capacity for flexible loads.
- Deploying CCS for hydrogen production from fossil fuels could help generate economies of scale in carbon sequestration projects and support its use for other applications, such as in cement production or in NETs.

An indicative shortlist of technology priorities is presented in Figure 7, provided here to prompt stakeholder views and feedback and inform the priorities to be outlined in the first Low Emissions Technology Statement. These priorities will be further refined and updated through subsequent statements although our commitment to resolving the key short, medium and long term challenges will remain firm.

Figure 7: Indicative shortlist of priority technologies

Electricity	Transport	Buildings (residential and commercial)
• Pumped hydro • Large-scale batteries • Ultra-low-cost transmission • Concentrated solar thermal (CST) • Large-scale solar • Technologies that increase the efficiency of the existing thermal generation fleet • Gas generation to firm variable renewables • Onshore/offshore wind • Grid security technologies • Distributed energy resources integration • Remote area power systems/micro-grids • Solar photovoltaic (PV) (next generation technologies)* • Grid simulation technology • Small modular reactors (SMRs)	• Battery, hybrid and plug-in hybrid electric vehicles • More efficient internal combustion engine vehicles • Fleet technologies e.g. driver aids and feedback, maintenance technologies, improved telematics and logistics, Internet of Things route planning, and backload optimisation • Mode shift technologies • Micro-mobility* • Biofuels • Hydrogen fuel cell heavy vehicles	• Heat pumps • Thermal storage and improved thermal envelopes, including phase change materials • Low embodied carbon materials • Building integrated PV—transparent PV windows; solar tiles • Smart appliances • Natural and new refrigerants
Industry—feedstocks / industrial processes	**Industry—process heating**	**Agriculture and land use**
• Direct reduction of iron using hydrogen • Bio-coke • Carbon capture use and storage (CCUS)* • Hydrogen for ammonia production • Alternative cements—geopolymer, high blend, magnesium	• Heat pumps and other electric technologies • Bioenergy* • Solar thermal • Geothermal* • Hydrogen • Heat integration and system optimisation	• Storing carbon in soil • Storing carbon in vegetation • Livestock productivity
Fugitive emissions and waste	**Hydrogen (cross-cutting)**	**Enabling technologies**
• Ventilation air methane abatement technologies • Landfill gas* • Anaerobic digestion* • Combustion* • Gasification* • Pyrolysis*	• Electrolysers* • Hydrogen supply chain technologies*	• Digital technology enablers e.g. artificial intelligence, Internet of Things, blockchain, digital twins*, remote sensing

• Refrigerant management*		
Mining and industrial equipment	**Negative emissions**	
• Energy management technologies/Control system optimisation	• Range of early-stage technologies	

* Note: the survey of these technologies is still under way and will be included in the first Low Emissions Technology Statement mid-2020.

Stage 5: Identifying most efficient deployment pathways and setting economic goals for key technologies

Uptake of new technologies is ultimately led by industry, consumers and communities leveraging private sector capital. Although government has an important supporting role, finding pathways to the deployment of priority technology will require partnerships with industry and private sector capital, including universities who are one of the largest investors in research.

The Government has established a Ministerial Reference Panel to support the Minister for Energy and Emissions Reduction in identifying commercially viable and efficient deployment pathways for priority technologies. This group of industry, investor, research, government and community leaders will primarily be tasked with finding practical solutions to improve the deployment of commercially ready technologies identified through the Roadmap.

Identifying the need for public funding of innovation

Before designing technology investments, it is important to identify the specific private sector investment gaps that can be corrected through public support. Government has an important role to play in supporting innovation to overcome a range of market failures. The basic research carried out in universities requires public funding, since any commercial applications are highly uncertain. Benefits are likely to accrue to parties beyond the researcher, despite efforts to protect intellectual property through patents and other measures. Put another way, there are positive spill-overs from RD&D that government support can help to realise.

Although Australia has well developed financial systems, venture capital and early-stage financing are still relatively small compared to countries like the United States, Israel or the

United Kingdom. Governments can take on greater risk than private investors, and can place direct value on these benefits, including for disadvantaged Australians and those in regional areas. Government support for innovation in the energy sector means the public can benefit from this innovation sooner, through reduced energy costs, a more secure and reliable energy system, faster emissions reduction or new sources of jobs and growth.

Government support for innovation can take a range of forms. Grant funding addresses the lack of capital available for early-stage projects that are too risky for the private sector. There can sometimes be a role for Government as a venture capital provider. Later stage debt funding helps commercial investors, including traditional banks, become familiar with new asset classes, decreasing risk premiums as well as increasing private capital. Examples include the pre-commercial grant and venture capital funding from ARENA and debt and equity from the CEFC for deployment-scale projects.

Government must strive to support technologies that can win, but must also be disciplined in recognising when technologies are struggling, and in leaving deployment of technologies that have reached commercial viability to the private sector.

Barriers to deployment of priority technologies

Technologies that are yet to enter the market face research and development needs, which can be measured by technological readiness levels (TRL). Once a technology is proven, the extent of commercialisation will broadly depend on the following factors, as identified by ARENA in its commercial readiness indicator (CRI):

- Regulatory settings.
- Stakeholder acceptance.
- Technical performance in a commercial setting.
- Financial proposition for investors including the impact of the new technology on capital, operating costs and revenues.
- Availability of product and skills supply chains required to support commercial uptake.
- Availability of viable markets (both local and overseas).

- Participation of mature and established companies with strong credit ratings and performance records.

CSIRO's 2017 *Low Emissions Technology Roadmap* included a broad survey of the barriers facing key technologies.[21] A comprehensive assessment of commercially viable deployment pathways for priority technologies will be conducted in 2020 with input from the Ministerial Reference Panel.

Stage 6: Balancing overall investment portfolio

The Government will signal refinements to its investment portfolio through annual Low Emissions Technology Statements, aiming to achieve an appropriate weighting of:

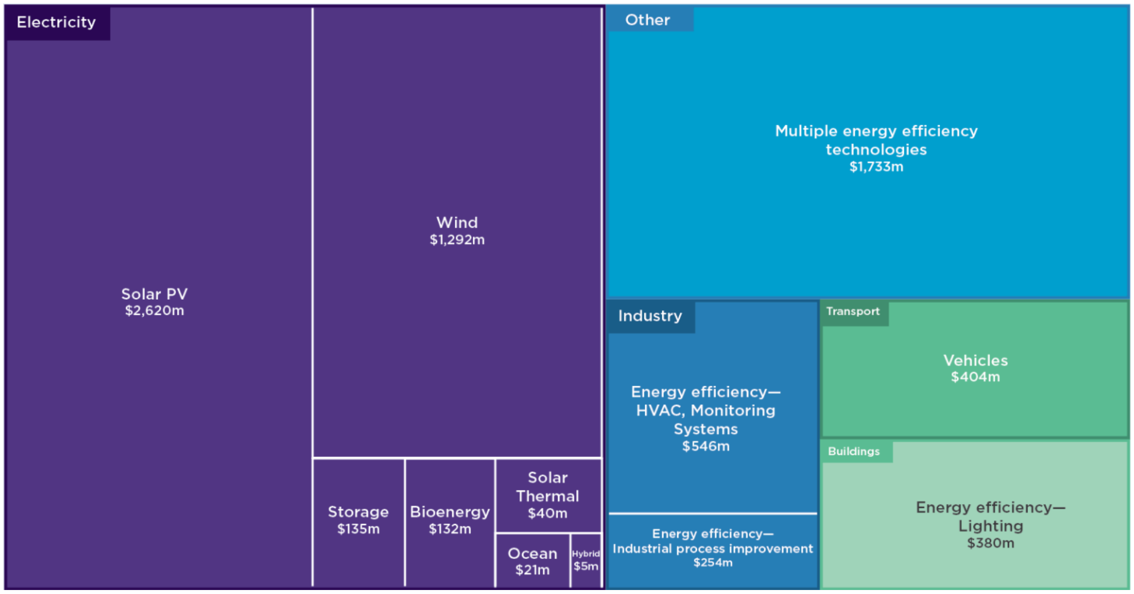
- Commercial and technical risks (that is, by appropriate balance of investments across innovation stages, i.e. R&D, demonstration, deployment).
- Weighting of high and low TRL/CRI technologies.
- Weighting across time horizons (short, medium, and long term).

The overall investment portfolio will also be fine-tuned to account for contemporary technological developments and global trends.

The Government has reprioritised ARENA's and the CEFC's investment focus over time. For example, ARENA initially made substantial investments in large-scale solar, and this focus has now shifted to grid firming and reliability technologies. It is important that our technology strategy is supported by implementation flexible enough to meet changing priorities.

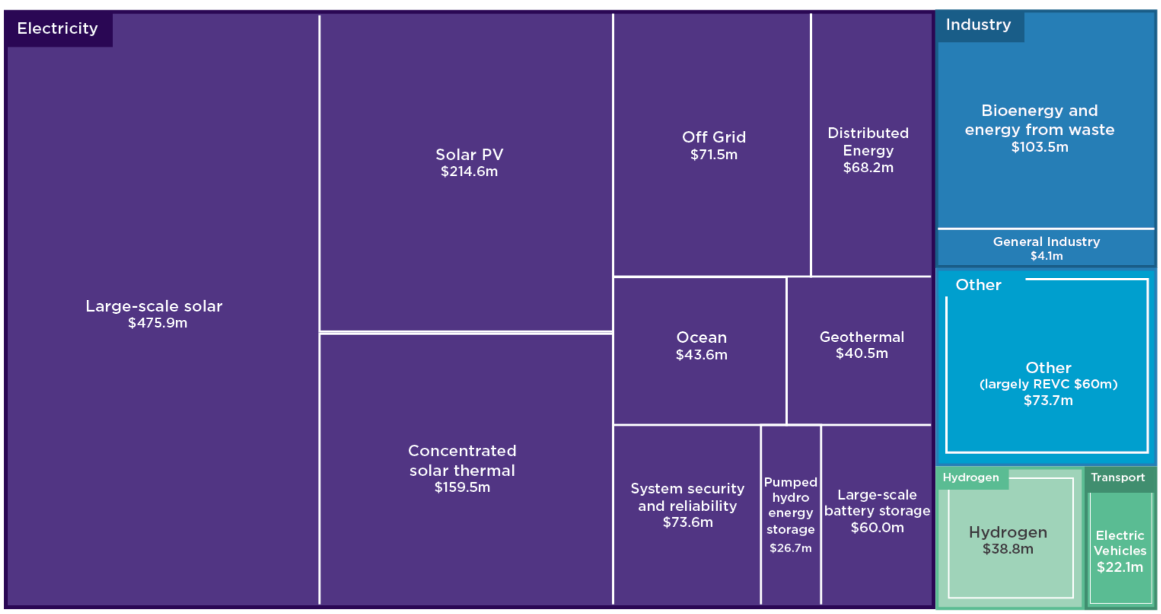
[21] CSIRO, 2017a, p. 71.

Figure 8: CEFC funding commitments 2013–2019 (total $7.6 billion)



Note: to September 2019

Figure 9: ARENA funding commitments to projects 2012–2019 ($1.5 billion)



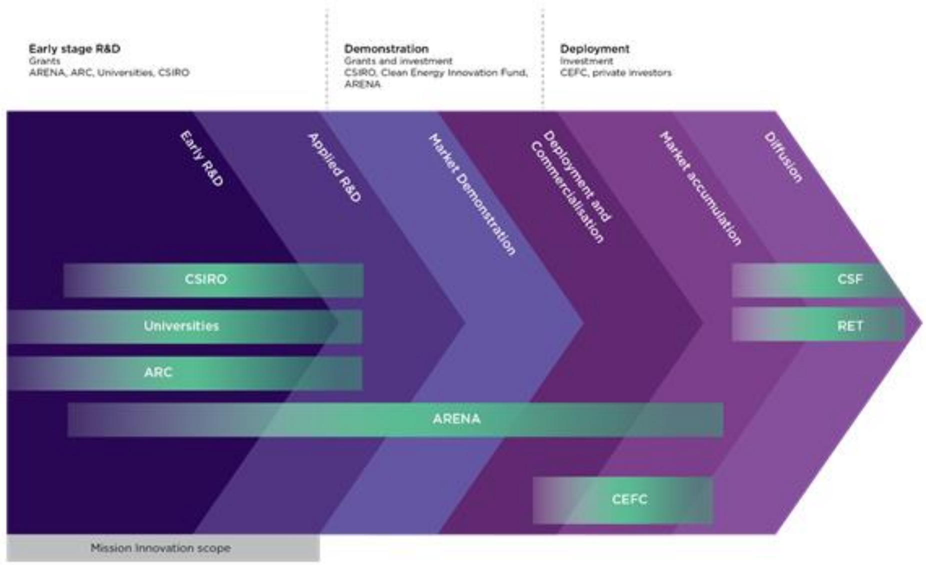
Note: to 30 September 2019

Stage 7: Implementing investments (institutional structure)

Current innovation institutions

Australia has strong public institutions that support clean energy innovation from early-stage R&D to commercial deployment. These include the Australian Research Council (ARC), CSIRO, ARENA, the CEFC, and cooperative research centres (CRCs).

