Australian Government

Department of Industry, Science, Energy and Resources

LOW EMISSIONS TECHNOLOGY STATEMENT 2021

Contents

Message from the Minister

The Technology Investment Roadmap and its Low Emissions Technology Statements set out Australia's technology-led approach to accelerating the development of technologies essential to achieving net zero emissions.

Our goal is to drive down the cost of a portfolio of low emissions technologies, because getting them to commercial parity with existing approaches will make them more attractive to consumers at home and abroad. Our approach is technology not taxes, because it's the only way to reduce emissions without imposing new costs on households or businesses, or raising the price of existing energy sources.

To achieve this goal, we are investing more than $20 billion in new energy technologies over the coming decade, to drive between $80 billion and up to $120 billion of combined public and private investment and creating 160,000 jobs. Like the government's 10 year funding model for infrastructure investment, we have adopted a decade-long funding model to bring forward private sector investment in low emissions technologies.

The government will continue to refine its investments over time. Since the release of the first statement (LETS 2020) in September 2020, we have committed an additional $1.7 billion in new funding across a range of areas including clean hydrogen, carbon capture and storage, soil carbon measurement and a series of international partnerships.

The release of LETS 2021, the second annual statement under the roadmap, is an important element of Australia's Long-Term Emissions Reduction Plan to achieve net zero emissions by 2050. Annual reviews of our technology priorities and the investments we are making are part of our commitment to being accountable for progress under our Plan.

LETS 2021 expands the priorities set out in LETS 2020, adding a new priority technology and associated stretch goal, as well as identifying new actions the government will take to establish Australia as a leader in low emissions technologies.

Getting the cost of solar energy down to less than $15 per megawatt hour, around a third of today's cost, will help us achieve dramatic cost reductions in clean hydrogen produced from electrolysis and in low emissions materials. Clean, low cost, bulk electricity supply will also help maintain Australia's traditional advantage in affordable and reliable energy. Our continent has the highest levels of irradiation of any in the world and we have an incredible track record of driving innovation in solar photovoltaics, with more than 90% of solar panels manufactured around the world using Australian technology.

LETS 2021 also adds enabling infrastructure as a new technology category, which will focus on infrastructure to help deploy priority and emerging low emissions technologies at a commercial scale, including for electric vehicles.

I would like to thank the Chair of the Technology Investment Advisory Council, Dr Alan Finkel, and the other council members – Drew Clarke, Jo Evans, Grant King, David Parker, Justin Punch, Steven Skala, Alison Watkins, Shemara Wikramanayake and Ben Wilson – for their invaluable expertise and advice in developing this year's statement.

The Hon Angus Taylor MP
Minister for Industry, Energy and Emissions Reduction

Message from the Chair

The decade is still young, a decade during which we must accelerate progress in low emissions technologies into broad and lasting benefits.

This technological transformation has the potential to fuel our long-term prosperity, pave the way for net zero emissions by 2050 and preserve our planet. But it rests on our ability to promote Australia's unmatched enterprise and creativity and expand early wins in low emissions technologies into mainstream solutions.

The 2021 Low Emissions Technology Statement (LETS) represents the second important milestone in the development of a roadmap to guide our path toward this target.

LETS 2021 is technology agnostic – selecting priorities through the filters of abatement potential, economic benefit, Australia's comparative advantage and responsiveness to government investment – while taking action to lower the adoption costs for new and emerging low emissions technologies.

It underscores the importance of research and development, regulations, community engagement, voluntary action and efficient operation of markets. It introduces new policy initiatives, adds ultra low-cost solar as a priority technology in recognition of the contribution clean electricity makes to the success of the other priority technologies, and provides a new focus on enabling infrastructures that are essential to curbing emissions across the electricity and transport sectors.

As the global challenge of climate change has become dramatically evident in recent years, so too has the need for greater international cooperation. We have fostered partnerships with Germany, Japan, the Republic of Korea, Singapore and the United Kingdom, to advance the development and deployment of low emissions technologies and embrace our collective responsibility to protect our common home.

It is a privilege to be part of such a strategic, rigorous and adaptive approach that reflects the vigour and vision this challenge demands. I thank Minister Angus Taylor for the opportunity to contribute, and for his wise guidance and engagement throughout.

I also express my sincere thanks and appreciation to my fellow council members. They have reflected deeply on the technology challenges, and opportunities, for Australia. Their astute counsel has made it possible to take the next step in this journey.

I acknowledge the strong capability and professionalism from the Department of Industry, Science, Energy and Resources and I offer my specific thanks to the dedicated team that has implemented the work.

Finally, I thank all our industry partners who have shared their expert knowledge over the past year.

Dr Alan Finkel AO
Special Adviser to the Australian Government on Low Emissions Technology
Chair of the Technology Investment Advisory Council

Our Vision

A prosperous Australia, recognised as a global low emissions technology leader

Australia's big technology challenges

Delivery of low-cost, clean and reliable energy to households and industry for transportation, heating, lighting and production

Expanding production and increasing productivity, creating jobs and substantially reducing emissions from Australia's primary industries

Preserving and expanding onshore manufacturing of energy-intensive products and capturing new export markets for low emissions commodities

Scaling geological and biological sequestration to provide globally significant sequestration of CO_2

Australia's principles for emissions reduction

Technology not taxes

Expand choices, not mandates

Drive down the cost of a range of new technologies

Keep energy prices down with affordable and reliable power

Be accountable for progress

How government will make a difference

Invest in low emissions technology research, development, demonstration and early-stage commercialisation

Facilitate voluntary action by businesses and consumers to reduce emissions

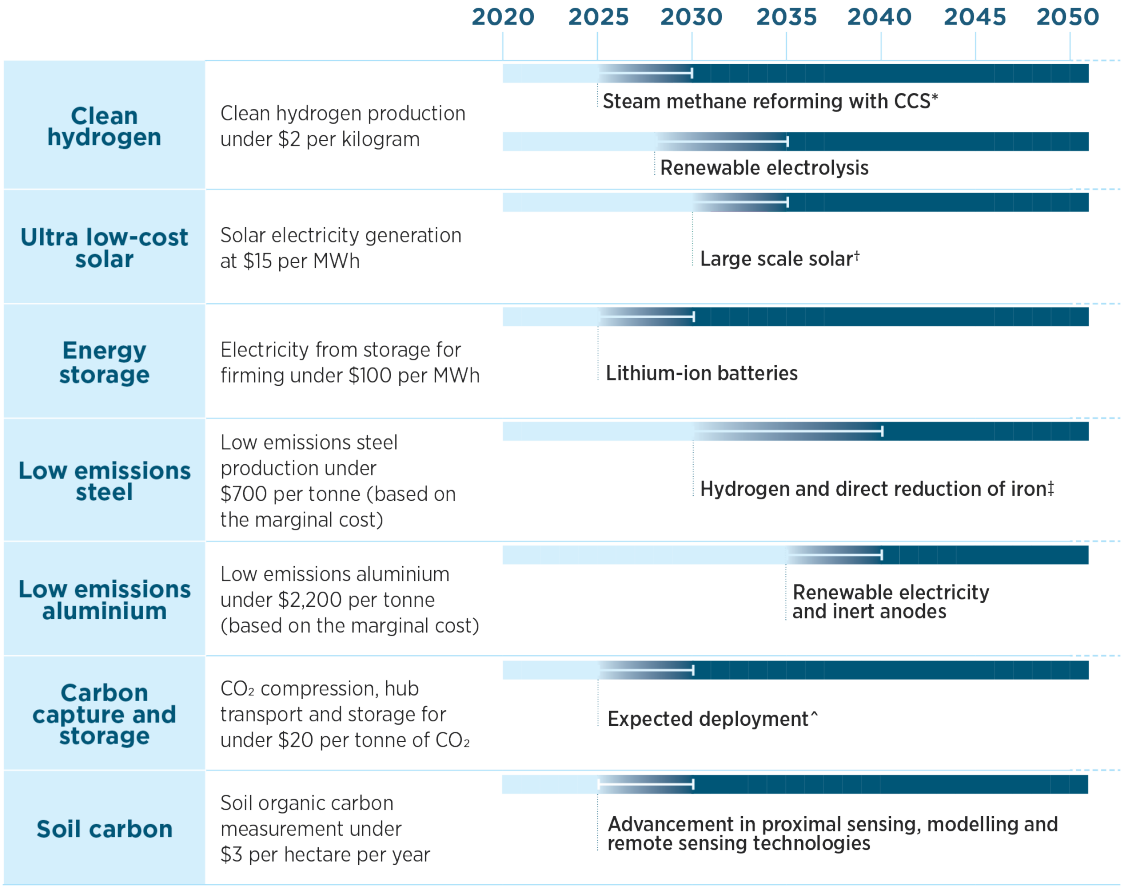
Invest in enabling infrastructure and technology

Ensure transparency and accountability to inform consumers

Work with international partners

Priority Technologies

Achieving our economic stretch goals



* clean hydrogen produced from natural gas with emissions captured and stored permanently underground is technically and economically feasible, but subject to offtake agreements, development approvals and the adoption of a hydrogen Guarantee of Origin scheme

† price assumptions for the other priority technologies don't yet include the reduction in electricity prices expected from ultra low-cost solar, or the associated upside benefits for meeting the stretch goals

‡ economically viable in the late 2020s, but subject to capital development cycles

^ subject to offtake agreements and development approvals

Our Actions

Enabling infrastructure

BATTERY CHARGING AND HYDROGEN REFUELLING STATIONS

DIGITAL GRID
to support growth in wind and solar generation

A new category for infrastructure that will help deploy priority, emerging and proven low emissions technologies at commercial scale, and support consumer choice.

Emerging technologies

LIVESTOCK FEED SUPPLEMENTS
to reduce methane emissions from cows and sheep

LOW EMISSIONS CEMENT

Two emerging technologies show promise for prioritisation in future statements and will be supported by early investments.

New government actions in 2021

SOLAR 30 30 30 INITIATIVE

VOLUNTARY ZERO EMISSIONS GAS MARKET

CLEAN HYDROGEN INDUSTRIAL HUBS

INFRASTRUCTURE ASSESSMENT

Advancing the roadmap

IMPACT EVALUATION FRAMEWORK
Outlines metrics to track our progress

ACCELERATING DEPLOYMENT OF PRIORITY LOW EMISSIONS TECHNOLOGIES
Identifies opportunities to meet our stretch goals

AUSTRALIA'S RESOURCES OPPORTUNITY IN A NEW ENERGY ECONOMY
Highlights resource opportunities for Australia through the global adoption of low emissions technologies

At a glance

About the Low Emissions Technology Statement 2021

This is the second Low Emissions Technology Statement (LETS 2021) released by the Australian Government. Annual statements are released under the Technology Investment Roadmap. The roadmap is the cornerstone of Australia's Long-Term Emissions Reduction Plan to meet net zero emissions by 2050. It is an enduring process to accelerate the development and commercialisation of new and emerging low emissions technologies to reach cost parity with existing high emissions technologies.

The Australian Government's technology-led approach will reduce emissions without imposing new costs on households, businesses or the economy.

Priority low emissions technologies

The first Low Emissions Technology Statement, released in 2020 (LETS 2020), identified five priority technologies and set economic stretch goals for each one:

- clean hydrogen – production under $2 per kilogram (kg)
- energy storage – electricity from storage for firming under $100 per megawatt hour (MWh)
- low emissions materials (steel and aluminium) – low emissions steel production under $700 per tonne and low emissions aluminium production under $2,200 per tonne[1]
- carbon capture and storage (CCS) – carbon dioxide (CO_2) compression, hub transport and storage under $20 per tonne of CO_2
- soil carbon – soil carbon measurement under $3 per hectare per year.

Economic stretch goals are ambitious but realistic goals to bring priority low emissions technologies to cost parity with existing high emissions technologies.

LETS 2021 introduces **ultra low-cost solar** electricity generation as another priority technology. Cheap, clean electricity is integral to unlocking the economic, employment and abatement potential of other priority low emissions technologies and supporting electrification of other sectors such as transport, buildings and industry. We have set an economic stretch goal for solar electricity generation at $15 per MWh, or approximately a third of today's costs.

Government actions

LETS 2021 also highlights how the government will support the deployment of low emissions technologies:

- investing in research, development, demonstration and early-stage commercialisation
- investing in enabling infrastructure
- enabling voluntary action and informing choice for consumers and businesses.

[1] LETS 2020 identified this priority technology as 'low carbon materials (steel and aluminium)'. This change has been made to clarify that the priority technology focus is on low emissions production for steel and aluminium products rather than products that contain low elemental carbon content. To be consistent with other priority technologies, the low emissions materials stretch goals have been refined to reflect cost targets rather than price targets.

LETS 2021 prioritises the following actions.

Solar 30 30 30

This initiative aims for solar photovoltaic (solar) to achieve 30% efficiency at 30 cents per installed watt by 2030. Led by ARENA, the initiative will help drive down costs to meet the stretch goal for the newly prioritised technology: ultra low-cost solar. Ultra low-cost clean electricity is also key to meeting the stretch goals for other priority technologies, including clean hydrogen, low emissions steel and aluminium, and electrical energy for storage for firming.

Assessing infrastructure needs

The Australian Government is already conducting a National Hydrogen Infrastructure Assessment. Building on this, a complementary assessment of infrastructure needs for other priority technologies will be conducted. This will include exploring ways to reduce costs by locating hydrogen, energy storage, and CCS infrastructure near manufacturers such as steel and aluminium companies.

Growing Australia's hydrogen industry

The government is investing $464 million in seven clean hydrogen industrial hubs to concentrate demand for hydrogen in one geographic region to reduce costs and share information. These hubs will bring hydrogen producers, users and exporters together. They will lower the cost of production, encourage innovation and enhance skills and training efforts.

Developing a voluntary zero emissions gas market

The government will develop a voluntary zero emissions gas market in Australia to increase early demand for clean hydrogen and other zero emissions gases and recognise consumers' voluntary purchase of zero emissions gas. This market will drive early demand for clean hydrogen and other zero emissions gases.

Enabling infrastructure

LETS 2021 introduces the category of enabling infrastructure – infrastructure that will help deploy priority, emerging and proven low emissions technologies at a commercial scale, and support consumer choice.

The government's first enabling infrastructure priorities are:

- **battery charging and hydrogen refuelling stations** to support consumer choice in electric vehicles
- **a digital grid** with enhanced management systems and capabilities to support rapid growth in solar and wind generation.

Emerging technologies

LETS 2021 updates the government's list of emerging technologies.

Emerging technologies are low emissions technologies that have transformative potential, but require continued monitoring of global learning rates, research and investment trends.

LETS 2021 explores, in detail, two emerging low emissions technologies that show promise for prioritisation in future statements and will be supported by early investments:

- livestock feed supplements to reduce agricultural methane emissions
- low emissions cement.

Accelerating deployment of priority low emissions technologies

The government's ambition is to reduce the costs of priority low emissions technologies to meet the economic stretch goals as soon as possible.

For the priority technologies, LETS 2021:

- identifies technology deployment pathways
- identifies opportunities to reduce the cost of each technology
- estimates when each priority technology will meet the economic stretch goal.

Australia's resource opportunity in a new energy economy

LETS 2021 explores future global demand for the resources needed to deploy low emissions technologies at scale, many of which are found here in Australia.

Batteries and other storage technologies will drive most of the demand, but Australia can also supply the resources for solar panels, wind turbines, inverters and electric motors. We look at the potential to grow Australian industries around these resources and downstream processing.

Impact evaluation framework

LETS 2021 introduces an impact evaluation framework for the Technology Investment Roadmap. The framework includes the metrics we will use to track progress through annual Low Emissions Technology Statements.

Introduction

The Australian Government's Technology Investment Roadmap is a comprehensive and enduring investment strategy. It will accelerate the development and deployment of new and emerging low emissions technologies. The roadmap is the cornerstone of Australia's Long-Term Emissions Reduction Plan.

Our vision

A prosperous Australia, recognised as a global low emissions technology leader.

Australia's big technology challenges

Australia's technology-led approach to emissions reduction addresses the technology challenges and opportunities facing the country. These are:

- delivery of low-cost, clean and reliable energy to households and industry for transportation, heating, lighting and production
- expanding production and increasing productivity, creating jobs and substantially reducing emissions from Australia's primary industries
- preserving and expanding onshore manufacturing of energy-intensive products and capturing new export markets for low emissions commodities
- scaling geological and biological sequestration to provide globally significant sequestration of CO_2.

Our approach

In May 2020, the government released a discussion paper establishing a strategy for a technology-led approach to reduce emissions. This strategy, known as the Technology Investment Roadmap, set an enduring process to accelerate the development and commercialisation of new and emerging low emission technologies by:

- surveying new and emerging low emissions technologies across the economy
- identifying priority technologies through four filters: abatement potential, Australia's comparative advantage, scale of economic benefit and where government action can make the most meaningful impact
- setting economic stretch goals for each priority technology to help achieve cost parity with existing high emissions technologies
- identifying deployment pathways for priority technologies
- balancing the overall investment in low emissions technologies
- measuring the impact of investments.

The roadmap aims to help low emissions technologies achieve cost parity with existing high emissions technologies.