Figure 10: Australian Government investment across the innovation chain



Note: RET: Renewable Energy Target; CSF: Climate Solutions Fund.

Optimise delivery vehicles

This Roadmap will provide guidance on technology priorities for our technology investments. It will guide and provide clearer priorities and goals for how individual agencies (including the CEFC and ARENA) set their investment strategies. The Roadmap will allow the flexibility for agencies to respond to emerging opportunities when they arise and to react to their own clients and portfolio needs.

One of the key focus of investment when ARENA and the CEFC were established was to make renewable energy sources, such as solar PV, competitive with other technologies. It was not anticipated how quickly costs would reduce, especially for solar PV.

The focus of ARENA and the CEFC support now includes integrating variable generation technologies into the electricity grid, to ensure a secure and reliable energy supply. Other priorities include abatement of emissions in the industrial sector and supporting the development of the emerging hydrogen sector. The Government has also asked the CEFC to lead innovative financing in Australia's recycling industry.

Stage 8: Assessing the impact of technology investments

The impact of the Government's investments under this Roadmap will be measured against two key metrics. The first will be the measurable economic technology 'stretch goals' outlined above including 'H2 under $2'. These technology stretch goals will provide a yardstick to track progress on deployment of priority technologies.

The second measure of success will be the extent to which private sector capital and other investment follows the Government's commitments. The expected private sector buy-in may vary according to stage of innovation supported as well as the overall context of the project. Proponents and agencies like ARENA and the CEFC will be expected to anticipate the extent of private sector buy-in they expect over the duration of the investments and achieve appropriate benchmarks.

The Roadmap will encourage consistent impact evaluation across investments within its remit. Greater consistency at a national level of technology investment impact assessment will enable tracking the progress of the overarching investment portfolio against overarching goals. Enhancing performance measurement frameworks will provide a results-driven basis for future investments in low emissions technology.

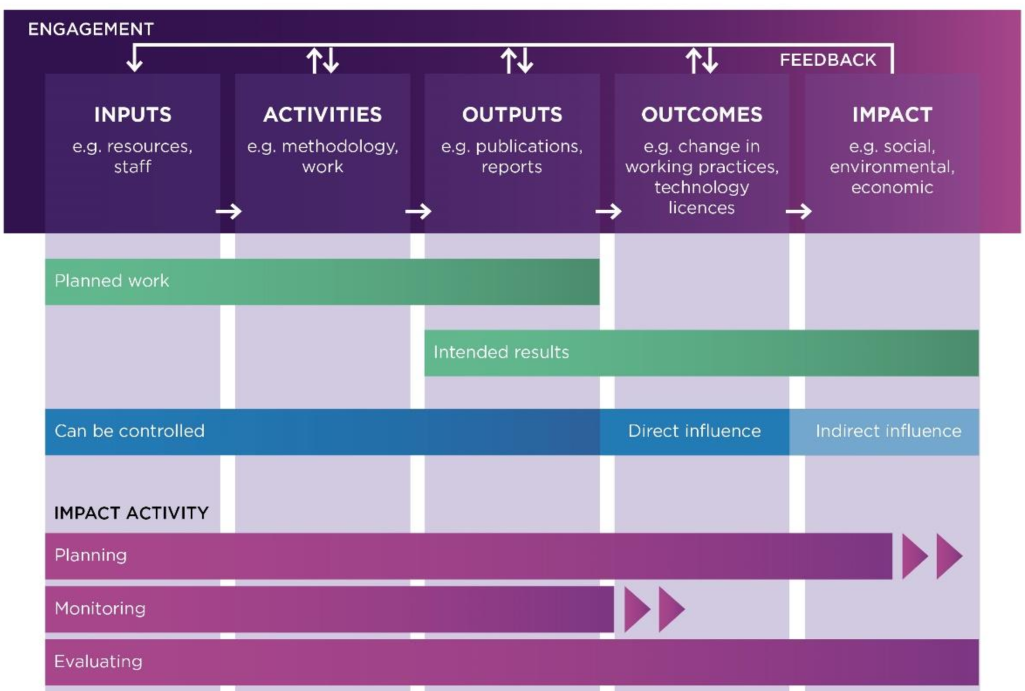
The aim will be to encourage better and more consistent impact assessment to drive improvements in effectiveness over time. The approach will not be prescriptive but will provide broad guidance to investment agencies and project proponents on best practice impact assessment.

Impact assessment will be modelled on the framework developed by CSIRO in its 2015 *Impact Evaluation Guide*.[22] CSIRO's Impact Evaluation Guide is used across the whole organisation and supports comparability of results from each evaluation over time (Figure 11).

The CSIRO guide describes the minimum requirements for all CSIRO impact evaluations, regardless of the purpose of the evaluation or the 'unit of evaluation' (which could be an individual project, subject area or business unit or the whole enterprise). It guides researchers, CSIRO staff and engaged external support to address key relevant questions in a logically consistent manner, to select the appropriate resources and methods in the evaluation of CSIRO research, and to ensure consistency in analysing results.

Evaluating impact will also consider social factors, where relevant, given that technology solutions can have different impacts and benefits across regions and demographics, including those in rural and regional areas.

Figure 11: CSIRO's impact framework[23]



[22] CSIRO, 2015.

[23] CSIRO, 2018.

Global technology trends and priorities

Australia's understanding of global energy trends and priorities will be key to aligning our national priorities and development pathways. International engagement will support these activities and ensure Australia maximises domestic opportunities from the global shift to lower emissions.

Priority actions recommended by the International Energy Agency

As energy systems become increasingly complex, digitised, and interlinked, greater coordination and balancing across the Government's investment portfolio will be important. The IEA advised G20 countries on priority actions to optimise public sector innovation support in its report *Technology Innovation to Accelerate Energy Transitions*.[24]

The IEA recommendations highlight the need for rigorous tracking of public sector investment in energy technology; prioritisation of technologies that reduce costs; partnership with the private sector; and taking a portfolio approach. The strategic and system-wide approach to technology investments established by this Roadmap is informed by the IEA's recommendations.

Understanding global technology needs

International collaboration is vital to solving global energy technology challenges. Regional energy technology innovation collaboration is a feature of many national innovation strategies. Countries including the United States, Japan, Singapore, South Korea, and the United Kingdom are actively encouraging international collaboration through measures such as exchanging researchers, establishing international campuses of government or research bodies (e.g. CSIRO) and export financing of energy projects.

The sustainability of manufacturing and industrial sectors is a pressing issue internationally, and governments are looking for deeper political and technical cooperation on reducing emissions while ensuring continued economic growth. There are several multilateral efforts and potential partner countries that are focused on setting the international agenda for energy innovation and finding practical technological solutions.

[24] IEA, 2019b.

Australia is already an active member of Mission Innovation and co-leads its ‘hydrogen challenge’. Mission Innovation is a global initiative of 24 countries to accelerate clean energy innovation. Another example is the Leadership Group for Industry Transition, which is a public-private effort to ensure that heavy industries and mobility companies can find workable pathways to deliver the goals of the Paris Agreement. These efforts are strongly supported by emerging and developed countries in our region. Australia’s influence is essential to ensure the global energy innovation agenda supports the interests of our industry and communities.

The Government will continue to engage with existing and emerging international cooperation to lend our expertise in particular sectors and help accelerate practical solutions in hard-to-abate sectors. Enhanced bilateral partnerships will also support industry decarbonisation in a way that builds the Australian economy, particularly for our emissions-intensive trade-exposed industries.

The IEA’s *Tracking Clean Energy Progress* report has surveyed global technology needs and categorised technologies as ‘on track’, ‘more efforts required’ or ‘not on track’. Australia’s technology investments should be designed to support our businesses and research that contribute to global technology needs wherever possible.

Figure 12: Global energy technology—IEA view of where effort is needed

	Power	Transport	Industry	Fuel supply	Energy integration	Buildings
On track	Bioenergy Solar PV	Electric vehicles Rail			Energy storage	Data centres & networks Lighting
More efforts required	Hydropower Natural gas-fired power Nuclear power Offshore wind Onshore wind Renewable power	Aviation International shipping Trucks and buses	Aluminium Cement Chemicals Iron & steel Pulp & paper		Demand response Hydrogen Smart grids	Appliances & equipment Cooling
Not on track	CCUS in power Coal-fired power Concentrating solar power Geothermal Ocean	Fuel economy Transport biofuels	CCUS in industry & transformation	Flaring emissions Methane emissions from oil & gas		Building envelopes Heat pumps Heating

Note: CCUS: Carbon capture utilisation and storage
Source: IEA, 2019a.

Trade and investment international engagement

Mobilising our trade and investment agreements to build supply chains for technology (both to bring overseas technologies to Australia and to export our own innovation) is an important part of the Government's overall strategy. The Government will work to find opportunities for Australian businesses and regional communities in global low emissions value chains. We will use trade and investment agreements to further those opportunities with our major trading partners, including by improving standards and conformity assessment around low emissions value chains.

Building a technology partnership

Positioning Australia as a leader in low emissions technologies requires a partnership with other levels of government, the private sector and researchers as well as close collaboration internationally. To build that partnership this Roadmap will be supported by:

- **Low emissions technology statements** published each year to communicate progress towards defined technology goals. Each statement will provide an update of global technological developments and fine-tune the Government's investment portfolio while retaining commitment to our long term vision.
- **Ministerial Reference Panel** composed of industry, private investment, government and research leaders to advise the Minister for Energy and Emissions Reduction in the preparation of Low Emissions Technology Statements. While the panel will advise generally on technology priorities, it will have a key role in identifying pathways for efficient deployment of new technologies. Dr Alan Finkel, Australia's Chief Scientist, is the inaugural Chair of the Ministerial Reference Panel.
- **Technical expert review** to ensure that the Low Emissions Technology Statements are supported by the best available data and analytics.
- **Targeted industry and community consultation** to test the assumptions behind the Government's technical analysis and build partnerships with stakeholders.
- **Open public consultation** through the Department of Industry, Science, Energy and Resources website. Consultation seeks input from all Australians on the direction of the Government's technology roadmap.

The first Low Emissions Technology Statement will be published in 2020 with input from the above. All Australians are invited to contribute to this important national conversation.

Stakeholder Input

The Technology Investment Roadmap will help inform Australia's first Low Emissions Technology Statement and will be a critical input to Australia's Long Term Emissions Reduction Strategy. The Australian Government is committed to consulting widely with businesses, the community and Commonwealth, state and territory agencies in developing these products.

The Government welcomes stakeholders' views on the Roadmap, including with respect to:

a) The challenges, global trends and competitive advantages that should be considered in setting Australia's technology priorities.

b) The shortlist of technologies that Australia could prioritise for achieving scale in deployment through its technology investments (see Figure 7).

c) Goals for leveraging private investment.

d) What broader issues, including infrastructure, skills, regulation or planning, need to be worked through to enable priority technologies to be adopted at scale in Australia while maintaining the support of local communities.

e) Where Australia, including its regional communities, is well placed to take advantage of future demand for low emissions technologies, and support global emissions reductions by helping to deepen trade, markets and global supply chains.

In particular, the Government would welcome suggestions for economic stretch goals that could help establish pathways for the cost-effective deployment of priority technologies. As outlined in this Roadmap, these stretch goals would include producing hydrogen under $2 per kilogram, but could also cover carbon capture use and storage (CCUS), biological sequestration (in soil and vegetation), firmed renewables, and long duration energy storage. The Government is interested in partnering with industry, research institutions and others with relevant commercial or technical expertise to develop these economic stretch goals, which should be ambitious but achievable.

Written submissions should be provided to https://consult.industry.gov.au/ by 11:59pm (AEST) Sunday, 21 June 2020.

Glossary of selected technical terms

Term	Definition
Biochar	A carbon-rich form of charcoal that can be used to increase the amount of carbon in soil, used as a form of carbon capture and storage to reduce emissions and provide benefits to soil fertility and productivity.
Biomass	Made of organic materials like wood waste and municipal waste that can be used to produce heat or energy (such as electricity and liquid fuels) or even recycled into new material like concrete.
Carbon capture and storage (CCS)	A process that captures carbon dioxide (CO_2) from industrial processes, energy generation, or the atmosphere and stores it underground. May also involve carbon capture utilisation and storage (CCUS) where the CO_2 is used, for example, to manufacture biofuels, to boost plant growth, or in food and drink production.
Combined cycle gas turbine (CCGT)	A generator with a gas heat recovery steam generator that captures heat from the turbine's exhaust to produce steam and drive an additional turbine to improve thermal efficiency.
Concentrated solar thermal (CST)	Similar to solar photovoltaic (PV) used to generate electricity but CST uses sunlight to generate heat that can be used to produce electricity, drive industrial processes, or be stored in batteries. CST can generate larger amounts of heat to power large energy users or at a grid scale.
Demand-side energy	The side of the energy market (opposite to supply side or energy generation) that demands or needs energy, such as households and businesses. For example, energy-efficient technologies can lower the demand-side need for energy and relieve pressure on energy supply.
Distributed energy resources (DER)	Energy resources that are spread out or distributed away from larger scale generation such as at a power plant. DER includes household or business rooftop solar PV, batteries, and thermal storage.
Electric arc furnaces	Industrial process and equipment that use the energy produced by an electric arc to reuse raw or recyclable materials into end-use products, such as iron ore into iron or scrap steel into liquid steel.
Electronically commutated (EC) fans	A type of efficient fan that combines AC and DC voltages and allows greater/variable speed control.
Electrification	A change of processes that ordinarily rely on heat, gas or liquid fuel source to use electricity instead. Electricity can then come from renewable sources such as wind or solar energy.
Geothermal	A type of renewable energy that uses the Earth's internal heat.
Grid simulation	A process to model or analyse the electrical grid.
Grid-forming inverters	Equipment that converts DC electricity (e.g. from a solar farm) to AC and provides services such as voltage and frequency control.
Heat pump	A technology that transfers heat using mechanical energy. For example, a heat pump water heater uses the transferred heat to heat water.

Term	Definition
Hydrogen	The most abundant chemical element in the universe. Hydrogen can be used as a gas or liquid to produce energy or to generate other materials, such as ammonia, for use in energy processes.
Integrated grid	Digital systems to better manage the grid, such as demand response, virtual power plants, and grid models.
Low embodied carbon materials	Housing or other construction materials that produce less emissions in the manufacture, transport and use of the material. Can include materials such as low carbon bricks.
Microgrid	A localised grid of electricity generation and loads that is usually connected to a larger grid but can disconnect and operate independently in ‘island mode’.
Network augmentation and frequency control	Changes required to ensure network security and reliability with increased use of renewable energy resources.
Passive design	Building design to best capture and use the local climate to control the heating and cooling of a building. Passive design reduces the amount of energy needed to heat and cool a building.
Phase change materials	Materials that change from solid to liquid and vice versa at certain temperatures, sandwiched between polymer or aluminium sheets to improve the thermal mass of a building and reduce temperature changes within the building, reducing the amount of heating and cooling needed.
Process integration tools	Tools that optimise energy and heat requirements in manufacturing and industrial processes. Can reduce the amount of energy needed to power a process or generate heat.
Solar thermal	A technology that harnesses the sun’s power to generate heat that can be used to heat water or stored to generate energy for later use or for other purposes.
Synchronous condensers	A motor that is not connected to a load, used to adjust conditions (such as voltage) in a power grid.
Thermochromic and electrochromic glazing	Materials that can be applied to glass to regulate temperature. Can help reduce heating and cooling needs in buildings.
Ventilation air methane (VAM) technologies	A range of technologies designed to abate the methane emitted through the ventilated air of underground coal mines.
Virtual power plant (VPP)	A network of distributed energy resources, operated together to provide power and/or other services to the grid.

Reference list

Australian Energy Market Operator (AEMO). (2019). *South Australian Electricity Report*. Retrieved from AEMO: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2019/2019-South-Australian-Electricity-Report.pdf

Australian Renewable Energy Agency (ARENA). (2014). *Commercial Readiness Index for Renewable Energy Sectors*. Retrieved from ARENA: https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf

ARENA. (2019a). *Renewable energy options for industrial process heat*. Retrieved from ARENA: https://arena.gov.au/assets/2019/11/renewable-energy-options-for-industrial-process-heat.pdf

ARENA. (2019b). *Feasibility Study for a Green Hydrogen and Ammonia Project*. Retrieved from https://arena.gov.au/projects/feasibility-study-for-a-green-hydrogen-and-ammonia-project

ARENA. (2019c). *NT Solar Energy Transformation Program*. Retrieved from https://arena.gov.au/projects/northern-territory-solar-energy-transformation-program

business.gov.au. (2019). *Regional and Remote Communities Reliability Fund Microgrids 2019–20*. Retrieved from https://www.business.gov.au/Grants-and-Programs/Regional-and-Remote-Communities-Reliability-Fund-Microgrids

COAG Energy Council Hydrogen Working Group. (2019). *Australia's National Hydrogen Strategy*. Retrieved from Department of Industry, Science, Energy and Resources: https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

Commonwealth of Australia. (2019). *Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2019*. Retrieved from Department of the Environment and Energy: https://www.environment.gov.au/system/files/resources/8d47dec2-cd70-4a67-a7ab-85d67f3d53be/files/nggi-quarterly-update-jun-2019.pdf

Commonwealth Scientific and Industrial Research Organisation (CSIRO). (2015). *Impact Evaluation Guide*. Retrieved from CSIRO: https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F

CSIRO. (2017a). *Low Emissions Technology Roadmap—main report*. Retrieved from CSIRO: https://www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap

CSIRO. (2017b). *Low Emissions Technology Roadmap—technical report*. Retrieved from CSIRO: https://www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap

CSIRO. (2018). *How CSIRO ensures it delivers impact*. Retrieved from CSIRO: https://www.csiro.au/~/media/About/Files/Our-impact-framework/How_CSIRO_ensures_it_delivers_impact-PDF.pdf

CSIRO. (2019). *Australian National Outlook 2019*. Retrieved from CSIRO: https://www.csiro.au/en/Showcase/ANO

European Commission. (2017). *The Strategic Energy Technology (SET) Plan*. Retrieved from European Commission: https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

Export.gov. (2018). *Australia—Mining*. Retrieved from https://www.export.gov/article?id=Australia-Mining

German Federal Ministry for Economic Affairs and Energy. (2018). *Innovations for the Energy Transition: 7th Energy Research Programme of the Federal Government*. Retrieved from German Federal Ministry for Economic Affairs and Energy: https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/7th-energy-research-programme-of-the-federal-government.pdf?__blob=publicationFile&v=2

Graham, PW, Hayward, J, Foster, J, Story, O, and Havas, L. (2018). *Gencost 2018*. Retrieved from CSIRO: https://publications.csiro.au/rpr/download?pid=csiro:EP189502&dsid=DS1

Haque, N, and de Vries, M. (2012). *Greenhouse gas emission assessment of bio-coke from wood for application as bioanode in aluminium production*. Retrieved from CSIRO: https://publications.csiro.au/rpr/download?pid=csiro:EP124889&dsid=DS4

International Energy Agency (IEA). (2019a). *Tracking Clean Energy Progress*. Retrieved from https://www.iea.org/tcep

IEA. (2019b). *Technology Innovation to Accelerate Energy Transitions*. Retrieved from IEA: https://www.iea.org/reports/technology-innovation-to-accelerate-energy-transitions

IEA. (2019c). *Commentary: Growing preference for SUVs challenges emissions reductions in passenger car market*. Retrieved from https://www.iea.org/newsroom/news/2019/october/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-mark.html?mc_cid=add0ee51bd&mc_eid=ac3c6883ba

IEA. (2019d). *World Energy Outlook 2019*. Retrieved from IEA: https://www.iea.org/reports/world-energy-outlook-2019

International Renewable Energy Agency (IRENA). (2019). *Hydrogen: A Renewable Perspective*. Retrieved from IRENA: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf

Japan Ministry of Economy, Trade and Industry. (2018). *Strategic Energy Plan*. Retrieved from Japan Ministry of Economy, Trade and Industry: https://www.meti.go.jp/english/press/2018/0703_002.html

UK Department for Business, Energy and Industrial Strategy. (2017). *Industrial Strategy*. Retrieved from UK Department for Business, Energy and Industrial Strategy: https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

US Department of Energy. (2017). *Energy Innovation Portfolio Plan FY2018–FY2022*. Retrieved from Joint Chiefs of Staff: https://www.jcs.mil/Portals/36/Documents/Doctrine/Interorganizational_Documents/doe_energyinno_plan18_22.pdf?ver=2020-01-21-142918-657

US Department of Energy. (2015). *Quadrennial Technology Review—An Assessment of Energy Technologies and Research Opportunities*. Retrieved from https://www.energy.gov/quadrennial-technology-review-2015

Vast Solar. (2020). *Home page*. Retrieved from https://vastsolar.com/

Xi, F, Davis, S, Ciais, P Crawford-Brown, D, Guan, D, Pade, C, Shi, T, Syddall, M, Lv, J, Ji, L, Bing, L, Wang, J, Wei, W, Yang, K-H, Lagerblad, B, Galan, I, Andrade, C, Zhang, Y & Liu, Z (2016). Substantial global carbon uptake by cement carbonation. *Nature Geosci* 9, 880–883.

Appendix A: List of all technologies surveyed

Table 1: List of all technologies surveyed

Agriculture and land use
Alternative livestock feed—Desmanthus and Leucaena
Environmental plantings (non-harvest)
Livestock feed supplement—3-NOP (3-nitrooxypropanol)
Livestock feed supplement—FutureFeed—red algae (Asparagopsis)
Native forest regeneration
Plantation forestry (for harvest)
Building soil carbon
Commercial buildings
Chillers
Commercial catering efficiency technology
Commercial refrigeration efficiency upgrades
Condensing boilers
District cooling
Electrically commutated fans
Heat pump—domestic hot water
Heat pump—heating hot water
Heat recovery
Increased duct sizing
Indirect evaporative cooling
Passive design and phase change materials (PCM)
Passive radiant cooling
Personalised/task-based cooling
Smart controls
Solar thermal heating and cooling
Thermochromic/electrochromic glazing
Transparent photovoltaic windows
Electricity generation
Batteries—solar
Batteries—wind
Closed-cycle gas turbine
Hydrogen
Integrated grid (includes demand response, virtual power plants (VPPs), grid models)
Network augmentation, storage, and frequency control (solar and wind available with network augmentation, storage, and frequency control upgrades)
Nuclear

Nuclear (next generation)
Nuclear (small modular)
Pumped hydro with solar
Pumped hydro with wind
Solar
Solar thermal (includes concentrated solar thermal)
Ultra-low-cost transmission
Wind
Feedstocks
Aluminium Demand Response
Bio-coke
Bioplastic
Geopolymer and high-blend cements
Hydrogen reduction (includes direct reduced iron (DRI))
Inert anodes
Lead electrolysis
Magnesium cements
Recycling and other circular economy measures
Renewable ammonia (using hydrogen)
Fugitives
Flaring
Landfill gas and organic waste utilisation
Photo-catalytic oxidation
Ventilation air methane capture (VAMCAP)
Ventilation air methane catalytic turbine (VAMCAT)
Ventilation air methane mitigation (VAMMIT)
Mining and industrial equipment
3D impellers
Additive manufacturing
Biomass, biogas, waste
Compressed air storage
Control system optimisation
Energy management technologies
High-efficiency motors
Optimal comminution technologies
Optimised design technologies
Optimised maintenance technologies
Variable-speed drives
Negative emissions
Afforestation
Artificial upwelling or downwelling