We publish annual low emissions technology statements under the roadmap (Figure 1). These statements provide the opportunity to review and refine priority technologies, and the

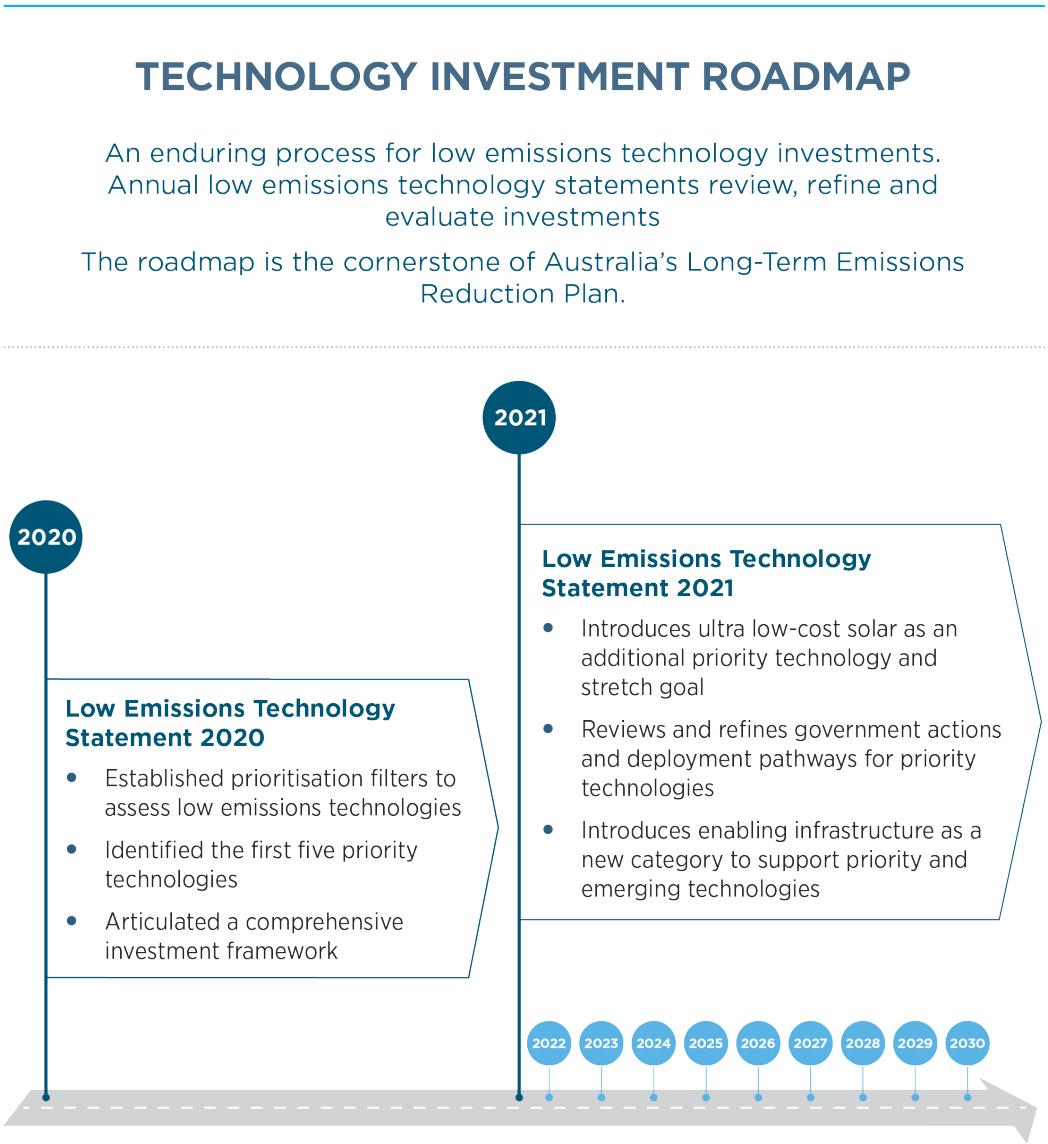
government's investment approach, to deliver the best economic and emissions reduction outcomes for Australia.

LETS 2020 was the first milestone under the roadmap, identifying Australia's big technology opportunities, introducing five initial priority low emissions technologies and articulating a comprehensive investment strategy. LETS 2021 builds on the first statement, prioritising an additional technology, identifying technology deployment pathways, committing to new actions and outlining the importance of enabling infrastructure to achieve our vision as a global low emissions technology leader.

Annual statements ensure our investment priorities and actions adapt to changing technology and market developments. Each annual statement focuses on key parts of the roadmap process to efficiently and transparently report on progress towards our vision.

Proven technologies like coal, gas, and wind electricity, where deployment is already being driven by the private sector, are not the focus of the roadmap, but the government may invest where there are market failures.

Figure 1: *Low Emissions Technology Statements under the enduring strategy of the Technology Investment Roadmap*



Technology categories

LETS 2021 introduces a new technology category, enabling infrastructure. We have also refined the emerging technologies category from LETS 2020 and merged it with 'watching brief' technologies (Figure 2).

Figure 2: *Technology categories under the Technology Investment Roadmap*

Priority technologies

Technologies with potential for transformative economic and abatement impacts, aligned with Australia's comparative advantages, and where the government can make a difference.

Enabling infrastructure

Infrastructure that is critical for enabling commercial deployment of low emissions technologies. The government's first enabling infrastructure priorities are battery charging and hydrogen refuelling stations to support consumer choice in electric vehicles, and a digital grid with enhanced management systems and capabilities, to support rapid growth in solar and wind generation.

Emerging technologies

Emerging technologies have transformative potential, but require continued monitoring of global learning rates, research and investment trends. LETS 2021 updates the government's list of emerging technologies. Livestock feed supplements and low emissions cement are two emerging low emissions technologies that show promise for prioritisation in future statements and will be supported by early investments.

Priority low emissions technologies and economic stretch goals

We prioritise low emissions technologies by assessing them against four filters:

- **Abatement potential**. How big are the potential emissions reductions from this technology?
- **Economic benefit.** What are the potential economic benefits for Australia of deploying this technology at a large scale? Benefits include creating and preserving jobs, especially in regional areas.
- **Australia's comparative advantage.** Does this technology play to Australia's strengths? Our strengths include abundant energy and mineral resources, skilled workers, strong institutions and trusted trading relationships with major energy consumers.
- **Where government can make a difference.**[2] Will government investment help develop and deploy this technology? This includes whether government action will help accelerate cost reductions.

[2] This was previously called 'Technology Readiness Level'

We also set an economic stretch goal for each technology (Figure 3). These ambitious, but realistic, goals aim to bring priority low emissions technologies to cost parity with existing high emissions technologies. Economic stretch goals also signal to private investors that priority low emissions technologies are of long-term strategic importance to the government.

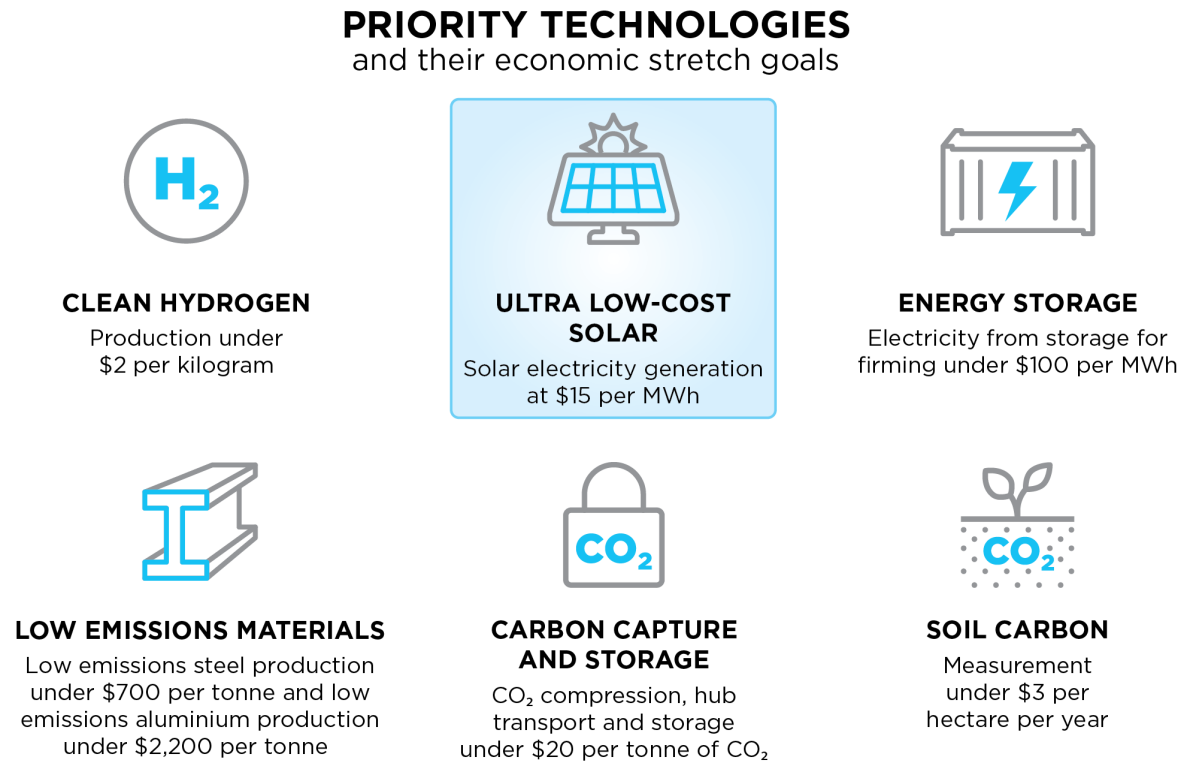
A newly prioritised technology: ultra low-cost solar

This year's statement adds **ultra low-cost solar** as a priority technology. This is based on Australia's comparative advantage in solar technology and the need to accelerate cost reductions in clean electricity generation. Ultra low-cost solar will unlock the economic, employment and abatement potential of clean hydrogen, low emissions steel and aluminium, and electrical energy for storage for firming.

Ultra low-cost solar will also reduce costs for electrification of other sectors such as transport, buildings and industry. Driving the price of clean electricity lower will help Australian industry, manufacturers and other businesses stay internationally competitive while reducing emissions and supporting the wider economy.

We have set an economic stretch goal for ultra low-cost solar electricity generation at $15 per MWh, or approximately a third of today's costs.

Figure 3: *Priority low emissions technologies and their economic stretch goals*



Tracking progress

Our technology-led approach is enduring, iterative and adaptive. We report our progress every year through annual Low Emissions Technology Statements. This ensures our investments are:

- lowering the cost of priority technologies
- attracting co-investment from others

- helping address Australia's big technology challenges.

We have developed an impact evaluation framework to track progress, inform government decisions and maximise investment impacts. The framework tracks progress in three areas:

- **Enabling policy and investments** – policies and investments that help develop and deploy low emissions technologies.
- **Co-investment and employment outcomes** – co-investment in government-funded projects from the private sector and other jurisdictions, as well as jobs supported.
- **Other technology, economic and abatement impacts** – impacts the government aims to influence, but also influenced by external factors. These include:
  - technology deployment and costs
  - exports supported by priority technologies
  - emissions reductions.

Our strategy

Reduce emissions and grow the economy

Australia is already reducing emissions while growing our economy.

The roadmap will build on this momentum and capture new opportunities. Our technology-led approach will:

- build on our global reputation as a trusted exporter of energy, resources and agricultural products
- support jobs and take advantage of growth opportunities as the world shifts towards lower emissions
- power the domestic economy with cheap, clean and reliable energy.

The roadmap will guide at least $20 billion of Australian Government investment in low emissions technologies over the decade to 2030. We expect to drive over $60 billion in co-investment, which will result in at least $80 billion total public and private investment, and support 160,000 jobs.

Drive down costs

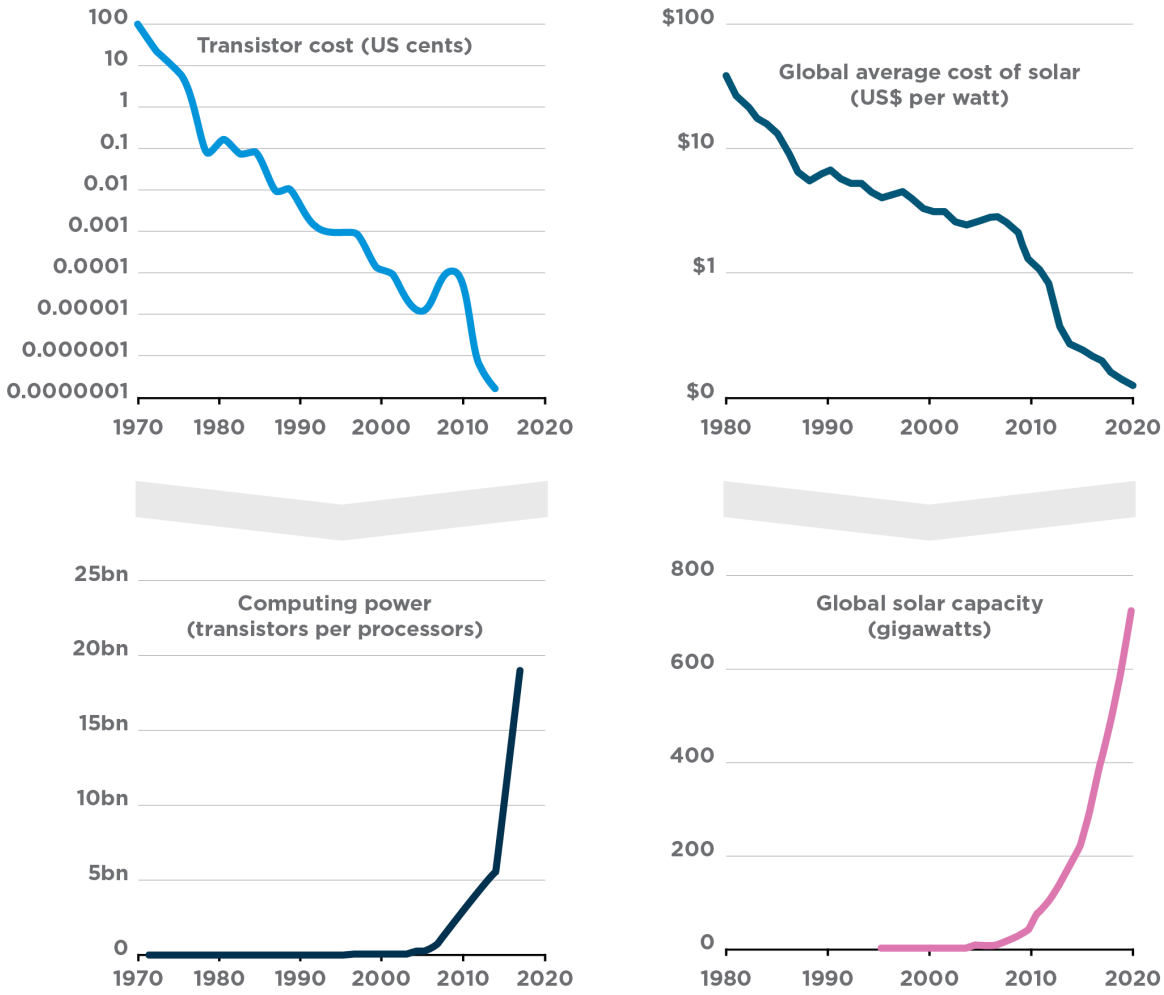
Australia's technology-led approach aims to help new and emerging low emissions technologies achieve cost parity with existing high emissions technologies.

When alternative low emissions technologies can compete with existing technologies on price, they will be adopted at large scale across the economy, significantly reducing emissions without additional costs.

History has shown the non-linear relationship between technology costs and deployment. Our experience with globally significant technologies like transistors and solar demonstrates how falling costs and a concerted innovation effort can catalyse an exponential increase in deployment (Figure 4). Achieving rapid deployment growth for the priority technologies is the ultimate goal of the roadmap.

It took until 2002 for the world deploy its first gigawatt of solar generation. A decade later, 100 gigawatts had been deployed. By the end of 2022, we expect 1,000 gigawatts to be deployed. This means that 90% of all solar deployment has occurred in the last 10 years, as the cost of solar cells has fallen dramatically.

Figure 4: *Declining cost of technology can catalyse widespread deployment*



Work with state governments, the private sector and other countries

Widespread deployment of low emissions technologies will mainly be driven by the private sector. The roadmap aims to attract an average of $3 or more co-investment for every $1 of Australian Government investment in the decade to 2030. The government is working with the private sector to achieve this goal.

State deals are bilateral energy and emissions reduction agreements that provide a clear way for the Australian Government, state and territory governments and industry to engage. They cover mutual priorities, including low emissions technologies, and can maximise government and private co-investment.

Australia is also working closely with other countries to develop and deploy low emissions technologies, including through bilateral partnerships. This:

- lets us share expertise with other nations
- supports innovation that makes low emissions technologies cheaper
- helps attract investment.

In 2020, the Prime Minister appointed Dr Alan Finkel, Australia's former Chief Scientist, as Special Adviser to the Australian Government on Low Emissions Technology. Dr Finkel is brokering international partnerships on low emission technologies. Australia has already announced partnerships with Germany, Japan, the Republic of Korea, Singapore and the United Kingdom.

Expanding international collaboration will create new trade and economic opportunities. It will accelerate the development and expansion of international supply chains for low emissions technologies and energy, including clean hydrogen and its derivatives.

Australia's international partnerships will deliver industry-led projects to reduce costs and deploy low emissions technologies. These will expand low emissions industries and help Australia become a leading exporter of low emissions technology and energy.

Australia is also engaged in multilateral forums to accelerate the deployment of low emissions technologies. This includes Mission Innovation where Australia has gone from participating in every innovation challenge to co-leading the new Clean Hydrogen Mission and the Net Zero Industry Demonstration Mission. Fifteen member countries have committed to the Clean Hydrogen Mission's goal to make clean hydrogen commercially viable by reducing the cost of production and delivery. The Industry Mission will foster collaboration to see pilots and large-scale demonstrations of low-emissions heavy industry technology.

Part of a whole-of-government strategy

The roadmap forms the cornerstone of Australia's Long-Term Emissions Reduction Plan.

The roadmap complements and draws on other Australian Government policies and strategies, including:

- Australian Energy Market Operator (AEMO) Integrated System Plan
- Critical Minerals Strategy
- Emissions Reduction Fund
- Future Fuels Strategy (forthcoming)
- Global Resources Strategy
- Modern Manufacturing Strategy
- National Energy Productivity Plan
- National Hydrogen Strategy
- National Soil Strategy
- National Waste Policy and Action Plan
- Post-2025 Energy Market Reforms

Technology Investment Advisory Council

The Technology Investment Advisory Council advises the Minister for Industry, Energy and Emissions Reduction in preparing annual low emissions technology statements. The council is made up of leaders from science, business, technology and government.

Current members

Dr Alan Finkel AO, Chair

Special Adviser to the Australian Government on Low Emissions Technology

Drew Clarke AO PSM

Chair of the Australian Energy Market Operator and CSIRO Board Member

Jo Evans

Deputy Secretary at the Department of Industry, Science, Energy and Resources

Grant King

Chair of the Climate Change Authority

David Parker AM

Chair of the Clean Energy Regulator

Justin Punch

Chair of the Australian Renewable Energy Agency Board

Steven Skala AO

Chair of the Clean Energy Finance Corporation Board

Alison Watkins

Non-Executive Director of the Reserve Bank of Australia and Chancellor of the University of Tasmania

Shemara Wikramanayake

CEO of Macquarie Group

Ben Wilson

CEO of Australian Gas Infrastructure Group and Chair of Energy Networks Australia

Consultation and collaboration

Partnership with the private and research sectors is vital to achieving our vision.

The government has undertaken public and targeted consultation to inform the development and implementation of the roadmap.

Public consultation for the roadmap discussion paper in 2020 received around 500 written submissions. Over 150 businesses, researchers, community organisations and associations participated in targeted industry workshops, led by Dr Alan Finkel, and more than 400 people attended an online webinar.

This consultation, along with one-on-one industry, academia and cross-government engagement, informed the development of LETS 2020.

Consultation has continued for LETS 2021 with targeted industry consultation and new engagement with our international partners.

Ongoing consultation and collaboration is key. Achieving our vision is not possible without repeated and meaningful engagement. Following the release of LETS 2021, the government will undertake public and targeted consultation to inform the development of LETS 2022.

Australian Government investment

At least $20B more Australian Government investment in low emissions technologies in the decade to 2030, driving more than **$80 billion** of total public and private investment and supporting **160,000 jobs**

Building on $21 billion investment over the last two decades

$1.7B New government funding announced for LETS 2021, including:

$464M* Clean hydrogen industrial hubs

$250M CCUS hubs and technologies

$565M International partnerships

$73M Soil carbon and livestock feed supplements

Adding to the $1.9 billion announced for LETS 2020

*This includes $54 million from previous funding announcements

$2.5B Government investment committed to projects

through agencies including the ARC, ARENA, the CEFC, the CER, CSIRO, DISER and NAIF in the financial year ending 30 June 2021

This includes $1.1B invested in priority technologies

Co-investment leveraged

Co-investment leveraged by government investments in the financial year ending 30 June 2021 **$4.6B**

Estimated investment in renewable energy in Australia in 2020 **$9.7B**

Note: *The above content reflects year-to-date data for the financial year ended 30 June 2021 available from selected government agencies at the time the statement was prepared. We will publish updated figures for total investment as they become available. Estimated renewable energy investment data from Clean Energy Regulator 2021, Quarterly Carbon Markets Report – December Quarter, accessed 1 September 2021*

Project examples

Hydrogen

Murray Valley Hydrogen Park
AGIG

ARENA has given conditional approval for a $32 million grant to build a commercial scale 10 megawatt electrolyser to produce clean hydrogen in Wodonga, Victoria. This will be amongst the largest in the world. Under this project, 10% hydrogen will be blended into existing gas pipelines supplying 40,000 homes and businesses, a key step towards decarbonising Australia's gas networks. This is one of three projects conditionally approved for $103.3 million in total under ARENA's Renewable Hydrogen Deployment Funding Round.

Aluminium

Low Emissions Alumina
Alcoa & Rio Tinto

ARENA provided an $11 million grant to Alcoa to trial electrification of steam production for process heat at its Wagerup alumina refinery in Western Australia. ARENA also provided a $579,000 grant to Rio Tinto to assess the viability of hydrogen calcination at its Yarwun alumina refinery in Gladstone, Queensland. Both projects will help decarbonise alumina, Australia's sixth largest export.

CCS

Carbon Capture, Use & Storage (CCUS) Development Fund

In LETS 2020, the government signalled its intention to invest in supporting the commercialisation of CCS technologies. Under the CCUS Development Fund, $50 million was awarded to six businesses to pilot, demonstrate and support the commercial deployment of CCUS technologies. These include direct air capture and removal, capture and geological storage from power plant operations, and capture and use of CO_2 in the production of construction materials.

Livestock supplements

Programs to reduce livestock emissions

The $6 million Methane Emissions Reduction in Livestock program supports research into the abatement potential and productivity benefits of livestock feed supplements. The $23 million Low Emissions Supplements to Grazing Animals at Scale program will help develop technologies to deliver low emissions feed to grazing animals. $1 million was also granted to commercially produce seaweed for low emissions feed.

International partnerships

International partnerships will help achieve:

Building on commitments in LETS 2020, in 2021 the Australian Government announced $565.8 million to establish international partnerships on low emissions technology. International partnerships are key to finding and developing the solutions to the world's climate challenges and reducing emissions while creating new economic opportunities.

Australia has already announced partnerships with Germany, Japan, the Republic of Korea, Singapore and the United Kingdom.

The partnerships will foster greater cooperation on low emissions technologies. They will underpin the development of new technologies leading to emissions reductions, job creation, lower energy costs, new trade opportunities and greater investment in Australia.

International partnerships will be delivered through a range of mechanisms, including co-funding applied research, pilot and demonstration projects, establishing supply chains, exchanging expertise, and building industry connections. Projects and initiatives under the international partnerships will complement efforts across Australia to advance low emissions technologies. This includes the work of ARENA, CEFC, CSIRO, state and territory governments, and private businesses.

International partnerships will build on the work already being done by the Australian Government to establish supply chains to catalyse development of a world-leading hydrogen export industry.

Germany

Australia-Germany Hydrogen Accord

- HyGATE Program, with combined investment of approximately $130 million for RD&D projects along the hydrogen supply chain.
- Facilitating industry partnerships on demonstration projects in Australian hydrogen hubs
- Exploring opportunities to supply hydrogen and its derivatives to Germany

Japan

Low Emissions Technology Partnership

- Partnership to support technologies, including: clean hydrogen and ammonia; carbon capture, use and storage; lower emissions LNG; and low emissions steel and iron ore.
- Start of operations for Hydrogen Energy Supply Chain project, to produce and export liquefied clean hydrogen to Kobe, Japan.

Republic of Korea

Australia-Republic of Korea Low and Zero Emissions Technology Partnership

- Collaboration on low and zero emissions technologies, including: clean hydrogen and clean ammonia; low emissions iron ore and steel; hydrogen fuel cell electric vehicles; hydrogen power generation; carbon capture, utilization and storage; energy storage; solar; and the critical minerals supply chain.
- Research on hydrogen supply chains between Korean and Australian companies.
- Low emissions steel and iron ore initiative to reduce emissions across the supply chain.

Singapore

Low Emissions Maritime Initiative

- $30 million co-investment from Australia, Singapore and industry for pilot and demonstration projects to trial the use of low emissions technologies, including clean hydrogen and ammonia, in shipping and port operations. This builds on an existing MOU on low emissions technologies.

United Kingdom

Australia–UK Partnership on Low Emissions Solutions

- Cooperation on research and development across six key technologies including clean hydrogen; carbon capture and use and storage; small modular reactors including advanced nuclear designs and enabling technologies; low emissions materials including green steel; and soil carbon measurement.
- As a first initiative, we will develop a joint industry challenge to increase the competitiveness of industry, reduce emissions and support economic growth.

Government actions

The Australian Government's technology-led approach will reduce emissions without imposing new costs on households, businesses or the economy.

The private sector will lead the deployment of low emissions technologies. The government's role is to remove barriers to deployment and incentivise voluntary action and private investment in priority low emissions technologies by:

- investing in research, development, demonstration and early-stage commercialisation
- investing in enabling infrastructure
- facilitating voluntary action and informing choice for consumers and businesses.

The government has committed to invest at least $20 billion in low emissions technologies by 2030, to drive over $80 billion of total public and private investment over the decade. This investment will support 160,000 jobs across Australia. This builds on the $21 billion of investment in low emissions technologies made by the government over the last two decades.

The Technology Investment Roadmap, bolstered by annual low emissions technology statements, provides a comprehensive investment strategy to guide government investment in low emissions technologies.

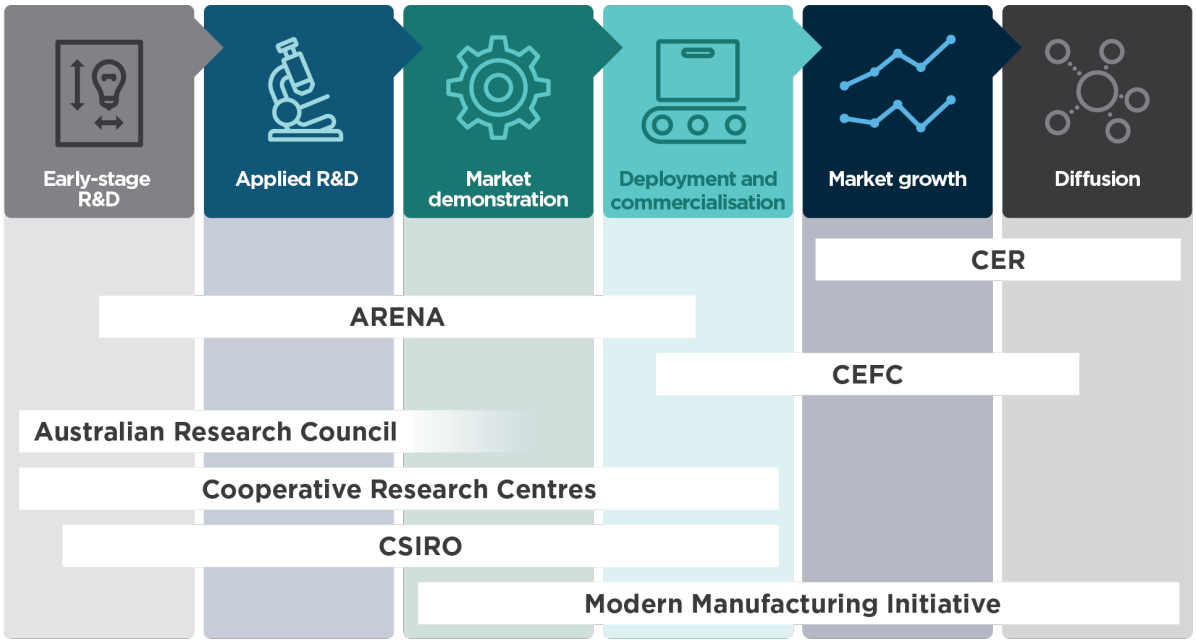
The government announced $1.9 billion in funding alongside LETS 2020.

Since the release of LETS 2020, the government has announced a further $1.7 billion in funding to support LETS 2021 initiatives and the roadmap.

Investing in the research to commercialisation pipeline

Supporting research, development, demonstration and early-stage commercialisation through co-investment is the main focus of the Technology Investment Roadmap (Figure 5).

Figure 5: *Australian Government investment across the technology development process*



Australian Renewable Energy Agency

The Australian Renewable Energy Agency (ARENA) supports innovation and commercialisation of renewable energy and low emission technologies. It bridges the gap between innovation and investment to help emerging and early-stage technologies become commercially viable.

In 2020, ARENA's funding was extended, providing it with an additional $1.4 billion of baseline funding over the next 10 years, and a further $193 million to deploy targeted programs associated with transport, industrial energy efficiency, and regional microgrids.

This year, the government expanded the role of ARENA, enabling it to support all of the priority technologies set out in LETS 2020. ARENA will play an important role in stimulating investment in the priority technologies and reducing their cost of deployment.

Since the roadmap was released in 2020, ARENA has provided funding to support several priority low emissions technologies, including hydrogen, energy storage and low emissions materials. This includes $103 million conditionally approved for three commercial-scale renewable hydrogen projects through ARENA's Renewable Hydrogen Deployment Funding Round. These are some of the largest clean hydrogen projects in the world.

Clean Energy Finance Corporation

The Clean Energy Finance Corporation (CEFC) plays a unique role in the Australian economy, working with the private sector to demonstrate the financial viability of near-commercial low emissions technologies and the bankability of new revenue streams.

The CEFC takes a commercial approach, providing tailored debt finance and equity to businesses and projects that:

- deploy proven low emission technologies
- develop and commercialise early-stage and late-stage clean energy technologies.

Since the roadmap was released, the CEFC has:

- incorporated the roadmap into its four-year corporate plan
- continued to invest in energy storage
- made its first investments in hydrogen, soil carbon sequestration and electrical transmission infrastructure
- supported early-stage technology development by investing in start-up companies.

The government and CEFC will continue to investigate how the CEFC can further support priority low emissions technologies.

Clean Energy Regulator

The Clean Energy Regulator (CER) administers Australian Government schemes for measuring, managing, reducing and offsetting Australia's greenhouse gas emissions. These include the Emissions Reduction Fund (ERF) and Safeguard Mechanism, the Renewable Energy Target, the National Greenhouse and Energy Reporting Scheme and the Australian National Registry of Emissions Units.

Since LETS 2020, the CER has developed a new ERF method to support CCS. The CER is also developing certification frameworks and platforms to give confidence to investors and consumers as new technologies and industries evolve. These include the Guarantee of Origin Scheme for Hydrogen, in collaboration with the Department of Industry, Science, Energy and Resources, and the Australian Carbon Exchange.

Australian Research Council

The Australian Research Council (ARC) expands knowledge and innovation for the benefit of the Australian community by funding the highest quality research, assessing the quality, engagement and impact of research, and providing advice on research matters.

The ARC administers an average of $800 million in grants every year. Grants are awarded to individuals, research teams and large-scale centres through the ARC's Discovery Program and Linkage Program.

Discovery Program

The ARC's Discovery Program supports individuals and small teams. It recognises the importance of fundamental research to national innovation.

Strong fundamental research capabilities are essential for Australia to play a leading role in developing new and emerging low emissions technologies.

Linkage Program

The ARC's Linkage Program supports national and international partnerships between researchers and business, industry, community organisations and other publicly funded research agencies. These partnerships help transfer skills, knowledge and ideas to secure commercial and other benefits.

Linkage Program funding already supports low emissions technologies through the Industrial Transformation Program. This program funds research hubs and training centres including research on low emissions technologies such as steel innovation and energy storage.

The Linkage Program provided $35 million for the ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals. The centre will work with academic, industry and government partners to develop transformational technologies for minerals beneficiation. These technologies are essential for meeting global demand for metals.

Commonwealth Scientific and Industrial Research Organisation

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) works with universities, research institutes and industry to develop technologies and support commercial uptake across many areas of the economy, including low emission technologies. CSIRO's relevant research areas include clean hydrogen production, energy storage, industrial decarbonisation and agricultural emission reduction.

CSIRO has also established a mission-driven multidisciplinary science and research program to drive major demonstration and investment activities in areas of high importance to Australia. CSIRO's missions include:

- the Hydrogen Industry Mission, which aims to demonstrate commercial uptake pathways for clean hydrogen production and end-use markets.
- the Towards Net Zero Mission, which will focus on technology uptake pathways to achieve low emission outcomes for Australian industry, agriculture and regional communities.
- the planned Critical Energy Metals Mission, which will aim to increase economic value from the energy transition by transforming our mineral resources into higher-value products and creating new manufacturing jobs and export-ready technologies.

Cooperative Research Centres

The government supports industry-led collaborative research through grants under the Cooperative Research Centres (CRC) Program.

CRCs have established projects in areas of competitive strength that align with government priorities, including developing and deploying priority low emissions technologies:

- The Heavy Industry Low-carbon Transition (HILT) CRC will receive $39 million in Australian Government grant funding over 10 years to develop Australia's heavy industries and de-risk the technology pathways for a profitable transition to internationally-competitive production of low-carbon products. Partners will contribute a further $176 million to the CRC.
- The Future Fuels CRC will receive $26 million in Australian Government grant funding over seven years to help adapt gas pipelines and storage systems to operate in a low-carbon economy using fuels such as hydrogen and biogas. Partners will contribute a further $64 million to the CRC.
- The Reliable Affordable Clean Energy (RACE) for 2030 CRC will receive $69 million in Australian Government grant funding over 10 years to reduce costs to business, enhance reliability, cut carbon emissions, improve energy affordability and develop Australian energy technology businesses. Partners will contribute a further $279 million to the CRC.

The government will continue engaging with CRCs on industry-led research into low emissions technologies and enabling infrastructure.

Modern Manufacturing Initiative

The $1.3 billion Modern Manufacturing Initiative (MMI) supports projects from market demonstration through to commercial scale-up. This includes translating high-quality research into marketable products, integrating intermediate products into new domestic and global value chains, entering new markets and creating transformational business-to-business and business-to-research collaborations.

The Recycling and Clean Energy National Manufacturing Priority roadmap is helping to guide industry engagement and co-investment under the MMI. It highlights manufacturing opportunities for Australia in hydrogen technologies, batteries, next-generation photovoltaic modules, and low emissions metals, among other products.

Supporting Australian manufacturers to pursue competitive, high-value manufacturing opportunities in these areas builds on and extends the government's broader support for low emissions technologies.

Investing in enabling infrastructure

The government is supporting shared infrastructure to facilitate the voluntary and commercially-driven uptake of low emissions technologies. This includes support for several transmission projects identified by AEMO's Integrated System Plan to fulfil National Electricity Market cost, security and reliability expectations. Up to $250 million has been committed for early works to progress three important new transmission lines:

- Marinus Link between Tasmania and Victoria
- Project Energy Connect between South Australia and New South Wales

- Victoria to New South Wales Interconnector West.[3]

Enabling infrastructure

LETS 2021 introduces the category of 'enabling infrastructure' – infrastructure that is:

- fundamental to a low emissions economy
- needed for Australia to deploy priority, emerging and proven low emissions technologies at a large scale.