Bioenergy with carbon capture and storage (BECCS)
Biochar
Carbon mineralisation
CO_2 capture (CO_2 scrubbing)
Coastal ‘blue’ carbon
Cropping and grazing
Direct air capture (CO_2 scrubbing)
Enhanced weathering
Geological sequestration
Negative emission hydrogen
Ocean alkalinisation
Ocean carbon capture
Ocean fertilisation
Ocean storage of CO_2
Soil
Process heating
Biomass
Electric arc furnaces
Heat integration
Heat pumps
Microwave heating
Molten silicon
Plasma arc furnaces
Thermal storage
Residential buildings
Batteries
Heat pump dryers
Heat pump hot water
Heat pump pool heaters
Hydrogen appliances
Induction for inbuilt cooktops, solar and batteries
Induction, solar and batteries
Inverter refrigerators
LED lighting
Low embodied carbon materials
Low embodied homes through value engineering
Natural refrigerants
New refrigerants
Oven insulation
Phase change materials

Reverse-cycle air conditioners
Smart appliances (other than air conditioning)
Solar PV
Solar PV with network upgrades
Solar tiles with distribution network upgrades
Thermal storage
Variable-speed pool pumps
Transportation
Battery electric vehicles
Bio and renewable diesel
Cellulosic ethanol
Continuously variable transmission (CVT) and improved transmission
Driver aids and feedback
e-bikes, scooters and similar
Fleet maintenance technologies
Fleet management technologies
High-speed rail
Hybrids
Hydrogen vehicles
Improved components and lightweighting
Latest engine technology
Liquefied natural gas (LNG)
Mode shift technologies
Novel biofuels
Plug-in hybrid electric vehicles
Public transport technologies
Sustainable aviation fuel
Telematics and optimised logistics
Turbine/propeller optimisation

Appendix B: Technology analysis by sector

Technology costs have been calculated by comparing the costs and savings of new technologies to those of practical replacement of existing, common-use technologies on a net present value (NPV) basis. A single discount rate of 7 per cent was applied. It is acknowledged that discount rates will vary across industries based on risk and return, and this analysis will be refined following industry consultation. For the electricity generation technologies, pumped hydro (solar and wind), nuclear, and batteries (solar and wind), abatement and cost were estimated on replacing existing generators within the grid over the time period. Where best available data has predicted cost changes over time for technologies, this information has been factored into estimates across time periods. Where no information on cost predictions has been available, standard learning rates were applied where the technology is still developing, however where the technology is mature in its current form, requiring a step change improvement, costs have been held steady at today's costs.

Technologies were evaluated based on the technology readiness level (TRL) globally, and on the commercial readiness index (CRI) developed by ARENA. CRI relates to commercial deployment in Australia. Emerging technologies were measured from TRL 1 (concept) to TRL 9 (full technological development). For technologies with a TRL of 9, the CRI has been shown in each chart listed in Appendix B. The TRL and CRI levels reflect the business as usual trajectory for a technology that could be reached by the end of the relevant time period.

Electricity supply (Figure 13)[25]

There are a range of new and emerging technologies with potential to improve reliability, security, affordability and emissions in the electricity generation sector, including:[26]

- Low-cost generation, namely solar photovoltaic (PV) and wind when combined with technologies to improve grid stability and increase the use of renewables, such as network augmentation, storage, gas generation, and frequency and voltage control technology.

[25] Survey included technologies used in the process of generating electric power, including renewables, storage, nuclear, solar thermal virtual power plants, distributed energy resources, and grid enabling technologies.
[26] For the electricity generation sector, the survey has used the existing work of CSIRO and the Australian Energy Market Operator (AEMO) in the GenCost 2018 report (Graham et al, 2018).

- Transmission technology to improve the connection of new generation to the grid.
- System security technologies to ensure stable operation of the grid as the share of inverter-connected devices grows—for example, grid-firming inverters, synchronous condensers.
- Grid simulation technology for optimising operation and augmentation of the grid.
- Technologies for integrating distributed energy resources (DER) such as rooftop solar PV, batteries and flexible loads into the electricity system—for example, virtual power plants (VPPs).

The affordability and abatement benefits delivered by wind and solar PV generation will depend on the rate of deployment of enabling technologies such as storage. For this reason, abatement attributed to deployment of renewable capacity is reflected in these technologies paired with enabling technologies including battery storage.

Firming technologies for solar PV and wind include storage technologies such as large-scale batteries and pumped hydro, as well as demand-side flexibility. These technologies have high technological readiness but are not yet widely commercially deployed in Australia. While solar PV is a mature technology there is still potential to drive substantial improvements in efficiency and, in turn, costs. Given Australia's global pre-eminence in solar PV research and development (R&D) and established paths to commercialisation, a continued focus on developing next generation and emerging solar PV technologies could drive significant affordability and emissions reductions benefits.

New nuclear technologies (for example, small modular nuclear) have potential but require R&D and identified deployment pathways. The engineering, cost and environmental challenges, alongside social acceptability of nuclear power in Australia will be key determinants of any future deployment.

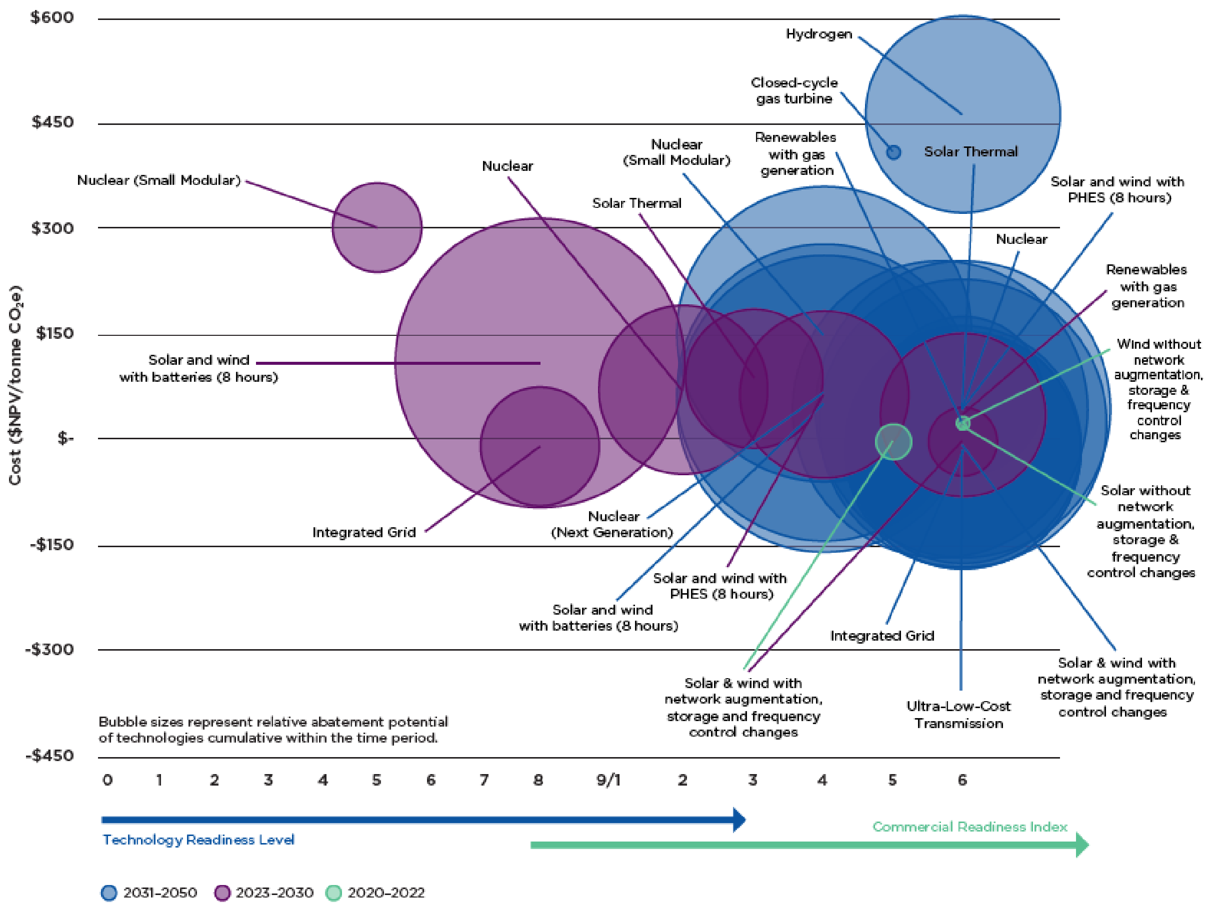
Other generation technologies, such as concentrated solar thermal (CST) could see broader commercial deployment over the medium term. Given its storage and firming applications, CST is likely to play a role in a least-cost energy system. Ultra-low-cost transmission technology also shows promise in delivering cheaper supply but is in the early stages of development and would require long term RD&D support to bring to market.

Increasing the deployment of DER integration technologies such as VPPs will support secure and reliable operation of the grid as more households and businesses deploy DER. They will also ensure distribution networks have enough hosting capacity without the need for expensive upgrades. Deployment of these technologies would require further demonstration projects to work through the complex regulatory, market and stakeholder issues involved. Continued research and development is needed to understand how best to operate the Australian electricity system as the share of renewables and DER increases.

Microgrids are power systems that can be grid-connected or operate off grid. Stand-alone power systems (SAPS) and remote area power systems (RAPS) are like microgrids but are not grid-connected. Both use local generation and enabling technologies such as batteries. Falling costs of new technology are increasingly allowing electricity services to be delivered through off-grid alternatives, which can be lower cost, lower emissions and more reliable than grid connection for remote and fringe-of-grid locations.[27] Comparatively higher costs of generating electricity in remote locations (for example, remote communities or mining sites) mean that new technologies can reach commerciality in these applications earlier than in other deployment contexts.

[27] The Regional and Remote Communities Reliability Fund—Microgrids was announced by the Australian Government to support feasibility studies looking into more reliable, secure and cost-effective energy supply to regional and remote communities in Australia. The program will fund feasibility studies of microgrid technologies to replace, upgrade or supplement existing electricity supply arrangements in off-grid and fringe-of-grid communities located in regional and remote areas (business.gov.au, 2019).

Figure 13: Electricity generation technologies, 2020–2050



Industry – process heating (Figure 14)[28]

Emerging technologies for process heating range from proven, commercially deployed technology (bagasse in sugar refining) to more prospective applications of hydrogen in industrial processes.

A range of emerging technologies are already competitive with fossil fuel alternatives in certain circumstances. Biomass is competitive provided that a low-cost feedstock is available, such as a waste stream. Heat pumps are competitive for low temperature lifts and if low-cost electricity is available. Solar thermal is competitive at low temperatures where land or roof space and a

[28] Survey included technologies used in the application of heat to enable an industrial process, such as heat pumps and heat integration.

good solar resource are available. Geothermal is commercial for low temperatures in areas with access to a good geothermal resource and where there is a large annual heat demand.[29]

However, options for high-temperature heating are typically further from commercial readiness. It is possible to reach temperatures over 1,000°C using concentrated solar thermal heating but its reliability in very high temperature industrial applications is not yet clearly demonstrated. Biomass fuels and their derivatives have potential across all temperature ranges but are yet to be deployed at scale.

A pathway to reducing emissions is the electrification of process heat. This pathway includes a variety of technologies (such as plasma arc furnaces, electric arc furnaces and microwave assisted heating). Electrification does not necessarily result in emissions savings compared to gas given that its abatement benefits are dependent on the emissions intensity of the electricity supplied. On a joule-for-joule basis, the electricity supplied needs to be approximately 75 per cent from zero emission sources for abatement to occur. Because these technologies do not inherently lead to abatement, they are not shown in Figure 14.

Some electrification technologies are able to deploy electricity in process heat at a different time to the initial consumption of electricity, with examples being hydrogen and thermal storage (such as electrically heated molten silicon). These can be linked to zero emissions electricity which is not constrained by the time of use, so their abatement potential can be measured on that basis.

Hydrogen in particular is likely to be an important technological option for high-temperature (>800°C) heat processes over the long term. Its applications could include alumina refining and iron and steel production (with hydrogen additionally acting as a reductant for iron production). The scale of its potential deployment in these industrial applications will become clearer over the medium term. The National Hydrogen Strategy considers strategies for leveraging those opportunities.