Enabling infrastructure must be available at the right time to support commercial investment, help deliver low-cost energy and give consumers more choice in low emissions technologies.

The government's first enabling infrastructure priorities are:

- battery charging and hydrogen refuelling stations to support consumer choice in electric vehicles
- a digital grid with enhanced management systems and capabilities to support rapid growth in solar and wind generation.

Electric vehicle charging and refuelling infrastructure

Battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs) will become price competitive over the next five to ten years as the world's largest vehicle manufacturers increasingly commit to their development.

Investment is required to prepare for a rapid increase in the number of consumers choosing BEVs and FCEVs, and to ensure enough charging and refuelling stations are made available to meet demand.

The government is supporting the rollout of battery charging and hydrogen refuelling stations through the $71.9 million Future Fuels Fund. The government's first round of the Future Fuels Fund, administered by ARENA, has provided $24.5 million of funding to five applicants across 19 projects. These 19 projects will deliver 403 new fast charging stations, each capable of charging at least two vehicles concurrently at 50 kW or greater.[4,5]

Integration of battery charging and hydrogen refuelling stations into Australia's energy networks needs to be well planned and managed to ensure the network operates efficiently. Good planning and management, facilitated by electricity market and network reforms, will help realise opportunities such as shifting demand to take advantage of periods of excess, low-cost supply. This will also lower costs for consumers by sharing the cost of the electricity network, while delivering broader benefits including emissions reduction, fuel security and improved air quality.

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[3] This is in addition to a $56 million grant to support Marinus Link in 2019. It also follows a joint commitment between the Australian and New South Wales governments in 2020 to underwrite up to $66 million and $102 million in early works for the HumeLink and Queensland-New South Wales interconnector (QNI) upgrade transmission projects.

[4] A BEV with a 75 kilowatt-hour (kWh) battery takes approximately 30 hours to charge from empty to full on a 2.4 kW domestic slow charger, 1.5 hours on a 50 kW fast charger, and just 15 minutes on a 350 kW fast charger. In practice it takes longer, because the power is progressively cut back during charging to prevent the battery from overheating.

[5] To ensure maximum convenience for Australian drivers, care will be taken to ensure that funded fast charging stations are fitted with the Type 2 AC plug that is now standard on all new Australian BEVs and that all BEV models are supported.

In addition, the government will investigate support for smart charging technology to bring forward the best outcomes for BEV motorists and the electricity grid. Well-integrated BEV charging will improve system security and reliability, reduce costs for BEV owners and deliver value to all other energy consumers through better utilisation of the electricity transmission and distribution systems.

Digital grid

Australia needs to support an electricity system increasingly powered by variable renewable generation in order to deliver low-cost, clean and reliable electricity. Australia is already world leading in this regard, with the highest solar capacity per person in the world and the highest combined wind and solar capacity of any country outside Europe.[6]

An enhanced operating system is required for the Australian Electricity Market Operator (AEMO), together with market participants such as generators, networks and policy makers, to continue to manage the electricity grid in a way that is effective, efficient, secure and reliable.

The government is supporting an initial investment of $13 million, through more than $2 million from ARENA, to help AEMO develop this operating system. The government will continue to build on existing work by AEMO to support the ongoing expansion of an enhanced operating system, to ensure a full suite of digital capabilities needed to manage high penetration of variable renewables over time.

Investment in a digital grid that complements the electricity market's Integrated System Plan and post-2025 reforms will allow Australia to fully benefit from the emissions reductions offered by the renewables revolution.

Building on the National Hydrogen Infrastructure Assessment

We are developing a National Hydrogen Infrastructure Assessment to guide government and private sector investment in clean hydrogen as the industry grows.

We will follow this with a complementary assessment of infrastructure needs for other priority technologies. This includes identifying opportunities to reduce costs by locating hydrogen, energy storage, and CCS infrastructure near steel and aluminium manufacturers.

Building on the hydrogen infrastructure assessment will help develop an efficient long-term framework for clean hydrogen industrial hubs.

[6] International Renewable Energy Agency 2021, *Renewable Capacity Statistics 2021*, accessed 5 August 2021

Clean Hydrogen Industrial Hubs Program

Through the Clean Hydrogen Industrial Hubs program, the government is investing $464 million to accelerate the development of an Australian clean hydrogen industry.

Clean hydrogen industrial hubs seek to concentrate demand for hydrogen in one geographic region, thereby helping to reduce costs and share information. Clean hydrogen industrial hubs will co-locate users, producers and potential exporters, allowing them to both leverage industrial, energy and transport resources and stimulate investment, innovation and workforce skills development in our regions.

The new clean hydrogen industrial hubs program will build Australia's potential to supply domestic users and international trading partners with low-cost clean energy, and will help to capitalise on global interest in investing in Australian hydrogen opportunities. Cooperation on hydrogen forms part of new low emissions technology partnerships with Germany, Japan, the Republic of Korea, Singapore and the United Kingdom announced this year. Australia's Hydrogen Accord with Germany includes a commitment to facilitating industry-to-industry cooperation on demonstration projects in Australian hydrogen hubs.

Clean hydrogen industrial hubs will provide opportunities for sector coupling through co-location of new energy resources, low emissions technologies, manufacturing, and potential export industries. These hubs will benefit from the regions' established infrastructure, transport mechanisms and workforces.

The government has identified the following locations as highly prospective hydrogen hub locations:

- Bell Bay (TAS)
- Darwin (NT)
- Eyre Peninsula (Whyalla, SA)
- Gladstone (QLD)
- Hunter Valley (NSW)
- La Trobe Valley (VIC)
- Pilbara (WA).

Community engagement

To realise the economic and employment benefits from emerging low emissions industries, communities must be given the opportunity to participate in and shape the development. Early and ongoing engagement, including with Traditional Owners, will be key to understanding community values, concerns and aspirations as low emissions technology sectors grow.

Factors including the perceived costs, risks and benefits, fairness, and awareness of adverse consequences all impact the overall acceptance and support for new technologies.[7] Building partnerships with communities over time through collaboration is essential, including through:

- clearly communicating costs, risks and benefits
- managing expectations and communicating realistic timeframes
- ensuring benefits are fairly distributed

[7] Australian Council of Learned Academies 2021, *Australian Energy Transition Research Plan*, accessed 4 August 2021

- ensuring nationally consistent messaging about low emissions technologies.[8]

Communities may have different attitudes to a technology depending on their interactions with it. Earning citizens' acceptance for a low emissions technology placed near their homes requires a different engagement process to a remotely placed low emissions technology.[9]

The government will continue to work with industry and communities to understand how different groups may be impacted by the development of low emissions technologies and to promote best-practice engagement.

Australian Energy Infrastructure Commissioner

The Australian Energy Infrastructure Commissioner, an independent role appointed by the government, receives and refers complaints from concerned community residents about wind farms, large-scale solar, energy storage facilities and new major transmission projects. The Commissioner also promotes best practices for industry and government to adopt when planning and operating these projects.

Facilitating voluntary action and informing consumer choice

The government will promote voluntary action and provide clear information to help consumers and businesses choose low emissions technologies, including through the existing Emissions Reduction Fund, certifications and standards, and the proposed Voluntary Zero Emissions Gas Market.

Emissions Reduction Fund

The Emissions Reduction Fund (ERF) encourages voluntary action to reduce emissions, providing financial incentives for farmers, businesses and communities to undertake voluntary projects that store carbon or avoid emissions and provide economic benefits. It is one of the world's largest offset programs, having delivered more than 100 million tonnes of abatement, and underpinned by a rigorous framework to ensure the integrity of the abatement generated. Under the fund, the CER issues Australian Carbon Credit Units (ACCUs) to projects that store carbon or reduce emissions using approved methods. An ACCU is equivalent to one tonne of CO_2-e stored or avoided. Once earned, an ACCU can be sold, kept, or retired.

Government purchases of ACCUs, combined with growing demand from business and consumers seeking to reduce emissions, can create strong voluntary markets. These markets can stimulate early demand for low emissions products and technologies.

The ERF now has over 1,000 projects delivering carbon abatement benefits across Australia and has contracted a total of 209 million tonnes of CO_2-e abatement. Contracts under the ERF will deliver over $2 billion to rural and regional communities, with over $640 million already delivered.

[8] Ashworth P, Witt K, Ferguson M, Sehic S 2019, *Developing community trust in hydrogen*, accessed 4 August 2021

[9] Australian Council of Learned Academies 2021, *Australian Energy Transition Research Plan*, accessed 4 August 2021

The CER administers the ERF and develops ERF methods. ERF methods are independently assessed before being made by the Minister to provide transparency and certainty to purchasers and consumers.

New methods for other low emissions technologies could fast-track the ability of project proponents to generate tradeable carbon credits. Through the 2020–21 Budget, the government provided $40 million of new funding to accelerate the development of new ERF methods to five per year.

Supporting low emissions technologies through the ERF

A new CCS method, released in September 2021, will enable ACCUs to be earned for every tonne of emissions avoided through CCS ERF projects. It will help drive voluntary emissions reductions across hard-to-abate sectors including cement, natural gas processing and steel production. The new CCS method will also support clean hydrogen production and the creation of CCS hubs.

A new method for soil carbon sequestration is under development to make it easier for farmers to develop and get support for projects under the ERF. For the first time, it will allow modelled estimates of soil carbon change to be used, in combination with measurement approaches, which is expected to materially reduce costs and increase returns. The method was released for public consultation in September 2021 and is expected to be finalised by the end of 2021. Soil carbon projects are attracting strong interest, making up a quarter of all new project registrations in 2021.

The government will develop a further five new ERF methods in 2022. These include methods aligned with priority technologies and enabling infrastructure in LETS 2021 including: electric vehicle charging and refuelling infrastructure, clean hydrogen, and carbon capture, use and storage.

Climate Active

Climate Active is an ongoing partnership between the Australian Government and Australian businesses to drive voluntary climate action.

Certification is awarded to businesses that credibly reach net zero emissions against a best practice carbon accounting standard by measuring, reducing and offsetting emissions.

Climate Active is developing new options to recognise voluntary climate action, including:

- where all offsets used in a carbon neutral certification are ACCUs
- where all the electricity used is matched with renewables.

Climate Active is also considering other forms of recognition, including for substantial and verified emissions reduction achievements.

Certification and standards

Transparent certification and standards can increase confidence in low emissions energy, products and materials. The government will continue to work with industry partners and other countries to ensure Australian certification and standards are consistent and recognised around the world. Our current work on hydrogen certification will pave the way for other technologies like low emissions materials and CCS.

Hydrogen Guarantee of Origin Scheme

The government is developing a Guarantee of Origin scheme for hydrogen – a vital step to provide markets with the transparent information needed for future global trade in this new clean energy.

The scheme will provide hydrogen consumers, whether they are national governments, companies or individuals, with data on how and where the hydrogen they purchase is produced. Most important, it will document the quantity of carbon dioxide emissions associated with the production of each tonne of hydrogen. It will also include the technology and energy source used to produce the hydrogen.

In June 2021, the government released a discussion paper, A Hydrogen Guarantee of Origin Scheme for Australia, outlining a proposed design for a domestic scheme.

Australia is taking a lead role in the Production Analysis Taskforce of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). This involves developing an internationally agreed methodology to determine the well-to-gate emissions from different hydrogen production pathways. The IPHE is focused on developing a common basis for calculating the emissions intensity of hydrogen to facilitate comparison across countries, rather than developing arbitrary definitions of zero or low emissions hydrogen. Australia's proposed Guarantee of Origin scheme aligns with the developing IPHE methodology.

The government has announced $9.7 million to help trial the Guarantee of Origin scheme in Australia. We expect the Clean Energy Regulator to conduct these trials.

Voluntary zero emissions gas market

The government will work with industry, consumers and state and territory governments over the next 12 months to develop a voluntary zero emissions gas market in Australia.

This market will drive early demand for clean hydrogen and other zero emissions gases and recognise consumers' voluntary purchase of zero emission gas.

Fostering this market will also provide the revenue clean hydrogen producers need to scale up quickly to bring down production costs closer to the $2 per kg stretch goal.

Certification and standards (such as the Hydrogen Guarantee of Origin scheme) will provide the transparency and traceability needed for a zero emissions gas market.

The National Hydrogen Strategy includes actions to amend the National Gas Law (and relevant jurisdictional laws and regulations) so that hydrogen and zero emissions gas blends can be injected into Australian gas networks.

Biomethane ERF Method

Biomethane is a low emissions natural gas substitute produced by capturing and refining organic waste methane emissions. Biomethane can be injected into the natural gas distribution grid, or used as a direct substitute for natural gas in other industrial and domestic applications. As biomethane is created from bio-based waste streams, it results in significantly lower emissions than natural gas.

In late 2020, the government prioritised the development of an ERF method to enable projects to earn ACCUs for generating and using biomethane. The method is expected to be finalised in coming months.

Priority technologies

Existing priority technologies

Priority technologies are the focus for government investment. The following five priority low emissions technologies and economic stretch goals were introduced in LETS 2020. Accompanying economic stretch goals are ambitious but realistic goals to bring priority low emissions technologies to cost parity with existing high emissions technologies.

Priority technologies are selected based on abatement potential, scale of economic benefit, Australia's comparative advantage and responsiveness to government investment.

Clean hydrogen

Stretch goal: production under $2 per kg.

Clean hydrogen is a transformative fuel that can be used to power vehicles, generate heat and electricity, and serve as a feedstock in industrial applications. It also allows for the export of renewable and low emissions energy, either as clean hydrogen or a hydrogen derivative such as clean ammonia. Australia's competitive advantages – abundant land and solar and wind energy, extensive carbon storage reservoirs, and excellent reputation as a trusted energy exporter – mean we are well positioned to be a world leading clean hydrogen producer.

Energy storage

Stretch goal: electricity from storage for firming under $100 per MWh.

Grid-scale electrical energy storage will be an essential element of Australia's future electricity system. Broad deployment of electrical energy storage will facilitate further integration of low-cost solar and wind electricity in the grid. Energy storage will provide system security services and be a source of reliable, dispatchable electricity, and reduce pressure on electricity prices by meeting peaks in consumer demand.

Low emissions materials

Stretch goal: low emissions steel production under $700 per tonne and low emissions aluminium production under $2,200 per tonne.

Steel and aluminium are important global commodities and thousands of people are employed in these industries in Australia, many in regional areas. Australia can help to unlock the technologies that will reduce emissions from these sectors across the supply chain, from mining to refined products.

Carbon capture and storage

Stretch goal: CO_2 compression, hub transport, and storage under $20 per tonne of CO_2.

Large-scale deployment of CCS will underpin new low emissions industries (including hydrogen) and provide a potential decarbonisation pathway for hard-to-abate industries such as natural gas processing and cement.

Australia has a comparative advantage in CO_2 transport and storage, with a number of sources of CO_2 located close to suitable geological storage basins and with established pipeline easements between the two.

Soil carbon

Stretch goal: soil carbon measurement under $3 per hectare per year.

Australia has untapped potential as a globally significant source of carbon sequestration in our soils. Offsets created by soil carbon projects can provide a valuable additional revenue stream for farmers, and provide decarbonisation pathways for new and existing industries, while preserving and creating jobs.

Furthermore, increasing the soil carbon concentration (in the form of organic material) may improve farm productivity and crop yields through better nutrient and water retention, boosting resilience to drought and erosion.

A newly prioritised technology – ultra low-cost solar

This year, we introduce ultra low-cost solar as a sixth priority technology, with an economic stretch goal for solar electricity generation at $15 per MWh, or approximately a third of today's costs.

Low-cost, clean electricity is key to reducing the costs of other priority low emissions technologies. It will unlock economic, employment and abatement potential for clean hydrogen, low emissions steel and aluminium, and electrical energy storage for firming. Low-cost electricity will also be important for operating compressors used in CCS. Achieving $15 per MWh for solar electricity generation could help deliver the world's lowest cost clean electricity, enabling Australian manufacturers and businesses to stay competitive and support the wider economy.

Advances in solar technology will reduce the cost of unfirmed electricity supply in Australia. Achievement of this stretch goal would see reductions in the cost of solar outpace reductions in wind energy, enhancing a source of Australian comparative advantage.

High penetration levels of ultra low-cost solar electricity in our grid will require the successful implementation of other priority technologies, enabling infrastructure and market reforms, including energy storage, the digital grid and recognition of the importance of dispatchable capacity in electricity markets. In the meantime, Australia's existing thermal generation fleet will continue an essential role in meeting customer and grid firming needs.

Australia's comparative advantage

Annual solar irradiation in Australia is the highest per square metre in the world, and we have significant land-mass suitable for large-scale solar developments, and proximity to large and growing markets.[10]

Australia's researchers have played a world-leading role in the development of commercially viable solar technologies, going back to the 1960s. Australian developed passivated emitter rear cell (PERC) technology is used in 90% of today's global solar photovoltaic (PV) manufacturing. Our universities and companies continue to develop cutting-edge technology to increase cell efficiency and reduce cost.

[10] Geoscience Australia, *Solar Energy*, accessed 9 August 2021

Economic stretch goal – ultra low-cost solar electricity generation at $15 per MWh

Solar electricity generation at $15 per MWh would fast-track Australia's ability to meet the clean hydrogen stretch goal of production under $2 per kg, and increase our competitiveness in hydrogen export markets.[11] It would also support cost-competitive production of low emissions steel and aluminium, and direct air capture of CO_2 (an emerging technology).

The $15 per MWh stretch goal for ultra low-cost solar has been set taking into consideration current and projected costs for utility-scale solar electricity, and alignment with international benchmarks.[12,13,14] The stretch goal assumes utility-scale solar PV without network or firming costs, and without subsidies.[15]

Solar 30 30 30

Reaching the stretch goal will require further innovation in the efficiency of solar modules and optimisation of large scale deployment. The government will work toward achieving **30% module efficiency** at **30 cents per installed watt by 2030**.

Australia is well positioned to drive the next phase of cost reductions in solar PV through a two-pronged approach across solar cell R&D, and innovation in assembly and deployment methods. In particular, there are two significant levers to facilitate cost reductions for solar electricity:

- improving module efficiency from about 22% to 30%
- reducing balance of plant costs by approximately 70%.

[11] Clean hydrogen production under $2 per kg requires clean electricity at around $20 per MWh, however to increase Australia's competitiveness in hydrogen exports, production costs closer to $1 per kg will ultimately be required, necessitating lower electricity costs.

[12] BloombergNEF, *1H 2021 LCOE Update*, accessed 9 August 2021

[13] Graham P, Hayward J, Foster J, Havas L 2021, *GenCost 2020-21: Final report*, CSIRO, accessed 5 August 2021

[14] US Office of Energy Efficiency & Renewable Energy, *Solar Energy Technologies Office Updated 2030 Goals for Utility-Scale Photovoltaics*, accessed 9 August 2021

[15] Other assumptions include: 25% capacity factor, 5.9% WACC, and 25 year operating life.

Enabling infrastructure

Enabling infrastructure is a new category in LETS 2021, identifying technologies and infrastructure that are essential for enabling commercial deployment of low emissions technologies and supporting consumer choice.

The government will take strategic and targeted action to ensure enabling infrastructure are available to support commercial investment and consumer uptake. Government action will also be focused on ensuring energy affordability for businesses and consumers.

The government's first enabling infrastructure priorities are:

- battery charging and hydrogen refuelling stations to support consumer choice in electric vehicles
- a digital grid with enhanced management systems and capabilities to support rapid growth in solar and wind generation.

Electric vehicle charging and refuelling infrastructure

Electric vehicles

There are broadly two types of electric vehicles (EVs):

- **Battery electric vehicles (BEVs)** are electric vehicles that exclusively use electrochemical energy stored in rechargeable battery packs to power one or more electric motors, with no secondary source of propulsion. BEVs require battery charging to restore the electrical energy in the battery by connecting it to a power supply.
- **Hydrogen fuel cell electric vehicles (FCEVs)** are electric vehicles that use electricity from a fuel cell powered by compressed hydrogen. FCEVs require hydrogen refuelling stations to refill the FCEVs hydrogen tanks in much the same way as a conventional petrol or diesel vehicle.

The voluntary uptake of BEVs and FCEVs by consumers and businesses in Australia has been hampered by:

- higher vehicle upfront costs
- limited deployment of public charging and refuelling stations
- lack of model variety.

Global advances will see electric vehicles reach cost parity with internal combustion engine vehicles, potentially around the middle of this decade.[16]

However, the market is likely to supply too few chargers for BEVs in rural and regional areas due to a lower population density and slower increase in demand. More chargers are needed to fill 'charging blackspots' across metropolitan, regional and rural Australia.

[16] McKinsey 2019, *Making electric vehicles profitable*, accessed 9 August 2021

Hydrogen refuelling stations will need to develop in line with FCEV deployment to ensure commercial viability in Australia.

The government is backing battery charging and hydrogen refuelling stations to enable greater consumer choice and support demand for electric vehicles in Australia.

The government has created the $71.9 million Future Fuels Fund to support businesses to integrate new technology vehicles into their fleets and deliver battery charging and refuelling stations across capital cities and key regional centres, helping to improve motorist confidence.

In July 2021, ARENA, on behalf of the Australian Government, announced $24.5 million of funding for round one of the Future Fuels Fund. This investment will build 403 fast charging stations for battery electric vehicles in 'charging blackspots' around the country, including: Sydney, Newcastle, Central Coast, Wollongong, Melbourne, Geelong, Brisbane, Gold Coast, Sunshine Coast, Perth, Adelaide, Canberra, Hobart and Darwin.

Further investment will be required to prepare for a rapid increase in the number of consumers choosing electric vehicles, including to:

- increase availability of public battery charging and hydrogen refuelling stations
- ensure that electricity networks can handle the increase in charging from households and businesses.

As demand for vehicle charging increases, we will need to consider possible impacts on electricity grid security and reliability. The government is continuing to work directly with the states and territories and through the Energy Ministers Forum to enable and incentivise BEV charging that will effectively and efficiently integrate BEVs into the National Electricity Market.

Smart charging for optimised grid integration

Fast charging infrastructure will be essential for long-range BEV driving across Australia. However, estimates suggest 75% of charging will occur at home.[17] Increased numbers of electric vehicles being charged at home at peak times could overload existing electricity networks, and require investment in distribution networks, which would be borne by all network users.

Investment in low power smart charging infrastructure will be required to optimise grid integration of BEVs. When coordinated and managed effectively by aggregators and grid operators, BEV charging offers a new form of flexible demand that could support the security, reliability and affordability of the electricity system for all energy users. Deployment of smart chargers will minimise the need to further invest in network upgrades.

Digital grid

Australia's electricity system is experiencing rapid growth in distributed and grid-scale renewable generation. At the same time, coal-fired power plants are progressively retiring. These changes will deliver continuing deep emission reductions in the electricity sector, support for decarbonisation in on-grid industrial sectors and the emergence of a clean hydrogen industry. LETS 2020 prioritised storage to firm renewable electricity as a critical technology to support this transition.

The transformation of Australia's electricity system is making the planning, investment and operation of the grid more complex. Existing software systems and capabilities were not designed to

[17] McKinsey 2018, *Charging ahead: Electric-vehicle infrastructure demand*, accessed 9 Aug 2021

cater for large amounts of variable renewable generation. An enhanced digital operating system is imperative for the Australian Electricity Market Operator (AEMO), together with market participants such as generators, networks and policy makers, to continue to manage a changing grid in a way that is:

- effective
- efficient
- secure
- reliable.

AEMO is world leading in responding to these changing needs, and has already begun to develop this operating system. This has involved taking a modular cloud-based approach that will enable the system to be built in a progressive and adaptive way. An initial investment of $13 million, including more than $2 million from ARENA, is already under way to develop a foundation module and a connections module. The foundation module creates a 'digital twin' of the National Electricity Market at transmission scale, including every grid-connected solar and wind farm in the system, to enable high-resolution grid simulations a hundred times faster than before. The connections module will help integrate solar, wind and storage faster and at lower cost by allowing modelling against the wide area network whilst protecting intellectual property of existing assets that are connected to the grid.

The government will support the ongoing expansion of an enhanced operating system, to ensure the full suite of capabilities needed to manage high levels of variable and distributed electricity generation are available over time.

The next priority identified by AEMO is the development of a distribution system module. This module will allow various distribution networks and AEMO to integrate distributed energy resources and distribution networks with the transmission-level system in the grid simulation. In partnership with the distribution businesses, this will help manage generation from rooftop solar, firming from residential and community batteries, electric vehicle charging and energy security. This will be particularly useful for rooftop solar, the output of which is weather dependent.

Other tools and capabilities for future development could include:

- similar modules for the Western Australian electricity market
- predicting operational constraints from renewables to inform electricity market operations and investments
- linking real-time grid operating data with the simulated grid
- adoption of precision weather forecasting for planning
- integration of gas systems and markets
- accurate frequency response modelling.

Enhanced operating systems will underpin the grid control rooms of the future across the world. For AEMO and policy makers, these systems are critical to the planning, design and operation of future electricity grids and markets. They will assist in the efficient development of the National Electricity Market through the Integrated System Plan, and post-2025 reforms. These systems will also reduce uncertainty and risk for developers and investors, and facilitate capital flows.

AEMO is not the only system operator facing the technical challenges posed by higher penetration of distributed and variable renewable electricity. Leading system operators around the world are now beginning to prioritise the development of new operating systems such as these. AEMO is currently

one of the international leaders in this area. As a foundation member of the Global Power System Transformation (G-PST) consortium, and with government support, AEMO will continue to collaborate with other grid operators in the development of advanced digital grids.

G-PST Consortium

The G-PST is an international group of electricity system operators collaborating with leading international researchers to accelerate the transition to low emissions, low-cost, secure and reliable power systems. The G-PST represents a major global commitment to implementing technologies and approaches to permanently reduce emissions trajectories, while simultaneously improving grid reliability, resilience, and security. AEMO is a founding member of the G-PST and, with CSIRO, leads the Australian research delegation contributing to the Consortium.

Emerging technologies

Emerging technologies have transformative potential, but require continual monitoring of global learning rates, and research and investment trends (Figure 6). This category includes technologies at an early stage or where developments are driven primarily overseas.

Figure 6: *Emerging technologies*

Technology Group	Description
Livestock feed supplements	Feed supplements that reduce methane from cows and sheep
Low emissions cement	Cement that uses alternatives to limestone, or carbon capture and storage, or use, to reduce emissions from the cement process
Energy efficiency	Providing the same service with less energy
Waste-to-energy	Reducing landfill volume and emissions by using waste to generate electricity
Low emissions ammonia	Made from clean hydrogen and renewable electricity powered processing plants, for use as a vector for hydrogen exports, and as a fuel
Negative emissions	Early-stage technologies to remove carbon dioxide from the atmosphere such as Direct Air Capture and Removal (DACR), or Bio Energy with Carbon Capture and Storage (BECCS)
Low emissions heat	Methods of producing heat with low emissions, such as solar thermal and heat pumps, in domestic, commercial, industrial and manufacturing applications
Demand flexibility	Moving the demand for electricity to times when low cost and low emissions supply is plentiful, without impacting on the service the energy provides
Raw materials processing efficiency	More efficient methods to process the raw materials mined in Australia
Hydrogen enabled appliances	Commercial and home appliances that can operate with up to 100% hydrogen in the gas network
Electricity sector technologies	Ultra low cost transmission, microgrids for off-grid and fringe-of-grid uses in agriculture or mining, solar thermal for use in manufacturing and mining.
Transport	More efficient and zero emissions drivetrains, public transport, and low emissions aircraft
Abatement of fugitive methane	Capturing the emissions ventilated from underground coal mines, and LNG production
Innovative generation	Small modular reactors and zero emission gas turbines such as Allam Cycle or hydrogen turbines
Buildings	Low emissions building materials, building integrated PV (such as, solar PV tiles), and new refrigerants

The Australian Government monitors emerging technologies to see if they can help address Australia's big technology challenges. These challenges include:

- reducing emissions
- expanding Australia's primary and manufacturing industries
- supporting jobs
- capturing export opportunities for low emission commodities.

In LETS 2021, we highlight two emerging technologies that show promise for future prioritisation and could help address Australia's emissions challenges.

The government will undertake further analysis on the potential of these technologies and promote early investments to support their development. They are:

- livestock feed supplements
- low emissions cement.

We also look briefly at three other emerging technologies from the list in Figure 6.

Livestock feed supplements

Australia is one of the world's top five exporters of red meat and in the top ten for milk. In the 12 months ended 30 June 2019, the red meat and livestock industry supported 189,000 direct jobs and 245,000 indirect jobs.[18]

Emissions from enteric methane – produced by microbial fermentation in ruminant animals – were 46 million tonnes CO_2-e in 2020, around 10% of Australia's total emissions.[19] The Australian red meat industry has committed to becoming carbon neutral by 2030.[20] This will require new technologies that reduce enteric methane emissions from livestock.

New livestock feed supplements such as *Asparagopsis* seaweed and the organic compound 3-nitrooxypropanol (3-NOP) could reduce emissions and improve meat yields.[21] Bioactive compounds in these feed supplements interrupt methane-forming bacterial processes in the animal's digestive system, thereby substantially reducing the formation of methane. In addition, food energy that would otherwise be lost to fuelling bacterial methane production is made available to be absorbed by the animal, leading to faster growth rates and consequent cost savings for the farmer.

Asparagopsis supplements have demonstrated potential emissions reductions of over 80%.[22] Australian company FutureFeed owns the global intellectual property for the *Asparagopsis* feed supplement, which was developed by CSIRO, Meat and Livestock Australia, and James Cook University.

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[18] Meat and Livestock Australia 2020, *State of the Industry Report 2020*, accessed 4 August 2021

[19] Department of Industry, Science, Energy and Resources 2020, *Australia's emissions projections 2020*, accessed 5 August 2021

[20] Meat and Livestock Australia 2020, *The Australian Red Meat Industry's Carbon Neutral by 2030 Roadmap*, accessed 4 August 2021

[21] Black J L, Davison T M, Box I 2021, *Methane Emissions from Ruminants in Australia: Mitigation Potential and Applicability of Mitigation Strategies*, Animals, 11, 951, accessed 5 August 2021

[22] Roque B M, Venegas M, Kinley R D, de Nys R, Duarte T L, Yang X, et al. 2021, *Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers*, PLoS ONE 16(3): e0247820, accessed 5 August 2021

Australia's livestock emissions could decline by over seven million tonnes CO_2-e a year if livestock feed technologies that reduce emissions by an average of 75% were delivered to:

- about half of Australia's cattle in feedlots and dairy farms
- 15% of grazing cattle and sheep.

Further development and validation of these supplements at a commercial scale could lead to voluntary adoption across the industry. This would see Australia prosper in markets for low emissions meat and dairy products, supporting industry growth, international competitiveness and jobs. It could also help create a domestic seaweed industry with additional economic and carbon sequestration benefits.[23,24]

Initially, livestock feed supplements will be more effective in places where delivery can be controlled, like feedlots and dairy farms. Emissions reductions will be significantly higher if supplements can be reliably delivered to the dispersed grazing herds that make up 95% of Australia's livestock.

The government is investing $30.7 million over six years towards promising feed technologies:

- $6 million for the Methane Emissions Reduction in Livestock program to support research into the abatement potential and productivity benefits of livestock feed technologies
- $23 million for the Low Emissions Supplements to Grazing Animals at Scale program to help develop technologies to deliver low emissions feed supplements to grazing animals
- $1.7 million to scale-up production of *Asparagopsis*.[25]

This investment will help us understand how feed technologies improve productivity and reduce emissions, and fast-track solutions to deliver feed supplements to grazing animals.

It may also inform frameworks under Climate Active and the Emissions Reduction Fund to recognise reduced emissions from feed technologies. This will help livestock farmers diversify their revenues by participating in voluntary carbon markets.

Low emissions cement

Concrete, of which the key ingredient is cement, is the most widely used construction material in the world. The Australian cement and concrete industry supports 18,000 direct and 80,000 indirect jobs.[26]

The concrete value chain involves:

- mining limestone, clay and sand to make clinker, which gives cement its binding properties
- producing clinker in high temperature kilns
- producing cement from ground clinker and other materials
- mixing cement, water and aggregates to make concrete.

[23] AgriFutures Australia 2020, *Australian Seaweed Industry Blueprint – A Blueprint for Growth*, accessed 5 August 2021

[24] Duarte C M, Wu J, Xiao X, Bruhn A, Krause-Jensen D 2017, *Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?*, Front. Mar. Sci. 4:100. doi: 10.3389/fmars.2017.00100, accessed 5 August 2021

[25] This includes a $1 million Accelerating Commercialisation grant under the Entrepreneurs' Program to scale-up production and support the commercialisation of Asparagopsis, and a $675,000 grant from the $30 million Commercialisation Fund to establish a processing and manufacturing facility for this seaweed product.

[26] Cement, Concrete & Aggregates Australia, *Concrete, Quarry & Cement Industries in Australia*, accessed 5 August 2021

Carbon dioxide is released as a by-product when converting limestone into clinker. The clinker production step accounts for 60% of the emissions from cement production. Fuels to heat the kilns account for 30% and electricity use makes up the remaining 10%.[27] Emissions from Australia's cement production were five million tonnes CO_2-e in the twelve months ended 30 June 2019, being just over 1% of Australia's total emissions in that period.[28]

The Australian cement industry has already reduced annual emissions by over 20% since 2010.[29] A number of solutions could help further reduce emissions associated with cement production. These include the use of renewable electricity, improving energy efficiency and clinker substitution.

In addition, CCS – a priority low emissions technology – will play a particularly important role because the release of CO_2 is an inherent output of the chemical reaction that converts limestone into clinker. Capturing the CO_2 and storing or using it is currently the only viable elimination pathway.

Australia is well placed to develop a low emissions cement industry thanks to our:

- strong research and development capabilities
- potential for clean cheap energy, and CCS.

The government is already investing in low emissions cement. This includes over $75 million for cooperative research centres (CRCs) like the SmartCrete CRC, Building 4.0 CRC and Low Carbon Living CRC.[30] The CEFC finances commercial and industrial building projects that reduce embodied carbon by using lower emissions cement. For example, in 2021 the CEFC provided $95 million for the Roe Highway Logistics Park in Perth, which will use low emissions concrete that can reduce emissions by up to 42% compared to traditional concrete. The government's investment in priority technologies like electrical energy storage and CCS also supports emissions reductions at various points along the value chain.

Other emerging technologies

Heat pumps

Emissions from the burning of fuels for heat, steam or pressure made up 20% of Australia's greenhouse gas emissions in 2020.[31]

More commonly known as reverse-cycle air conditioning, heat pumps can be used to provide heating and cooling in residential, commercial and industrial applications. For heating, they use electricity to concentrate and move heat from a cold 'source' to a hot 'sink', to produce hot air, hot water or steam.

[27] Cement Industry Federation 2020, *Australian Cement Report 2020*, accessed 5 August 2021 at: http://cement.org.au/wp-content/uploads/2020/08/CIF-Industry-Report-2020.pdf

[28] This includes scope 1 (process and thermal) and 2 (electricity) emissions.

[29] Cement Industry Federation 2020, *Australian Cement Report 2020*, accessed 5 August 2021

[30] $21 million for SmartCrete, $28 million for Building 4.0, $28 million for Low Carbon Living

[31] Department of Industry, Science, Energy and Resources 2020, *Australia's emissions projections 2020*, accessed 5 August 2021

The principal advantage of heat pumps over incumbent technologies is their efficiency. This is measured by the co-efficient of performance (COP), the ratio between electrical energy used and heat produced. For every unit of energy input, heat pumps can deliver multiple units of thermal energy. For example, heat pumps for residential space heating can have a COP from 3 to 6, while incumbent technologies such as gas-fired boilers are less than 1.[32]

Direct air capture

Direct air capture (DAC) is an early-stage technology that uses either chemical solutions or solid adsorption filters to capture carbon dioxide directly from the air. The captured CO_2 could then be used, or compressed and stored in geological formations.