Carbon capture and storage (CCS) is a proven technology that can separate the emissions from existing combustion processes using gas and coal, as well as non-combusting industrial processes such as limestone calcination. Generally CCS falls into two broad categories of application. More concentrated CO2 streams, such as those from gas and fertiliser production,

[29] ARENA, 2019a.

as well as alternative combustion processes such as chemical looping or oxy-fuel, have a relatively low cost per tonne to capture the CO2. CCS can also be applied to lower concentration streams of CO2, such as the post combustion flue gases from burning coal and gas, though generally at a higher cost per tonne of CO2 captured. CCS can also be combined across industrial sectors with biomass, depending on the availability of feedstock, for an ultimately carbon-negative process.

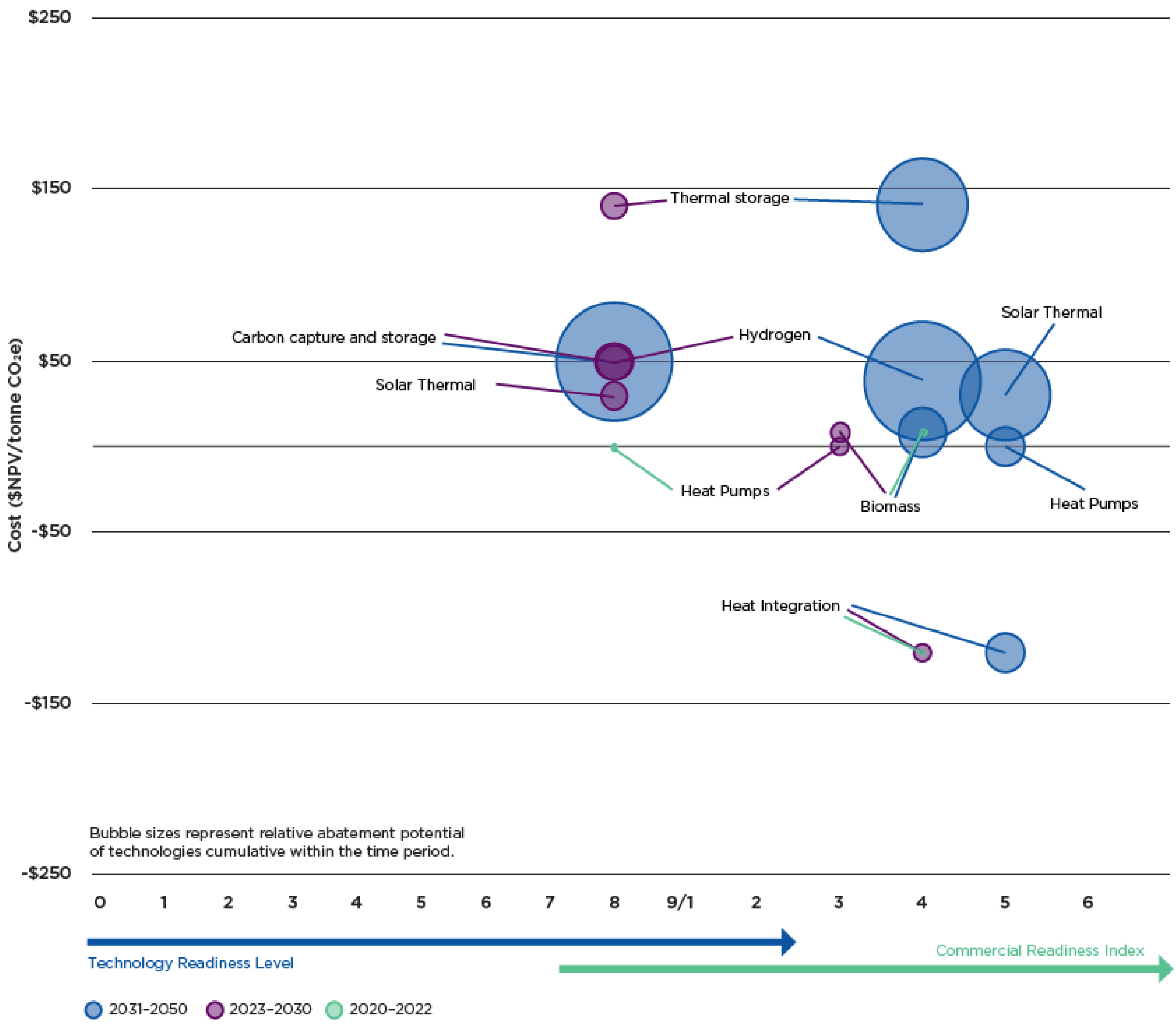
Technologies to optimise industrial processes can improve energy efficiency and bring down the costs of low emissions technologies. These technologies include digitised equipment to deliver heat at the point of use and closer to the minimum required temperatures.

In calculating the costs and abatement potentials for industrial process heating technologies, the survey assumed a continuation of the current emissions intensity of the electricity grid. In addition to the technologies shown in Figure 14, certain electric technologies may deliver substantial abatement if coupled with lower emissions generation, including electromagnetic heating, resistance heating and electric arc systems.

Box 10: Abatement of nitrous oxide emissions from nitric acid production

Nitric acid is a key precursor to nitrogen-based fertilisers but is a significant source of global emissions of nitrous oxide (N_2O), a very potent greenhouse gas. Catalytic reduction technologies are being developed by several manufacturers as a tool to help break down N_2O in ammonia burners and tail gas streams of nitric acid facilities. These technologies are increasingly being deployed globally, including in Australia, and some facilities have reported emissions reductions of 80–95 per cent, depending on factors such as catalyst quality and the physical setup of the abatement unit. Nitric acid production is responsible for around a third of the emissions from Australia’s chemicals sector, so further development and deployment of these technologies has the potential to achieve significant emissions reductions.

Figure 14: Industry – process heating technologies, 2020–2050



Mining and industrial equipment (Figure 15)[30]

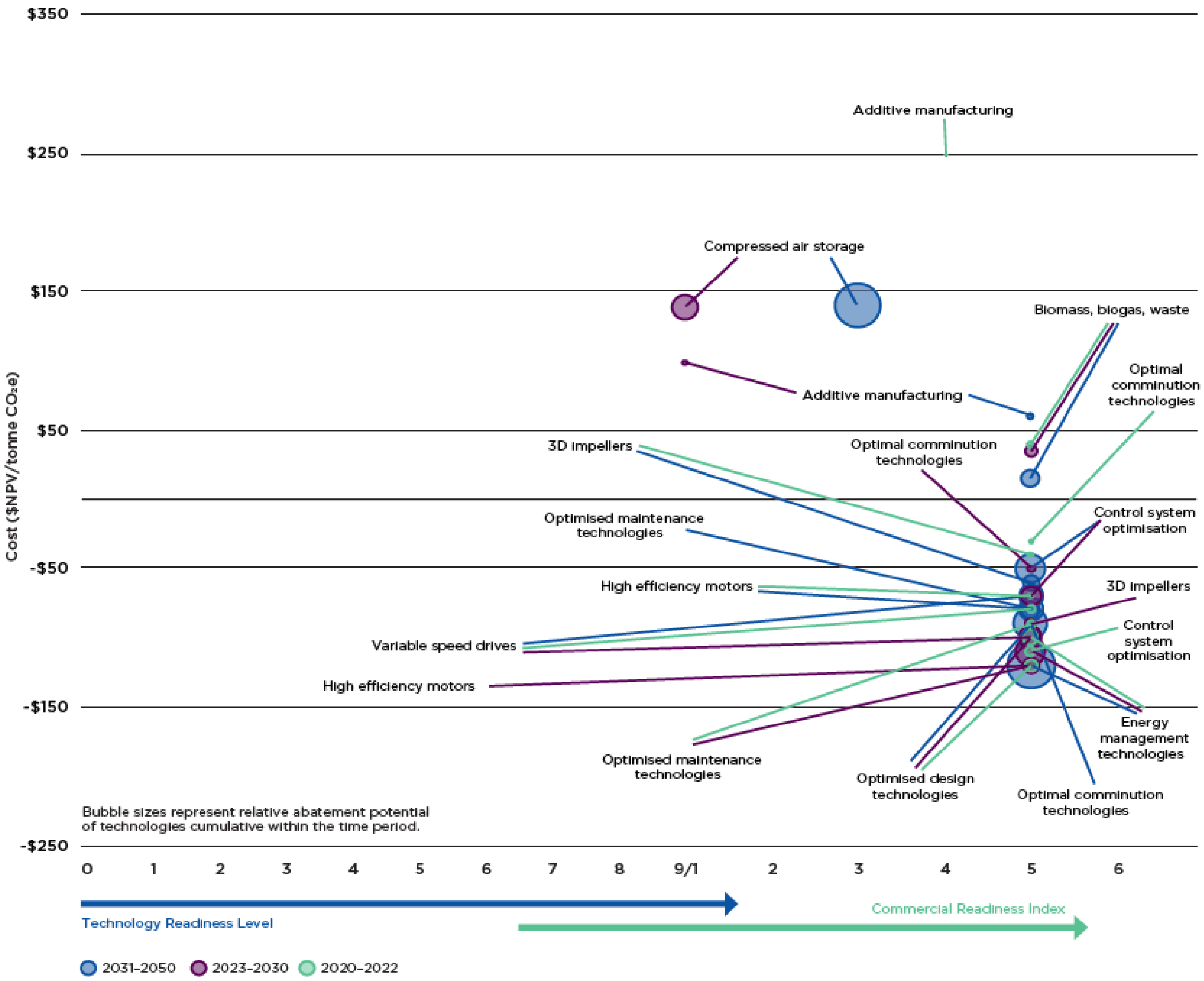
This category includes technologies such as pumps, fans and conveyors used in mining and minerals processing and manufacturing. The survey does not yet cover heavy mobile equipment such as haul trucks, excavators and drill rigs.

From the perspective of improving operational efficiency and reducing emissions, the most promising technologies identified relate to improved whole system design. Control system optimisation technologies allow better metering, monitoring and automated feedback including using AI systems. Energy management tools, technologies and approaches (for example, process integration tools) are proven in commercial settings both in Australia and overseas. They have potential to deliver significant savings by identifying the most cost-effective improvements available to a particular facility.

Industrial energy users are not necessarily passive participants in energy markets, and technological advances such as compressed air storage may allow the ramping up and down of production to respond to electricity price signals. This can result in emissions abatement by increasing the use of intermittent renewable electricity sources.

[30] Survey included technologies and industrial equipment that use or supply mechanical power in mining, manufacturing, and minerals processing.

Figure 15: Mining and industrial equipment technologies, 2020–2050



Feedstocks (Figure 16)[31]

Feedstocks are the raw materials used in industrial processes. In this sector the survey identified a variety of technologies with potential to improve or substitute feedstocks to reduce emissions and improve productivity.

Deriving coke from bioenergy instead of fossil fuels can save up to 88 per cent of emissions, but its application is currently limited by cost and the availability of biomass.[32] The process also

[31] Survey included technologies directly involved in a chemical reaction to produce a finished product, such as renewable ammonia from hydrogen and hydrogen reduction of iron.
[32] Highest emissions savings available with pumped hydro electricity generation as the production energy source (Haque and de Vries, 2012).

depends on less cost-effective technologies and can pose challenges in delivering metallurgical coke at international standards. Given the potential benefits, however, investments in the deployment of these technologies may be justified over the medium term.

Using direct iron reduction to reduce iron from its ores with hydrogen (instead of coke) in iron production is a proven technology that could be demonstrated and scaled up in Australia. The use of zero emissions hydrogen in these processes could deliver significant abatement over the medium and long term, and is currently being investigated in Europe. The primary challenge to commercial deployment will be to bring the costs of zero emissions hydrogen down.