DAC is technically feasible. However, it is expensive because carbon dioxide is much less concentrated in the air compared with the concentration in industrial flue gases. Estimates of capture costs currently range from US$100 to US$1,000 per tonne of CO_2-e.[33]

A few small DAC plants are operating commercially in Europe and North America, and two large-scale facilities are being developed in the US and Iceland. Interest in DAC has been growing, but the technology needs more support to demonstrate its viability at larger scales.

Australian company Southern Green Gas is developing Australia's first solar-powered DAC units. The technology is based on small modular units that can capture about a tonne of CO_2 per year. For significant capture, these small, modular units will be needed in the millions. They can be manufactured in Australia, creating jobs for Australians.[34]

Small modular reactors

Small modular reactors (SMR) are modern nuclear reactors that are small (less than 300 MW) compared with conventional nuclear reactors (greater than 1000 MW). Their small size means SMRs can be manufactured efficiently in factories and deployed to meet local needs. They have potential to be aggregated to scale up generation capacity to meet large-scale electricity demand.

The technology and economics of SMRs are still evolving. Further innovation and demand could reduce the cost of building and operating SMRs, which could provide zero-emissions electricity and support grid reliability.

SMRs could become an option for Australia if there is bipartisan support to lift Australia's ban on nuclear energy. In the meantime, there are opportunities for Australia to support the continued development of this technology and contribute the expertise of the Australian Nuclear Science and Technology Organisation (ANSTO) to these efforts.

The Australia-UK Partnership on Low Emissions Solutions includes a commitment to cooperate on research and development for SMRs, including advanced nuclear designs and enabling technologies such as advanced materials and waste processing.[35]

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[32] Energy Efficiency Council, *Back to basics: heat pumps*, accessed 5 August 2021

[33] International Energy Agency, *Direct Air Capture*, accessed 5 August 2021

[34] Southern Green Gas, *Negative Emissions : Australia's Jobs Creating, Renewable Energy Export Industry*, accessed 5 August 2021

[35] Minister Taylor 2021, *Australia-UK partnership to drive low emissions solutions*, Media Release 29 July 2021, accessed 1 September 2021

Accelerating deployment of priority low emissions technologies

The government has examined possible deployment pathways for the priority low emissions technologies, focusing on:

- identifying investments with the greatest impact on cost reduction
- estimating timeframes for when the economic stretch goals are likely to be met.[36]

Achieving our economic stretch goals

The government's ambition is to reduce the costs of priority low emissions technologies to meet the economic stretch goals as soon as possible.

We have assessed when the stretch goals may be achieved under a 'high technology scenario', recognising that the pace of reaching these goals will depend on a range of factors, including:

- technological advances
- capital and financing requirements
- approval and construction timeframes
- global uptake.

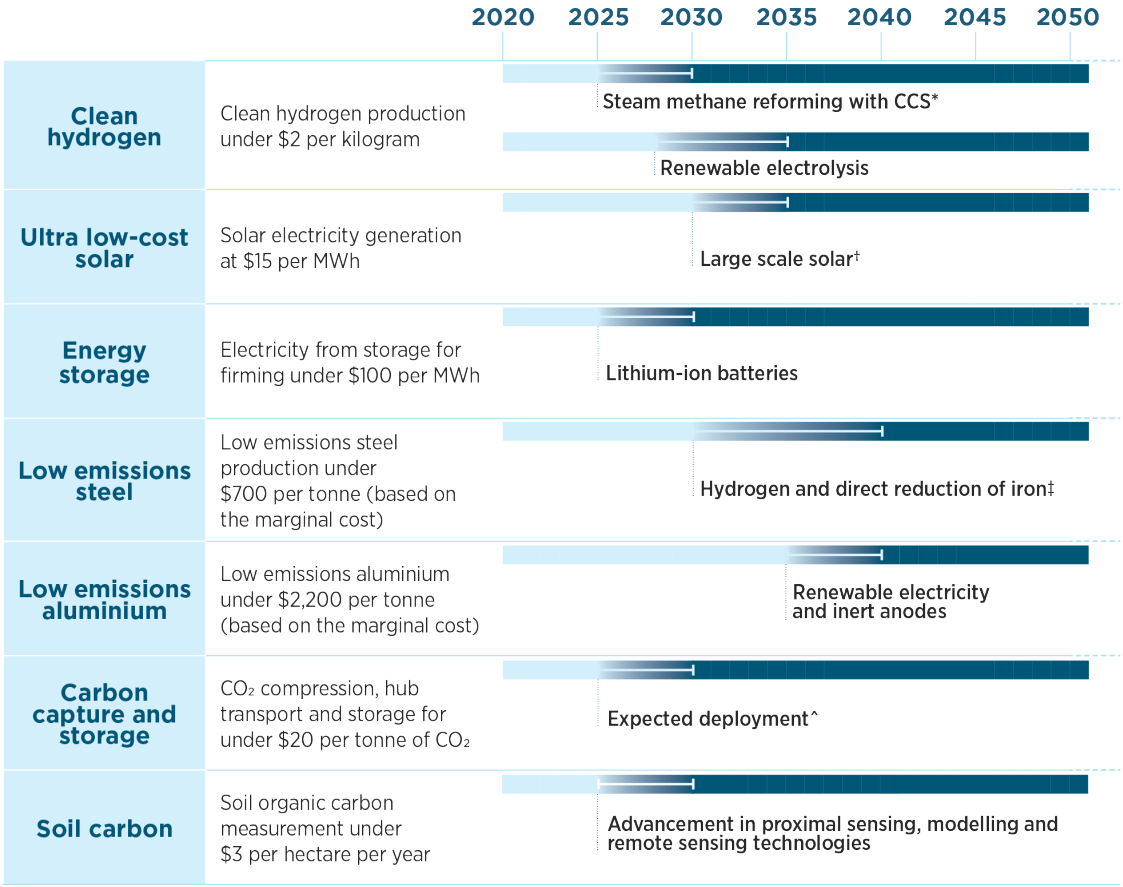
The 'high technology scenario' assumes accelerated global uptake of new and emerging low emissions technologies, driven by:

- public investments and policies that reduce risk for private investors
- a shift in consumer preferences towards low emissions supply chains
- private investments consistent with an average global temperature rise of no more than 2°C.

A range is given for the estimated timeframe of achieving each economic stretch goal, starting with the earliest date it could be met. Confidence of reaching the stretch goal increases towards the end of the range (Figure 7).

[36] This work for the five priorities from LETS 2020 was supported by analysis from McKinsey and Company. Initial analysis for the ultra low-cost solar was supported by work from ARENA, AEMO and the Department of Industry, Science, Energy and Resources. Input price assumptions for electricity prices were based on CSIRO 2020, *GenCost report 2019-20*, accessed 5 August 2021; Commodities prices were based on Department of Industry, Science, Energy and Resources 2020, *Australia's emissions projections 2020*, accessed 5 August 2021, and World Bank projections.

Figure 7: *Projected timeline for achieving economic stretch goals*



* clean hydrogen produced from natural gas with emissions captured and stored permanently underground is technically and economically feasible, but subject to offtake agreements, development approvals and the adoption of a hydrogen Guarantee of Origin scheme

† price assumptions for the other priority technologies don't yet include the reduction in electricity prices expected from ultra low-cost solar, or the associated upside benefits for meeting the stretch goals

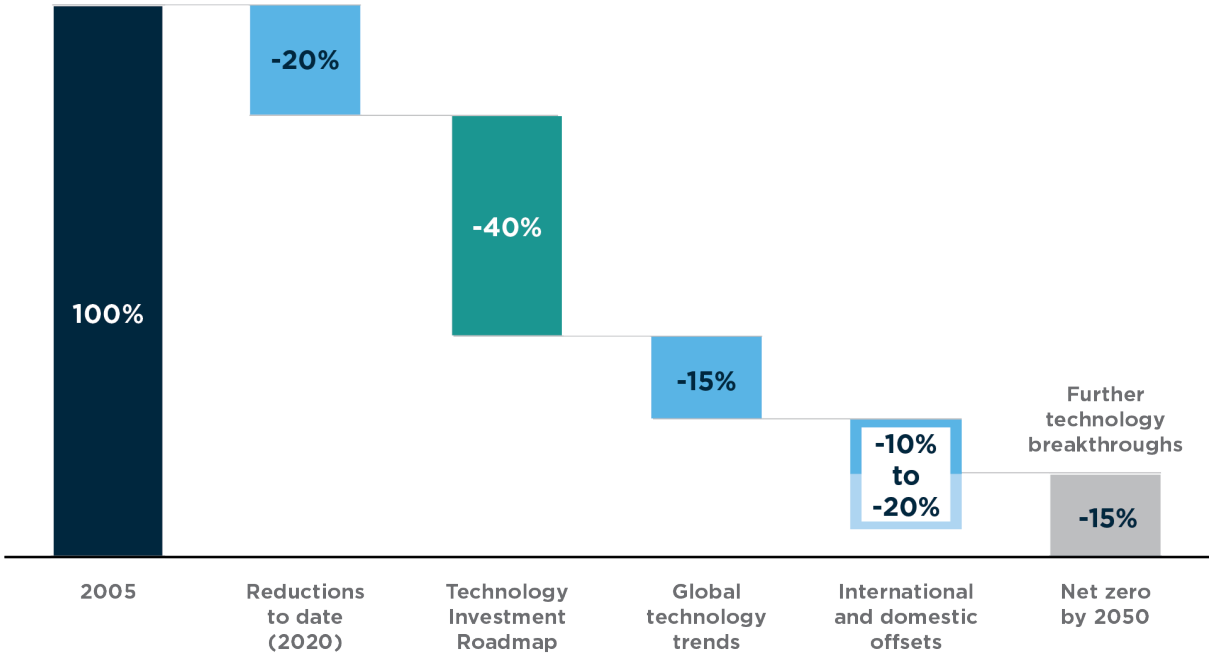
‡ economically viable in the late 2020s, but subject to capital development cycles

^ subject to offtake agreements and development approvals

Emissions reduction through deployment of priority low emissions technology

The Technology Investment Roadmap is the cornerstone of Australia's Long-Term Emissions Reduction Plan. Technology will be key to reducing emissions while ensuring the economy grows and jobs are created (Figure 8).

Figure 8: *Priority technology contribution to meeting Australia's net zero by 2050 target*



The priority technologies (identified in LETS 2020 and LETS 2021) could contribute around 40% of the annual emissions reductions needed to achieve net zero emissions by 2050.

Global technology trends, such as electrification of transport could deliver at least a further 15% of the annual reductions required.

Offsets will play a crucial role in closing the gap towards net zero. Modelling for the Long-Term Emissions Reduction Plan shows that modest contributions from land sector sequestration and targeted purchases of international offsets allow Australia to reduce its net emissions to around 85% below 2005 levels.

There are a range of ways that Australia can close the remaining gap to net zero emissions by 2050. Future technology developments and markets are inherently uncertain, and it is possible that technology costs will fall faster than anticipated for some technologies, and new and disruptive technologies may emerge. The roadmap will monitor low emissions technology developments through annual statements.

In addition to actions to support low emissions technologies, the government is also driving emissions reductions through other initiatives, including the Emissions Reduction Fund and Climate Active. The government's Long-Term Emissions Reduction Plan sets out our actions for reducing emissions across the economy.

As well as reducing our own emissions, meeting the stretch goals for our priority technologies will contribute to the global task of reducing emissions through low emissions exports and advancing innovation.

Clean hydrogen

Stretch goal: clean hydrogen production under $2 per kg

Potential for clean hydrogen in Australia

Australia has the opportunity to become a world-leading clean hydrogen producer and exporter.

Clean hydrogen will help decarbonise 'hard-to-abate' sectors through applications like:

- heavy haulage fuel cell electric vehicles
- clean ammonia as a chemical feedstock for making fertiliser, fuel for shipping, and co-firing for electricity generation in countries like Japan.
- thermal energy for industrial applications
- chemical reduction of iron ore to hot briquetted iron.

Clean hydrogen for fuel cell electric vehicles is likely to be one of the earliest applications to reach breakeven cost with conventional fuels, on the basis of kilometres driven. Production of clean ammonia is likely to reach cost parity with fossil-fuel based ammonia production before clean hydrogen will reach cost parity against natural gas for industrial heating, on a gigajoule equivalent basis.

Clean hydrogen blending into natural gas has the important benefit of building early production scale that can then support demand from other use cases. Gas customers may welcome the opportunity to purchase zero emissions gas at a small premium.

Clean hydrogen can also help firm the electricity grid. Electrolysers for production are a flexible load, which can be ramped up and down to match renewable electricity supply and provide other grid-support services, including potential for frequency regulation. This facilitates the incorporation of ever larger quantities of distributed and variable renewable electricity in the grid, while maintaining system security.

Countries across the world recognise that reducing the cost of clean hydrogen production is essential for widespread uptake.[37,38] The US government is aiming to reduce the costs of clean hydrogen production by 80% to US$1 per kg in one decade.

The Australian Government is providing significant investment to unlock hydrogen for key sectors and support the growth of our hydrogen industry.

A key focus of the government is to build domestic demand and export opportunities through the development of regional hydrogen hubs. This will help the industry build scale, which is critical for bringing costs down and becoming a globally competitive supplier. Hubs will also help the industry to reduce infrastructure costs, encourage innovation, and enhance skills and training efforts.

To activate these opportunities, the Australian Government is investing $464 million into the first steps for the development of up to seven hydrogen hubs in regional Australia.

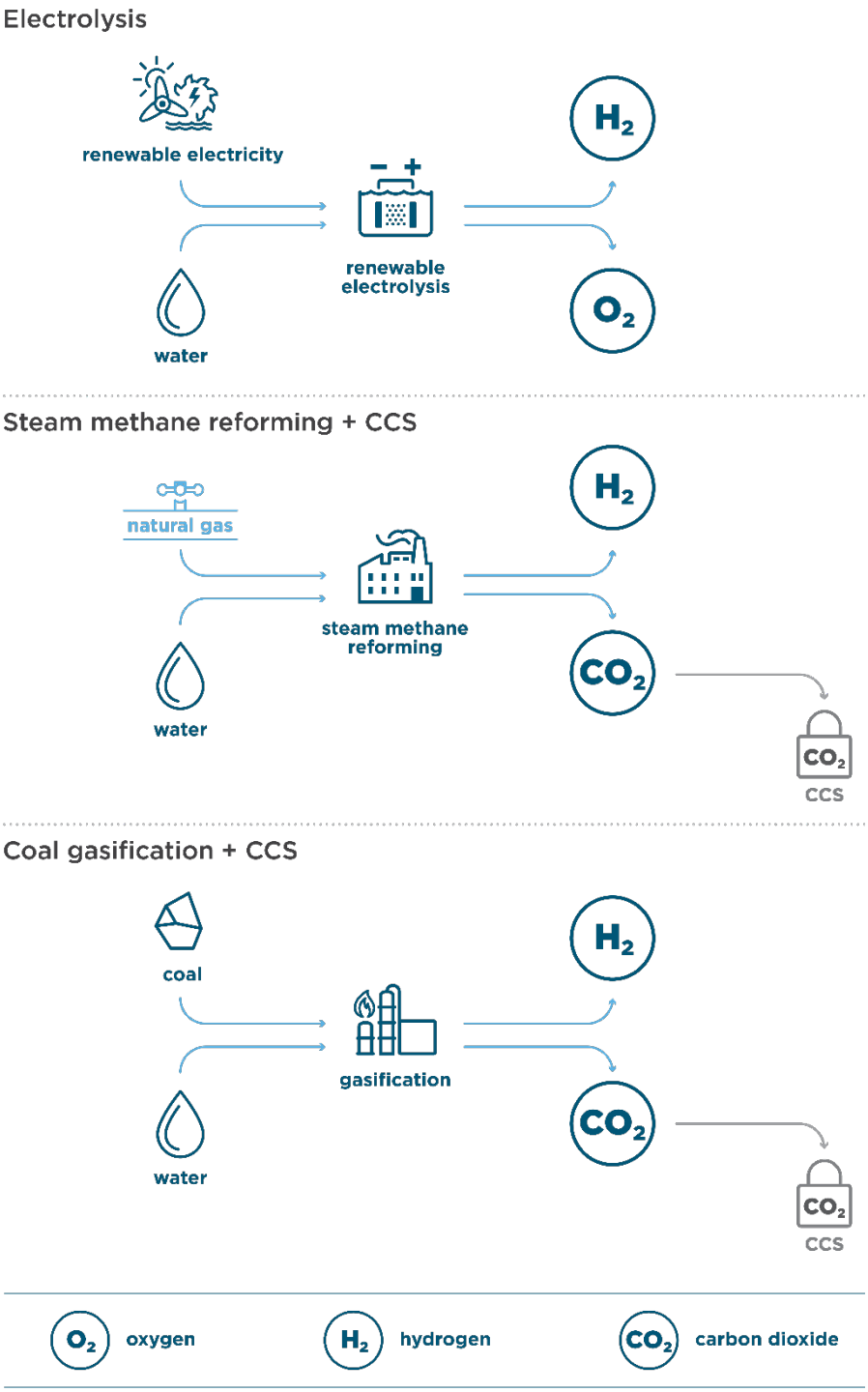
[37] Hydrogen Council 2020, *Path to hydrogen competitiveness, A cost perspective*, accessed 5 August 2021
[38] International Energy Agency 2019, *The Future of Hydrogen*, accessed 5 August 2021

Deployment pathways and cost drivers

A variety of methods are being explored for the production of clean hydrogen. The three main methods under consideration are (Figure 9):

- renewable electrolysis
- steam methane reforming with CCS
- coal gasification with CCS.