Hydrogen also has applications in chemicals manufacture. ARENA is currently supporting feasibility studies to produce ammonia using renewable hydrogen, including one by Queensland Nitrates and Dyno Nobel, with both projects announced in September 2019.[33]

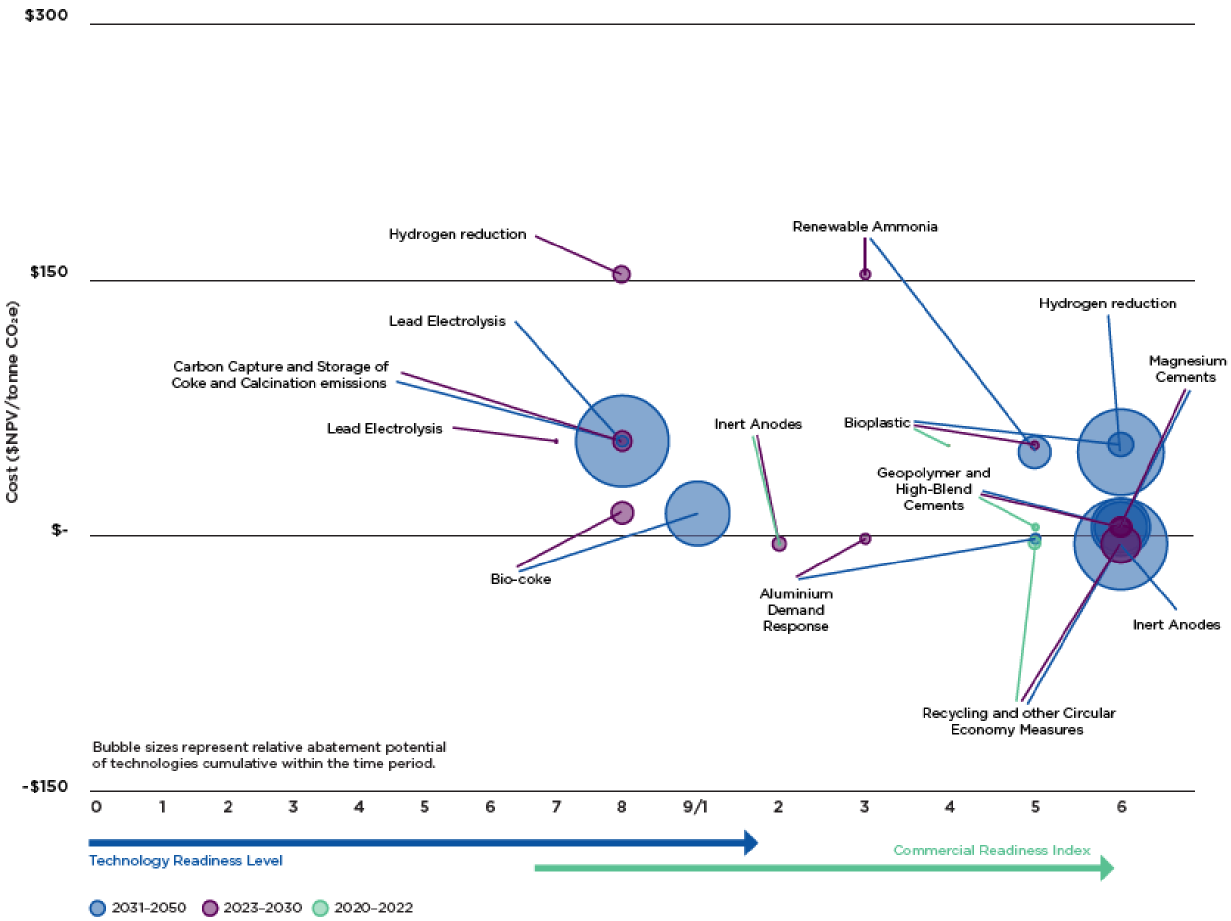
The carbon dioxide emissions associated with the inherent use of industrial feedstocks can be captured and stored, most likely through processing the flue gases from the plant. Carbon capture and storage can also be used to enable negative emissions, such as through capturing the emissions from a biomass source of coke.

Over the decades it's in use, concrete captures over 40 per cent of the CO_2 emissions directly associated with the calcination of limestone.[34] Other building materials at lower technology readiness levels, such as the mineralisation of calcium and magnesium, may find use in more applications and be able to capture CO_2 emissions to a greater extent.

Some industrial processes, like the manufacturing of urea and the Solvay process to make sodium carbonate, utilise CO_2 itself as a feedstock. There is also research into the utilisation of CO_2 as a feedstock for the manufacture of chemicals, such as methanol, that currently use other feedstocks. This CO_2 can come from other sources where the CO_2 would otherwise be emitted to the atmosphere. These materials are also functionally keeping CO_2 out of the atmosphere, and are effectively a form of storage. Processes that use CO_2 in this way can be referred to as Carbon Capture, Utilisation and Storage (CCUS).

[33] ARENA, 2019b; https://arena.gov.au/projects/feasibility-of-renewable-green-hydrogen/
[34] Xi *et al*, 2016.

Figure 16: Industry – feedstock technologies, 2020–2050



Transport (Figure 17)[35]

The transport sector is facing significant shifts in demand and consumer preference. Population growth and moves towards larger vehicles[36] are increasing transport activity and fuel consumption. There are opportunities to improve road transport efficiency and reduce emissions by increasing the use of hybrids, alternative fuels and electric vehicles.

Many of the technological challenges facing the transport sector will arise from the need to manage disruptions from increasing use of electric vehicles and (in the longer term) autonomous vehicles. Ensuring that refuelling infrastructure keeps pace with the growth of electric vehicles, and potentially fuel cell vehicles, will be an ongoing concern. Supporting the

---

[35] Survey included technologies used in the movement of humans, animals, or goods from one location to another, such as electric and hybrid vehicles.

[36] IEA, 2019c.

development and commercialisation of technologies to improve supporting infrastructure will complement the Government’s forthcoming National Electric Vehicles Strategy.

A host of technologies are close to commercial readiness but not being deployed at scale. For example, the latest engine and hybrid technologies (energy management technologies and electric vehicles, among others) are not reaching the Australian market in significant volumes.

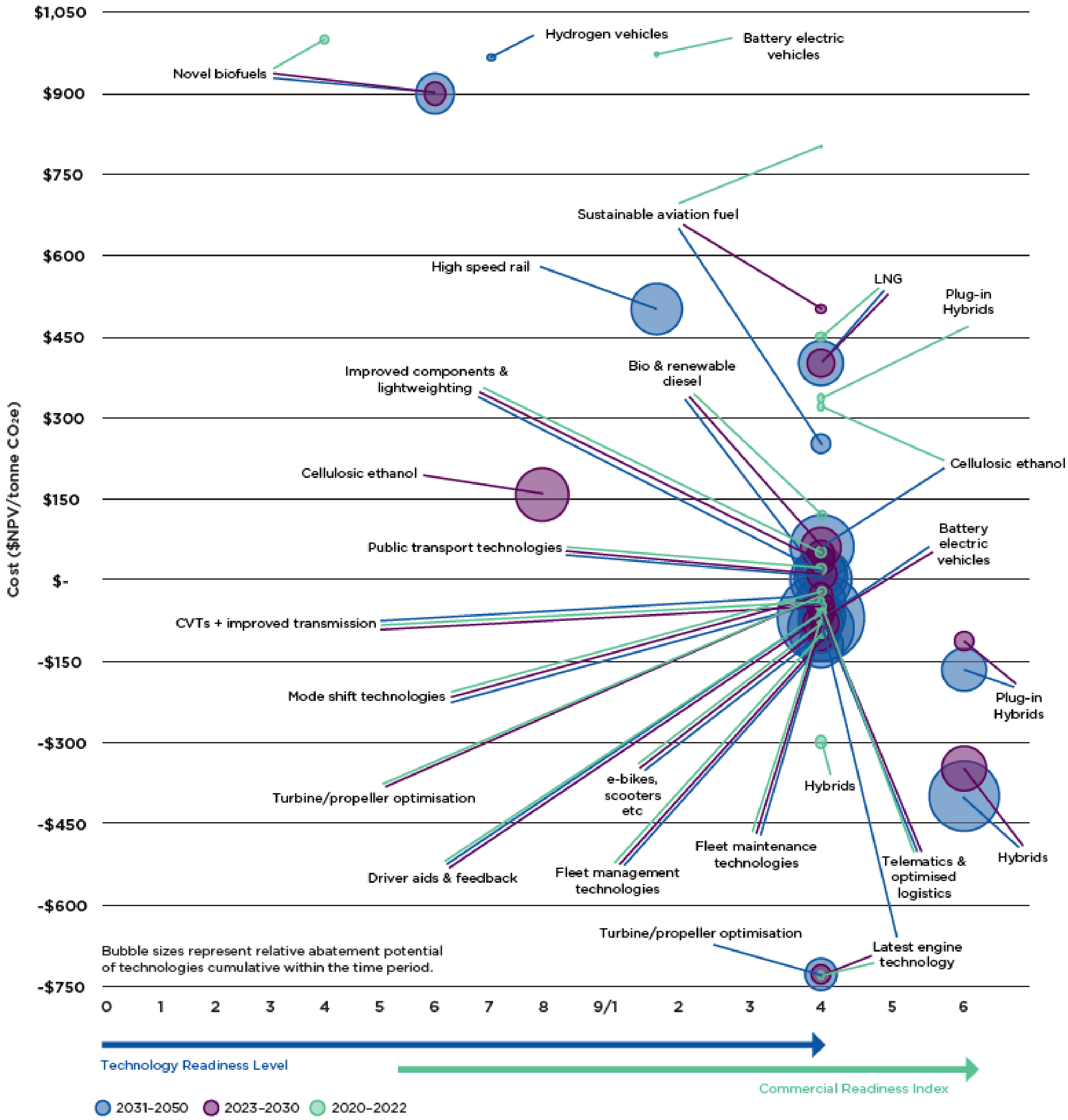
In the short term, hybrid vehicles and improved components/lightweighting offer the most potential for abatement. Improving componentry has benefits that will apply across any large fleet, both new and at the point of refurbishment, and is technology neutral because reduced energy consumption and emissions will result irrespective of fuel and power source.

Closer to 2030, increased adoption of electric vehicles would provide emissions reduction and cost savings, together with improved urban air quality and other benefits. Potential abatement from electric vehicles will increase as the share of renewable generation rises and, coupled with distributed energy resource management systems, could also deliver grid-firming benefits.

Biofuels could provide additional abatement without replacing existing vehicles or investing heavily in new infrastructure. Their use is expected to grow due to mandated blend rates but may be limited by the resources required to produce them and the rise of other vehicle types, such as electric battery vehicles.

The aviation sector has limited low emissions options. Accordingly, biofuels have potential to make a significant impact while also helping to address waste challenges and building new regional industries. Some aircraft manufacturers are also looking at the potential for batteries to reduce emissions through hybridised power plants.

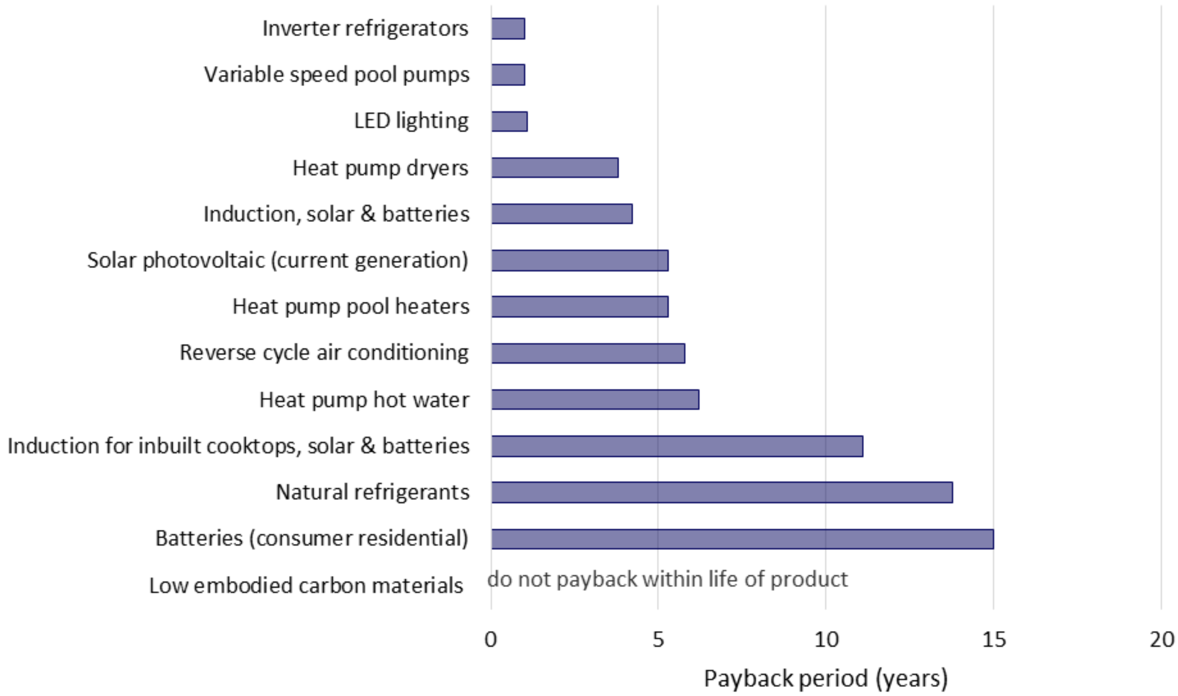
Figure 17: Transportation technologies, 2020–2050



Built environment (residential) (Figure 19)[37]

Several technologies are cost-effective in the residential sector and have the potential to reduce energy bills for consumers. The largest abatement potential may be achievable through increased deployment of heat pump technology (particularly heat pump hot water). However, consumers generally demand short payback periods on their investments in residential appliances and there are high transaction costs involved in identifying and adopting suitable technology (Figure 18).