Figure 9: *Clean hydrogen production methods*



Guarantee of Origin scheme

A domestic Hydrogen Guarantee of Origin scheme will be established to measure and track important characteristics of how and where hydrogen is produced, including direct and upstream carbon dioxide and methane emissions, and the production energy source and technology. All technologies to produce clean hydrogen will be considered under the scheme. This will enable

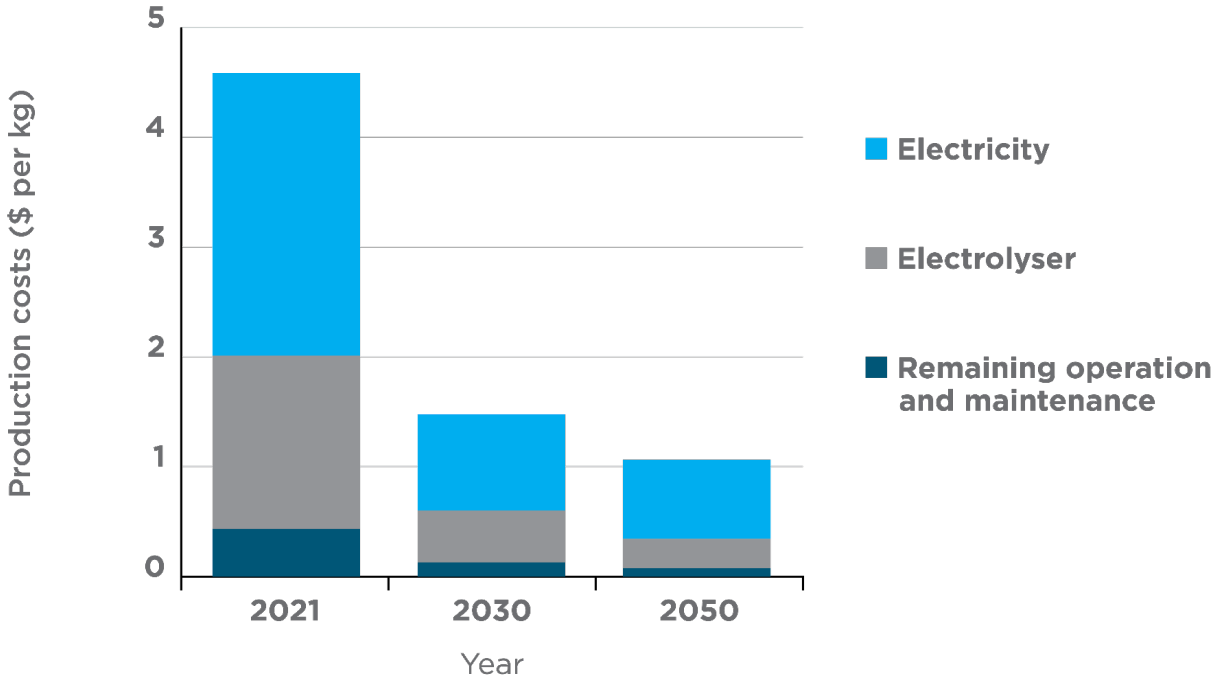
customers who buy clean hydrogen in the future to have the information they need to choose the product best suited to their needs.

Renewable electrolysis

Steep reductions in the costs of renewable electricity and electrolysers could make electrolysis the cheapest way to produce clean hydrogen as soon as 2028 (Figure 10).

While renewable electricity costs are projected to fall, the government will drive accelerated cost reduction through the newly prioritised technology, ultra low-cost solar, supported by the Solar 30 30 30 initiative. Cheaper and more efficient electrolysers will primarily be driven by industry, with government providing support for early projects to establish supply chains and drive scale.

Figure 10: *Electrolytic hydrogen production cost breakdown under a high technology scenario*



The renewable electricity generation required to produce hydrogen for export will be much larger than Australia's current electricity production capacity and require significant investment. For example, a hydrogen export industry supplying the same amount of energy as Australia's current liquefied natural gas exports would need approximately 2,200 TWh of electricity. This is eight times Australia's total electricity generation for 2019.[39]

[39] Finkel A 2021, *Getting to Zero: Australia's Energy Transition*, Quarterly Essay Issue 81

Steam methane reforming with CCS and coal gasification with CCS

Our analysis shows that clean hydrogen from natural gas with emissions captured and permanently stored underground could achieve the stretch goal now.

Deployment of hydrogen production from steam methane reforming with CCS in Australia is subject to development of CCS basins, securing low-cost gas, offtake agreements, development approvals and the adoption of the Hydrogen Guarantee of Origin certification scheme. Should these be achieved, the clean hydrogen stretch goal could be met as early as 2025.

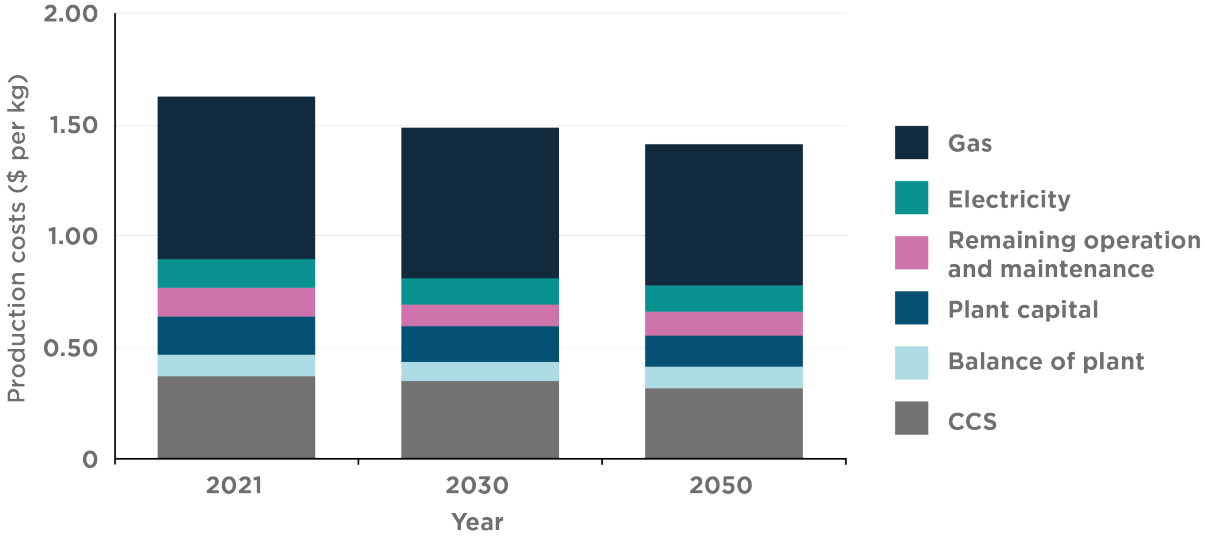
Natural gas prices have the largest impact on the cost of clean hydrogen produced from steam methane reforming and CCS. While Figure 11 assumes $5 per gigajoule of gas (i.e. gas available at the cost of production, from low cost sources), for every additional $1 per gigajoule in gas costs, we estimate the cost of producing clean hydrogen increases by around 13 cents per kg. For example, if gas costs a producer $5 per gigajoule in 2050, the cost of producing clean hydrogen from gas would be approximately $1.40 per kg. If gas costs $7 per gigajoule in the same year, the cost of producing clean hydrogen from gas would be approximately $1.70 per kg, still below the $2 per kg stretch goal.

The distance from the hydrogen production site to a suitable CCS reservoir will also affect costs. Other cost drivers are the high level of carbon dioxide capture required to meet customer expectations for clean hydrogen and the cost of minimising sources of upstream emissions.

Practically, clean hydrogen produced from coal or gas will support the development of early demand opportunities and position Australia to be an early global leader in hydrogen production. While clean hydrogen produced through electrolysis is significantly more expensive in 2021, its costs are expected to fall rapidly and will likely achieve parity with clean hydrogen from coal with CCS in the late 2020s or gas with CCS around 2030.

Consistent with the principles outlined in Australia's Long Term Emissions Reduction Plan, the Government will support all forms of clean hydrogen production and leave it up to customers, whether domestic or international, to choose their preferred production source. To inform customer choice, the government is developing a Guarantee of Origin scheme for hydrogen. The scheme will provide hydrogen customers with data on how and where the hydrogen they purchase is produced. Most importantly, it will document the quantity of carbon dioxide emissions associated with the production of each tonne of hydrogen.

Figure 11: *Cost breakdown of hydrogen production from steam methane reforming with CCS under a high technology scenario*



Hydrogen Energy Supply Chain Project

The Hydrogen Energy Supply Chain (HESC) Project is a world-first collaboration between Australia and Japan.

This innovative project will produce and transport liquefied hydrogen from the Latrobe Valley in Victoria to Kobe in Japan. This is the first time that liquefied hydrogen will be transported between continents.

The pilot involves:

- creating hydrogen gas by gasifying Latrobe Valley brown coal
- transporting the gas to the Port of Hastings, where it is liquefied
- shipping the liquefied hydrogen to Kobe.

The pilot started operations in March 2021. The first shipment of hydrogen to Japan is expected to occur between October 2021 and March 2022.

If the pilot is successful, then, subject to establishing an offtake agreement, the next phase of HESC will be a commercial-scale facility. This facility will use carbon capture (at a high capture rate) and storage to produce clean, economically viable hydrogen from coal. HESC is supported by industry partners and governments in both countries.

As the most advanced coal gasification with CCS project in Australia, HESC is likely to be the first able to meet the stretch goal for this type of hydrogen production.

Ultra low-cost solar

Stretch goal: solar electricity generation at $15 per MWh

Potential for ultra low-cost solar in Australia

Ultra low-cost solar is likely to deliver significant cost reductions for clean electricity. This will be necessary to unlock the economic, employment and abatement potential for clean hydrogen, low emissions steel and aluminium, and electrical energy storage for firming. Low-cost electricity will also be important for operating compressors used in CCS.

Ultra low-cost solar will also reduce costs for electrification of other sectors such as transport, buildings and industry. Driving the price of clean electricity lower will help Australian industry, manufacturers and other businesses stay internationally competitive while reducing emissions and supporting the wider economy.

Deployment pathways and cost drivers

Solar module technology has exhibited the most rapid cost decline of any low emissions technology in recent times, from an average wholesale module selling price of US$4.12 per watt in 2008 to US$0.17 per watt in 2020. This represents a 96% cost reduction over 12 years.[40]

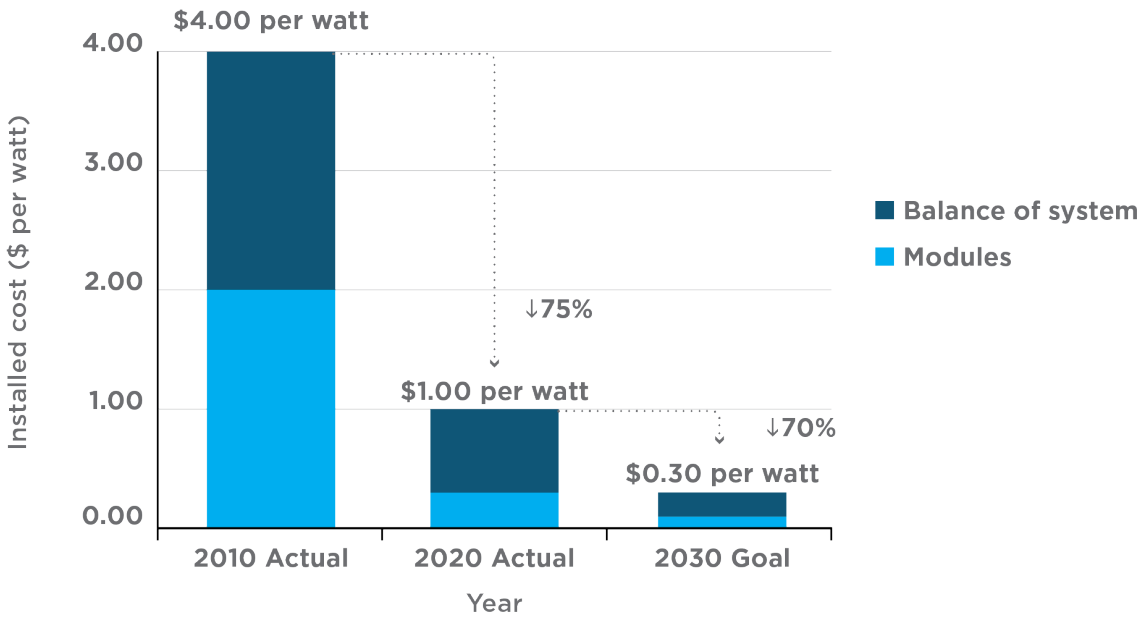
Enhancing the module efficiency from the current value of about 22% to about 30% over the next decade will be essential for driving down the cost of solar electricity generation (Figure 12). Assuming continuation of the current low financing costs, and 25-year service life of the modules, higher efficiency will directly contribute to lower levelised costs of electricity (LCOE).

Achieving improved module efficiency will require further R&D into many aspects of solar cell design. This includes the type of doping of the silicon in the cells, the cell structure, and the development of tandem solar cells in which the use of two or more photovoltaic layers better matches the spectrum of sunlight. Candidates for the additional photovoltaic layers include perovskites and kesterites.

[40] Green M 2021, *Solar Price Forecasts & Implications for Australia*, accessed 25 August 2021

Further reductions in the installed cost of solar will come from reducing the balance of system costs. Over the past 10 years, as module costs have declined, the fraction represented by the balance of system costs has increased from about 50% of the installed cost in 2010 to about 70%, and thus is a key target for further reductions.

Figure 12: *Installed cost of solar electricity generation*



Key opportunities for bringing down balance of system costs include:

- lowering the cost of construction materials by using less or using cheaper materials
- increasing the solar module size
- increasing the cell and module efficiency
- increasing the scale of solar farms
- lower cost inverters
- high throughput deployment methodologies.

Achievement of the $15 per MWh stretch goal will be underpinned by the ARENA Solar 30 30 30 initiative's goal to achieve 30% module efficiency and 30 cents per installed watt by 2030.

ARENA will build on its historic investment in Australian solar technology development and deployment to shape the R&D push, through funding strategic project initiatives.

Energy storage

Stretch goal: electricity from storage for firming (available on demand for eight hours) at under $100 per MWh.

Potential for energy storage in Australia

Emissions from electricity in Australia have been falling since 2016 as more renewable generation enters the market.

Almost all new electricity generation capacity in the past few years has come from solar and wind. Australia has the highest solar capacity per person (686 watts) in the world.[41] It also has the highest combined wind and solar capacity per person (1054 watts) of any country outside Europe.[42]

Capturing the full potential of Australia's renewable energy resources requires energy storage technologies. These technologies store electrical energy during times of peak supply and dispatch it on demand. Depending on the technology, they may also provide a range of essential system security services.

Increased electricity generation from solar and wind, combined with grid-scale energy storage, is essential for decarbonising other emissions-intensive sectors like transport, industrial processes and building heating.

Electrical energy storage is one of several approaches for balancing electricity supply and demand. Other possible approaches are:

- overbuilding variable renewable electricity capacity (with excess energy 'spilled' or used to produce clean hydrogen)
- building more transmission between states and renewable energy zones
- building peaking capacity, used to fill generation gaps, such as gas peaking generation with potential hydrogen fuel blending ahead of 100% hydrogen fuel
- demand response, where energy users are incentivised to reduce their energy use during peak demand periods
- building low-emissions dispatchable capacity, for example, Allam Cycle generation with CCS, or small modular reactors.

A combination of these approaches is expected to result in the lowest system cost, with the optimal mix determining how much storage is required. Australia's existing thermal generation fleet will continue to play an essential role in providing affordable and reliable power in the decades ahead.

The most pressing need for storage is for durations of several hours, such as for storing solar energy in the middle of the day to use in the evening.[43] Grid-scale batteries are the most cost-effective storage technology on this timescale and will be the main storage technology used.

In the longer term, as more solar and wind is added to the grid, longer duration storage, known as 'deep storage', will be needed for on-demand dispatch for intervals of days or weeks, to:

- manage infrequent weather events that last for days or weeks
- cover seasonal shortfalls.

The government is already investing in pumped hydro projects, including Snowy Hydro 2.0 and Battery of the Nation, which will provide deep storage at high capacity and long duration.

Coordinated investment from ARENA and the CEFC will unlock new and emerging deep storage technologies. An example is hydrogen storage, where electricity is used to make hydrogen when renewables are abundant. The hydrogen, is then stored for weeks or months and used to generate electricity when renewable electricity is scarce.

[41] International Renewable Energy Agency 2021, *Renewable Capacity Statistics 2021*, accessed 5 August 2021
[42] International Renewable Energy Agency 2021, *Renewable Capacity Statistics 2021*, accessed 5 August 2021
[43] CSIRO 2017, *Low Emissions Technology Roadmap*, accessed 9 August 2021

Deploying deep storage technologies could:

- complement hydrogen hub infrastructure
- provide energy security for high-use industrial and regional areas (as well as supporting the National Electricity Market)
- provide dual-purpose storage facilities for hydrogen export.

The right regulatory and market landscape will encourage investment in deep storage. As part of its post-2025 electricity market design, the Energy Security Board has provided advice on changes to the National Electricity Market to facilitate investment in the right mix of resources, including dispatchable storage capacity. To a large extent this will be achieved through the Retailer Reliability Obligation.