Figure 18: Consumer payback periods (years) for residential technologies



Other technologies with potential for short to medium term impact are appliances with more efficient refrigerants, solar PV (with network upgrades), phase change materials, and low embodied carbon materials. It is currently cost-effective for customers to upgrade to more efficient reverse-cycle heating and cooling, with 70 per cent of reverse-cycle units sold in Australia demand response capable. Coupled with grid integration technologies, discussed above, these appliances could deliver broader benefits for grid reliability.

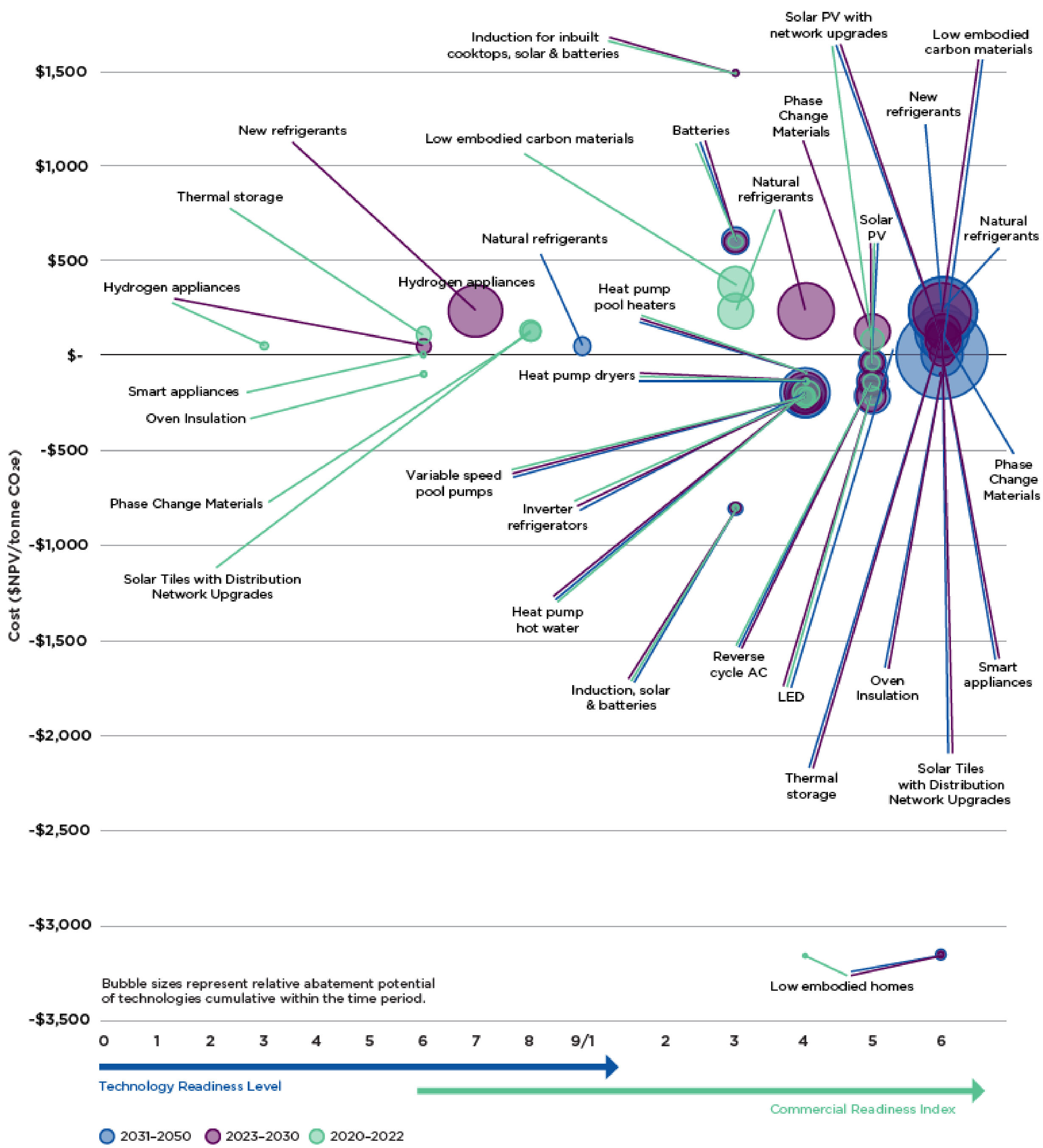
Thermal storage, new refrigerants, low embodied carbon materials and solar PV have significant potential. Thermal storage technologies include smart air conditioning, improved wall insulation, weather stripping and ceiling insulation. Thermal storage is much cheaper than electric storage and lessens the need for batteries at the grid level to deal with peak demand for

[37] Survey included technologies that use or supply energy within a home, such as in the building shell, appliances, and space/water heating.

heating and cooling. Encouraging household-level thermal storage could therefore reduce the cost of firming the grid for all households and businesses.

The phase-out of ozone-depleting substances is almost complete in Australia, and the phase-down of hydrofluorocarbon (HFC) imports by 85 per cent by 2036 will continue to be a driver of improved refrigeration technologies, along with the Minimum Energy Performance Standards and Energy Rating Labels.

Figure 19: Residential technologies, 2020–2050



Built environment (commercial) (Figure 20)[38]

The Department's survey has identified a range of technologies to support the electrification of commercial building hot water systems that have moderate energy-efficiency gains in the

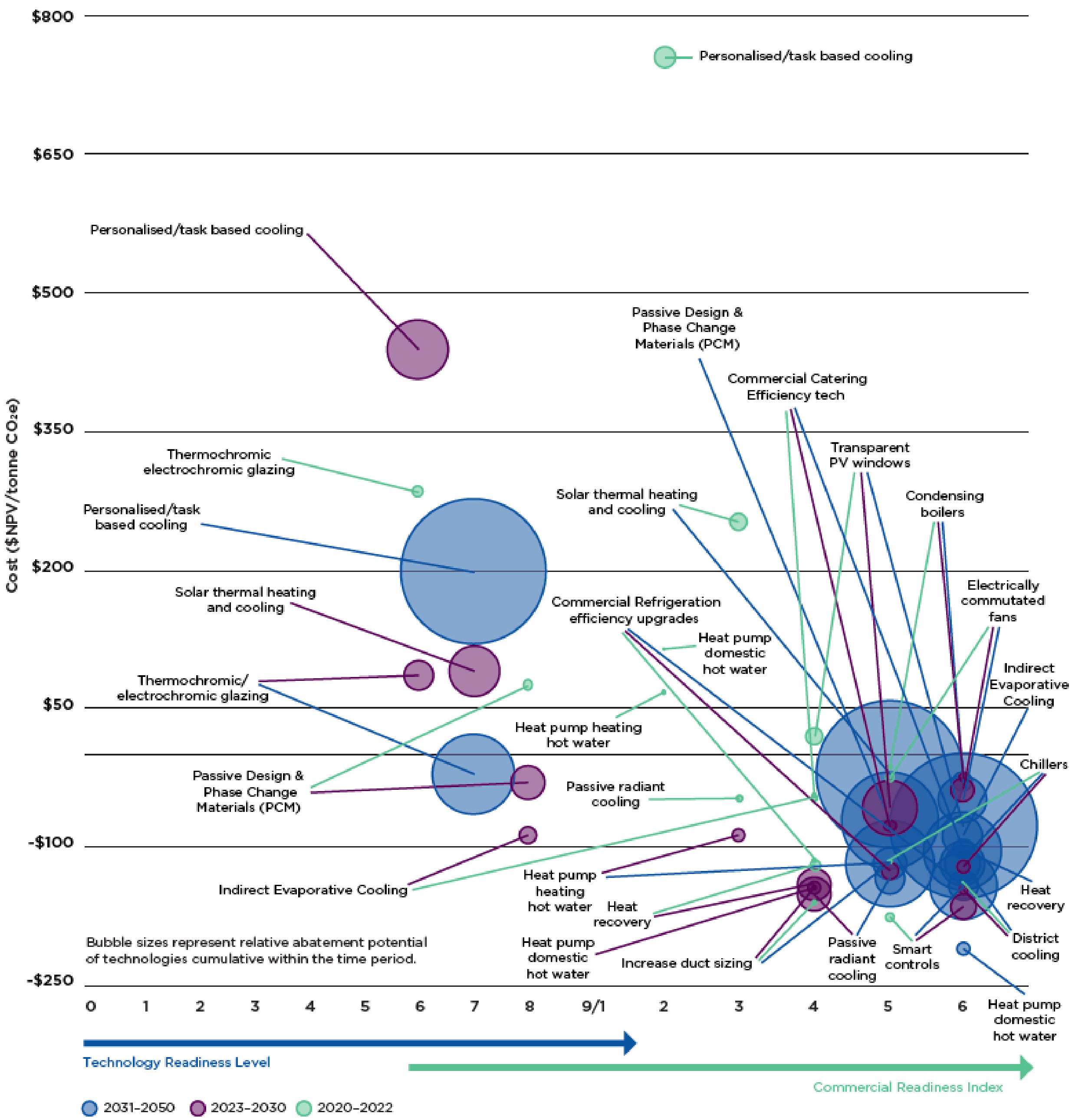
[38] Survey included technologies that use or supply energy within a building to enable a commercial activity (excluding industrial or agricultural), such as in the building shell, appliances, and space/water heating.

medium term. Heat pump hot water systems, while technologically proven and commonly installed overseas, have not seen the same deployment levels in Australia. Finding further pathways for large-scale deployment could therefore unlock significant abatement in the short term.

Investment in the deployment of technologies such as passive design, phase change materials, solar PV thin films and solar PV glass could also see impacts over the medium to long term. Advancements within solar PV glass technology could allow installation of solar PV in otherwise unsuitable locations, including glass facades and skylights. Further developments of phase change insulation products and thermochromic and electrochromic glazing may also provide substantial reductions in heating and cooling loads.

Technologies that enable a systems-based approach to building efficiency will unlock cost savings and emissions reductions through improved building management and control systems, electronically commutated fans, condensing boilers and improved part-load chiller efficiencies.

Figure 20: Commercial buildings technologies, 2020–2050



Fugitives (Figure 21)[39]

Fugitive emissions in the energy sector include carbon dioxide and methane (and small amounts of other greenhouse gases) released during exploration, extraction, processing and transport of fossil energy commodities. Capture and use of fugitive emissions, particularly methane, is a potential source of value for Australian industry and emissions reduction.

Sixty-five per cent of fugitive emissions from coal mining consists of ventilation air methane (VAM) from underground coal mines. After more than 15 years of research, CSIRO has developed three technologies that could have important impacts on reducing fugitive emissions from coal (both domestically and overseas) through converting methane to CO_2:

- VAMCAT (ventilation air methane catalytic turbine): A catalytic turbine system that can be operated with low methane concentrations for power generation. Test results for a VAMCAT prototype unit showed that the unit can be operated with 0.8 per cent methane in air and generate electricity. It has been recently trialled and demonstrated in Australia.[40]
- VAMMIT (ventilation air methane mitigation): A catalytic reactor[41] that destroys VAM through oxidation at over 99 per cent effectiveness. It can be operated with 0.3 per cent or greater methane concentration and requires approximately 10 times less energy to run than existing thermal technology.
- VAMCAP (ventilation air methane capture): Nanostructured carbon composite adsorbents used to enrich VAM, so that it can be used by the other techniques. This is currently pre-demonstration; further research may be required before this technology is ready for demonstration.[42]

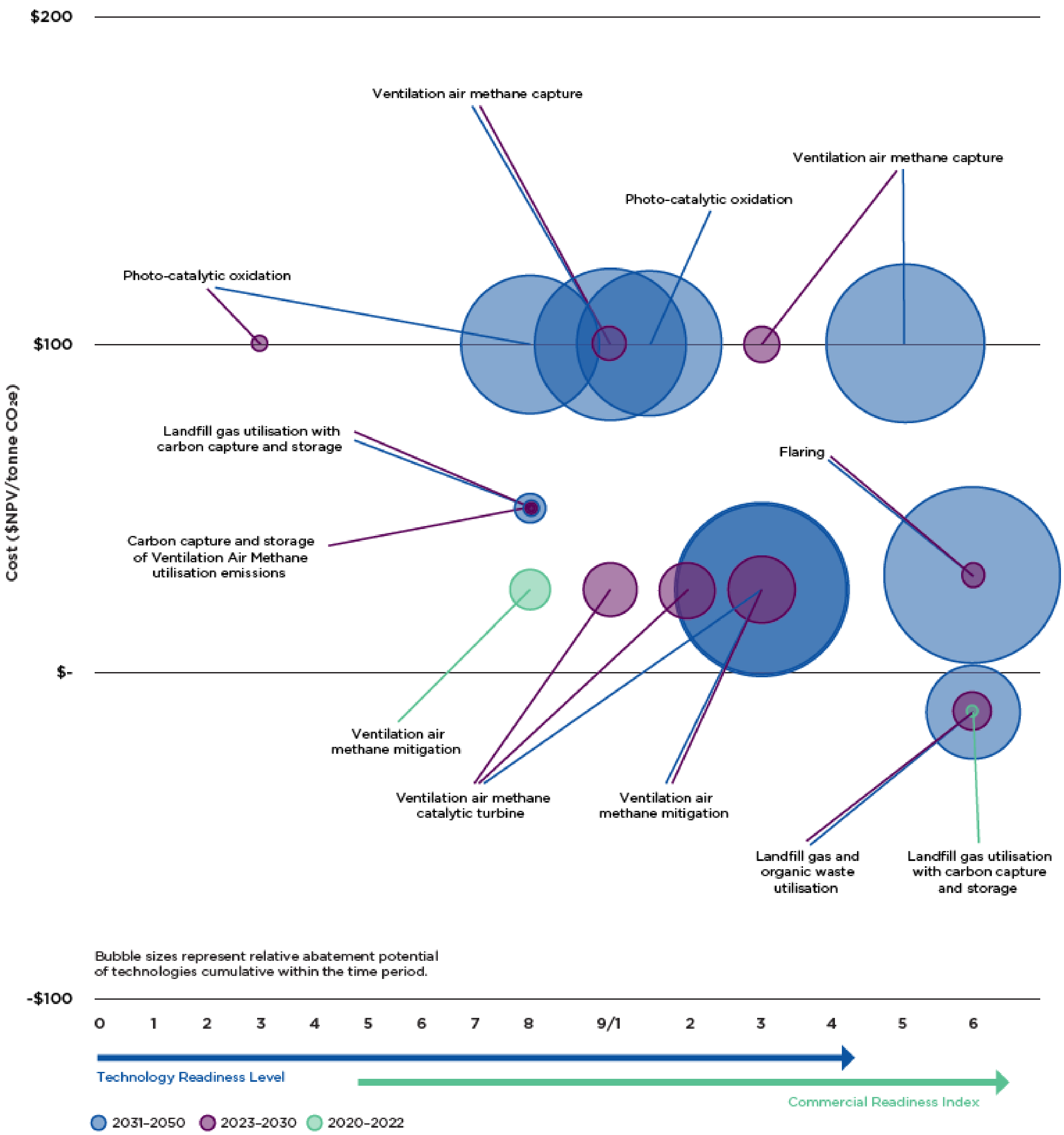
[39] Survey included technologies that are involved in the release of greenhouse gas emissions from coal mines and coal seam gas wells, such as ventilation air methane technologies.

[40] Technical report: Site trials of a suite of novel VAM technologies. CSIRO report EP191350.

[41] Catalytic systems work at lower temperatures of 450–800°C and use a catalyst to oxidise the methane, converting it to carbon dioxide. They are technologies for VAM abatement.

[42] CSIRO, 2017b, p. 100.

Figure 21: Fugitive technologies, 2020–2050



Waste[43]

Energy from waste (EfW) is a proven technology solution adopted widely across Europe, North America and Asia. In these regions EfW is used as part of an integrated waste management system to divert waste from landfill and reduce reliance on fossil fuels for energy generation. The key considerations for implementing EfW systems are to extract the highest value from the waste resource and responsibly process the residual waste streams and to control exhaust air emissions.

A variety of EfW technologies exist to process various waste feedstocks including mixed solid waste, process engineered fuel (PEF) and organics (e.g. food waste, biosolids, wood waste). EfW technologies can be used to generate a variety of primary and secondary products including:

- Co-generation systems for producing steam for direct use in industry along with electricity.
- Biogas for use in condensing boilers, conversion into heat and electricity in co-generation systems or further refining into bio-methane as a substitute for natural gas.
- Bio-fuels, biochar and other value-added products.

The initial survey identified a range of prospective EfW technologies including:

- Anaerobic digestion: Well-proven, widely adopted technology typically used to process organic source separated waste streams including food waste, agricultural waste and biosolids) to produce biogas which can be converted into electricity.
- Combustion (incineration): Well-proven, widely adopted technology typically used to process municipal solid waste (MSW) to produce high-pressure steam which can be converted into electricity.
- Gasification: Proven technology used to process separated waste streams (e.g. wood waste, biosolids) to produce a synthetic gas (syngas) which can be converted into electricity or other value-added products.

[43] Survey included technologies that utilise waste products for other purposes, such as energy generation.

- Pyrolysis: Emerging technology used to process separated waste streams to produce a syngas for conversion into electricity along with value-added products such as biochar.

Reducing demand for industrial feedstocks including through increased recycling of metals and plastic is also an effective means of improving efficiency and reducing global emissions. Technologies to improve recycling rates such as advanced waste sorting are already proven and starting to be deployed.

A comprehensive survey of waste technology will be completed in 2020, covering a broader range of circular economy technologies.

Agriculture and land use[44]

In the agriculture and land sector, there are opportunities to improve soil carbon levels and livestock productivity, as well as deploying technologies to enhance fertiliser use, store carbon in vegetation and improve fire management. Further research and development is needed to fully understand the abatement and productivity opportunities for this sector. Improvements in remote sensing technology have the potential to build on the success of the Emissions Reduction Fund and catalyse further emissions reductions through the Climate Solutions Fund. There are also opportunities to improve fuel and energy consumption and the supply of inputs for energy production and building construction. The Government will work with stakeholders to support investments in technology that are likely to have the greatest impact.

Some technologies to assist improved emissions reduction and accounting in the agriculture sector are still in the R&D phase and not yet commercialised. In livestock, increasing soil carbon has the potential to reduce emissions and increase productivity. Reducing the cost of measuring the impact of management activities on soil carbon sequestration is critical to realising this potential. Other promising technologies in the research and development phase include

[44] Survey included technologies that are involved in livestock productivity, soil management and vegetation.

alternative feeds for northern pasture cattle (Leucaena and Desmanthus) and the use of supplements (Asparagopsis (red algae) and 3-NOP) in beef feedlot and dairy systems.

The Government will continue to pursue opportunities to increase productivity and reduce emissions in agriculture through a range of mechanisms, including the Climate Solutions Fund.

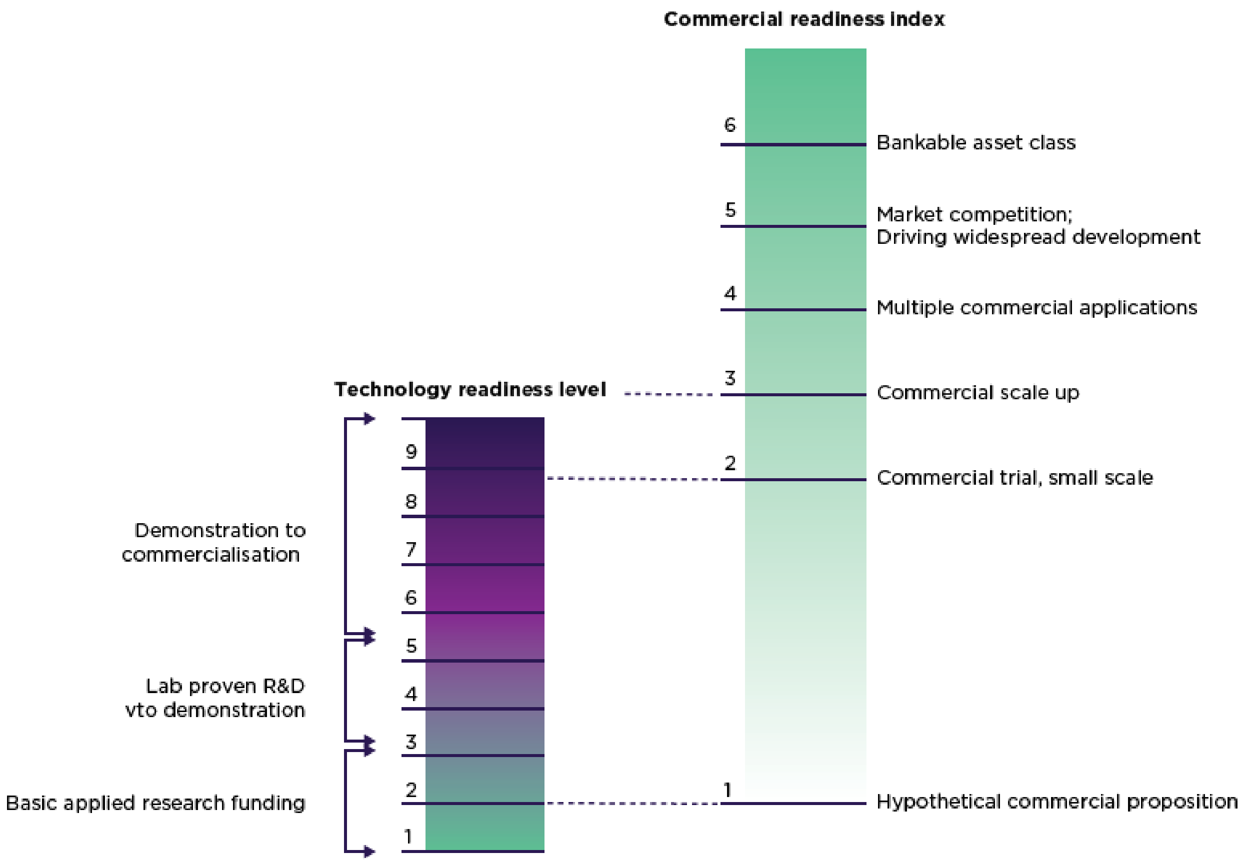
Negative emissions[45]

There are several negative emission technologies (NETs) with possibilities for Australia at various levels of technological readiness, cost and scale. Some are already being implemented on a small scale, including carbon capture and storage (CCS), afforestation and soil carbon, which, although it is still at an early stage of technological readiness and scientific understanding, has the potential to increase the carbon content in soils. Other NETs currently face cost barriers and significant support would be required to make them viable in the long term. For example, CO_2 scrubbing technology absorbs carbon dioxide from direct air capture to reduce emissions. If costs can be brought down, this technology has potential applications in bioenergy carbon capture and storage (BECCS), gas and coal powered electricity generation, LNG, steel, cement and fertiliser production.

[45] Survey included technologies to remove and sequester emissions.

Appendix C: Technology Readiness Level and Commercial Readiness Index

Figure 22: Technology Readiness Level and Commercial Readiness Index



Source: ARENA, 2014.