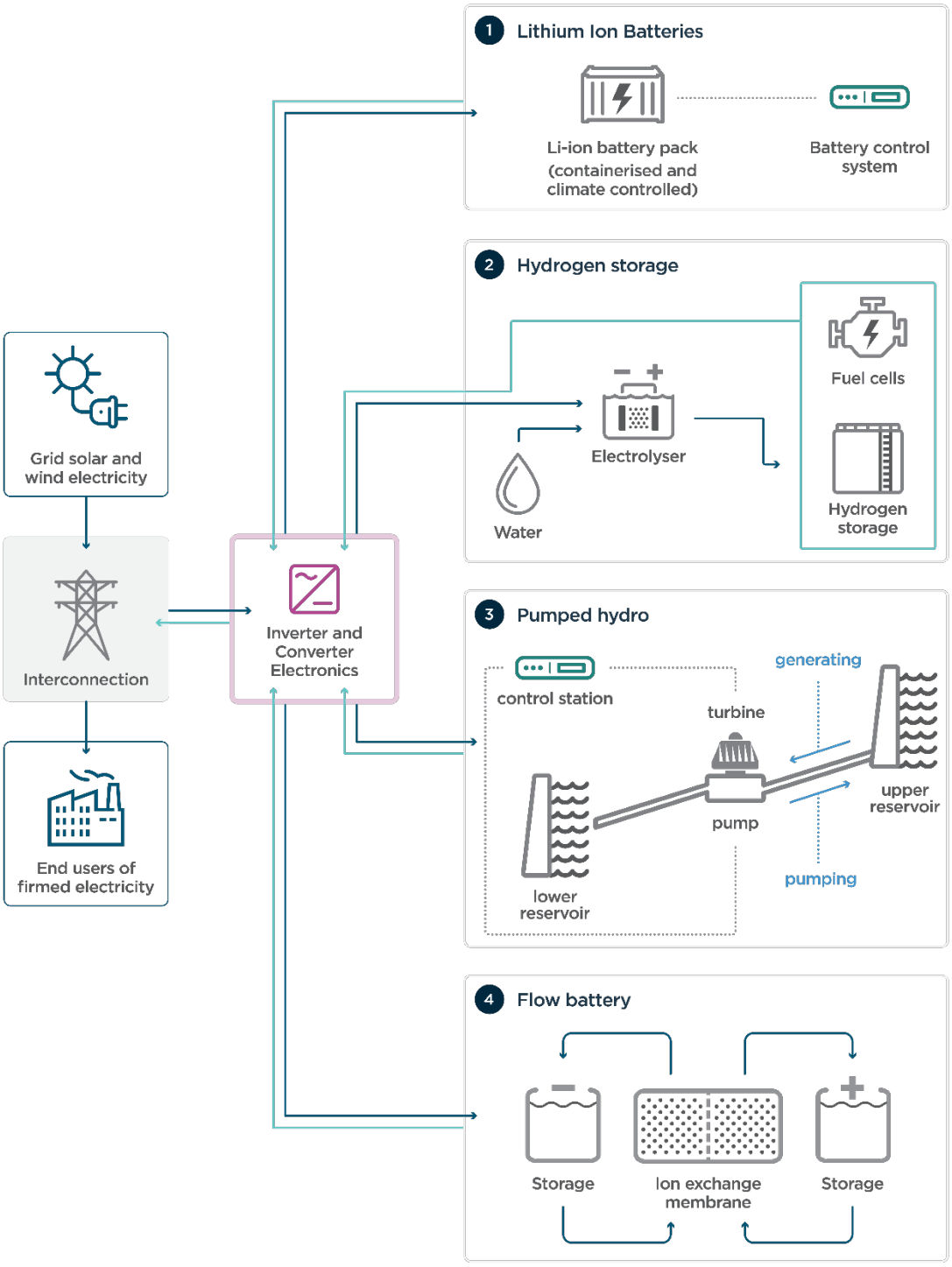
Deep storage will be examined further in the 2022 Low Emissions Technology Statement.

Deployment pathways and cost drivers

An evolving mix of storage technologies could be integrated into the market to provide system security and reliability (Figure 13). These technologies provide dispatchable clean electricity over different durations.

Lithium-ion batteries will likely be the main storage technology to manage daily shortfalls in an electricity system dominated by solar and wind generation.

Figure 13: *Utility scale energy storage technologies*



Lithium-ion batteries

Lithium-ion batteries are the cheapest form of grid-scale battery storage currently available. Costs are expected to fall further thanks to manufacturing scale up driven by the rapidly growing electric vehicles market.

Under a high technology scenario, the cost of electricity from storage for lithium-ion batteries is expected to decline from $170 per MWh in 2021 to below $100 per MWh over an eight-hour duration as early as 2025.

This cost reduction is due to improved cell chemistries. The cost of battery cells is mainly driven by overseas developments. However, domestic engineering, procurement and construction costs depend on local demand. Australia can reduce these costs by supporting scale up of battery installations and learning by doing.

Other storage technologies

As the need for deep storage grows, other battery technologies like zinc bromide batteries may play a more important role. Clean hydrogen may become a viable option for seasonal storage to balance renewable generation. Hydrogen can be used in fuel cells, or in turbines to generate electricity.

Solar thermal energy is another storage technology that can provide deep storage or be used for high-temperature industrial process heat applications. These technologies will complement existing pumped-hydro energy storage and gas-fired electricity generation, and could become cheaper as their scale and efficiency increases. Future statements will monitor the development of emerging storage technologies.

Innovative battery technologies

Zinc bromide batteries offer a number of advantages over other storage technologies. They can be discharged completely, are long-lasting and they are fireproof. In addition, unlike some other battery materials, zinc and bromine are cheap and readily available throughout the world.

Australian innovators are positioning Australia to play an important role in a battery-powered world.

In 2021 Australia's **Redflow** made its biggest ever flow battery sale to a bioenergy plant in California. The deal is worth around US$1.2 million to the Queensland company.

Anaergia's Rialto Bioenergy Facility in San Bernadino will install nearly 200 of Redflow's 10 kWh zinc bromide batteries in a microgrid to store bioenergy from the Rialto plant and discharge it into the electricity grid when demand peaks in the afternoon and evening.

Sydney's **Gelion Technologies** has re-imagined the internal chemistry of the zinc bromide battery to implement a non-flow format. Based on research at the University of Sydney, Gelion's batteries store energy using a patented gel. The gel enables greater efficiency through enhanced ion transport, leading to increased battery life and decreased charging time, and allows the battery to be highly scalable and portable.

Gelion's patented gel chemistry also reduces complexity, price and servicing costs, while maintaining the fireproof and high temperature safety characteristics as well as the recyclability of zinc bromide chemistry. Gelion's battery format and method of construction are very similar to lead acid batteries, enabling Gelion to partner with existing manufacturers worldwide for low-cost production.

Low emissions materials

Steel and aluminium production accounts for around 40 million tonnes CO_2-e of domestic emissions each year (approximately 8% of Australia's annual emissions).[44] Like clean hydrogen, low emissions materials could see Australia export renewable energy as embodied energy.[45]

[44] Department of Industry, Science, Energy and Resources 2020, *National Greenhouse Accounts 2019*, accessed 10 August 2021

[45] Analysis by McKinsey & Company prepared for the Department of Industry, Science, Energy and Resources.

To produce low emissions materials in Australia, we need low-cost:

- firmed renewable electricity
- clean hydrogen.

Low emissions cement is an emerging technology that could help address Australia's emissions challenges. It will be considered for future prioritisation as a low emissions material.

Low emissions steel

Stretch goal: low emissions steel production under $700 per tonne (based on marginal cost).[46]

Potential for low emissions steel in Australia

Australia only produces 0.3% of the world's primary steel. But it is the world's largest exporter of iron ore, with 53% of the global export market.[47]

Australian industry has a competitive advantage to capture a greater share of the steel value chain. Exporting upstream material for steel production could also provide jobs in regional areas. Potential exports include:

- iron ore mined with zero emissions equipment and transported on zero emissions trains and ships
- value-added products like beneficiated ores and hot briquetted iron.

These exports will help decarbonise global steel supply chains and reduce global emissions.

Deployment pathways and cost drivers[48]

Low emissions steel can be produced by:

- adding CCS to the traditional blast furnace and basic oxygen furnace process[49]
- direct reduction of iron and an electric arc furnace (DRI-EAF), fuelled by natural gas (with CCS) or clean hydrogen.

Molten oxide electrolysis could also produce low emissions steel if it can be proven at commercial scale (Figure 14).[50]

[46] In this statement, the stretch goal for low emissions steel has been revised from the average market price of hot rolled steel in the London Metals Exchange ($900 per tonne) to the average cost of production ($700 per tonne). The production cost does not take into account the cost of capital. Material changes in raw material costs may require the stretch goals to be updated over time.

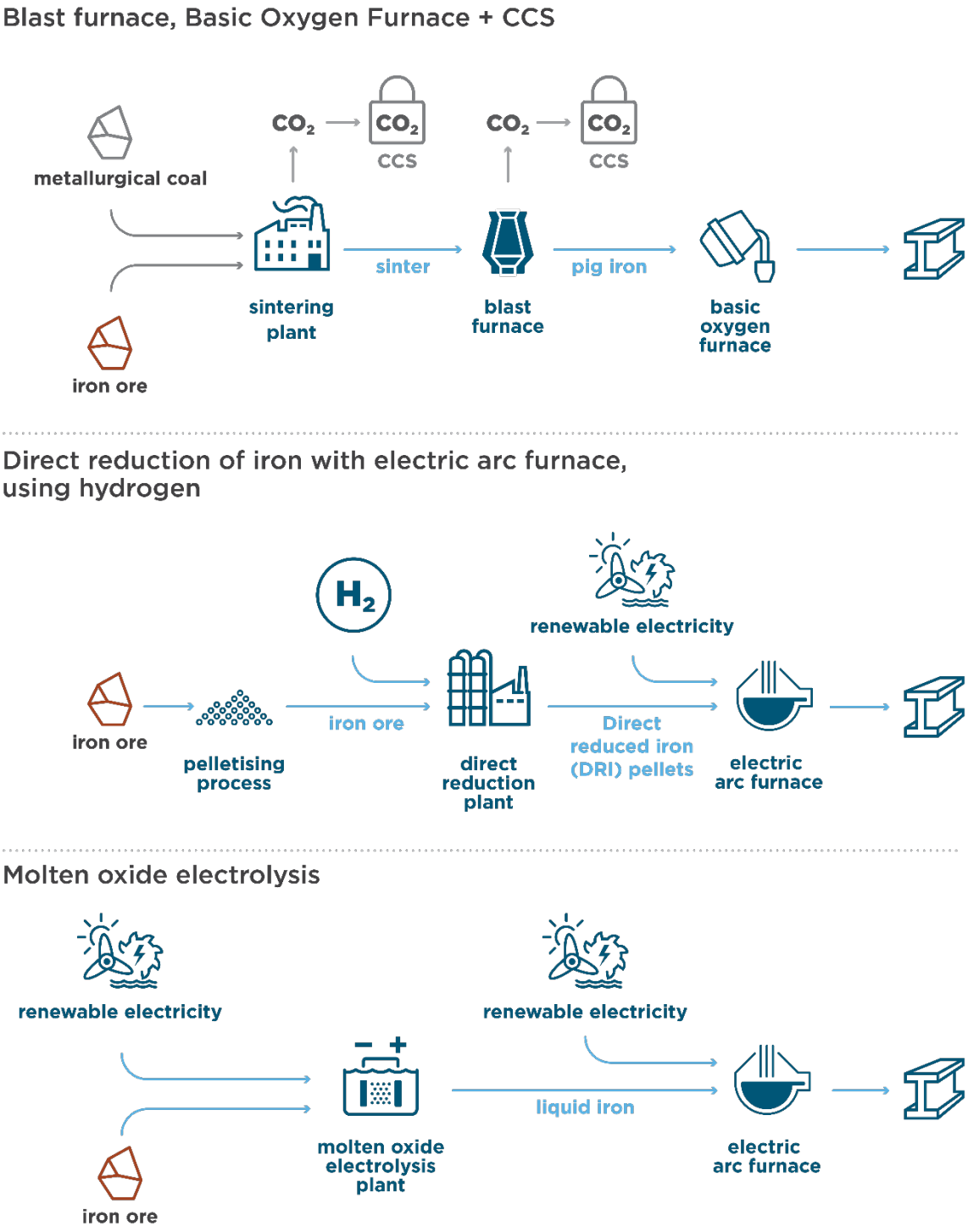
[47] Analysis by McKinsey & Company prepared for the Department of Industry, Science, Energy and Resources.

[48] Cost breakdowns are not included for low emissions steel due to the commercial-in-confidence nature of information and the limited number of steelmakers in Australia.

[49] Figure 14 shows the process commencing with iron ore fines.

[50] Energy Transitions Commission 2018, *Reaching net-zero carbon emissions from hard-to-abate sectors by mid-century*, accessed 5 August 2021

Figure 14: *Low emissions steel production methods*



DRI-EAF could be competitive on a marginal cost basis as early as 2030, as clean hydrogen and renewable electricity become cheaper. However, capital costs are the main barrier to DRI-EAF steel plants in Australia.

In the nearer term, steel producers will likely reduce blast furnace and basic oxygen furnace emissions by improving energy efficiency.

Earlier stages of the steel supply chain may offer more immediate opportunities. Australia's iron ore exports could supply future global DRI-EAF markets if we invest in new processing infrastructure. This could include:

- processing hematite ore into a higher grade product
- expanding magnetite ore production and processing.

Australia could also produce hot briquetted iron that is globally competitive with scrap steel and other EAF feedstocks.

Iron ore requires additional processing (beneficiation) for use in DRI and hot briquetted iron production. Research bodies, including CSIRO and the Heavy Industry Low-carbon Transition (HILT) Cooperative Research Centre, are looking at ways to produce low emissions feedstock.

The cost of beneficiation, combined with uncertain global pricing, may encourage Australian companies to use low emissions technologies that can process existing ores without further beneficiation. The government will watch the development of these, including the potential for molten oxide electrolysis.

Low emissions aluminium

Stretch goal: low emissions aluminium production under $2,200 per tonne (based on marginal cost).[51]

Potential for low emissions aluminium

While Australia's share of global aluminium production is modest (less than 3%), we are the world's largest producer of bauxite. Most of our bauxite is processed into alumina, and we are the world's largest alumina exporter.[52]

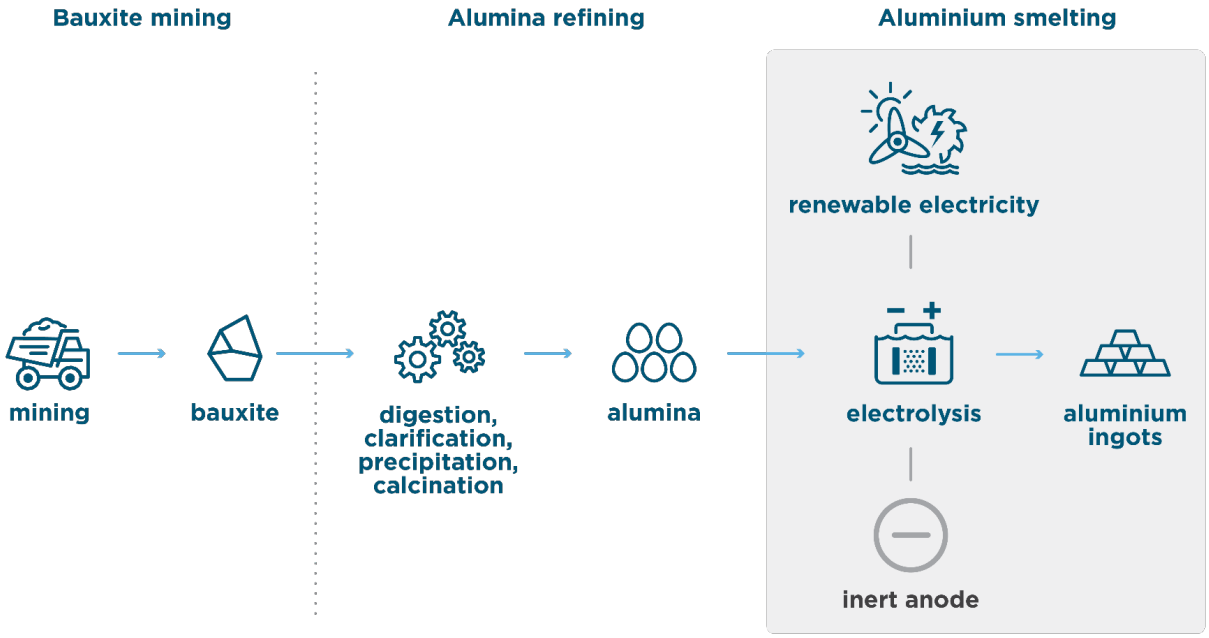
Low emissions aluminium is expected to become the choice of international purchasers.[53] Australia is well placed to reduce emissions throughout the supply chain, including alumina refining and aluminium smelting (Figure 15). We could maintain our world leading position by transitioning to become the world's largest exporter of low emissions alumina.

[51] In this statement, the stretch goal for low emissions aluminium has been revised from the average market price in the London Metals Exchange ($2,700 per tonne) to the average cost of production ($2,200 per tonne). The production cost does not take into account the cost of capital. Significant changes in raw material costs may require the stretch goals to be updated over time.

[52] Australian Aluminium Council, *Australian Industry*, accessed 5 August 2021

[53] Department of Industry, Science, Energy and Resources 2021, *Resources and Energy Quarterly March 2021*, accessed 12 May 2021

Figure 15: *How low emissions aluminium is produced*



Deployment pathways and cost drivers

Aluminium smelting

Aluminium smelting is the most energy-intensive and emissions-intensive step of aluminium production. Twenty million tonnes CO_2-e was produced from aluminium smelting in 2020.

Using renewable electricity would eliminate 90% of the emissions from Australia's aluminium smelters. The caveat is that the renewable electricity supply must be firmed because aluminium smelters cannot tolerate dips or outages in the electricity supply of more than an hour or two.

The last 10% can be eliminated by replacing the carbon anodes consumed during smelting with inert anodes.

Low emissions aluminium production could be cost competitive on a marginal cost basis with current aluminium production methods as soon as 2035. This would be driven by substantial cost reductions in renewable electricity and electricity storage (Figure 16).

Alumina refining

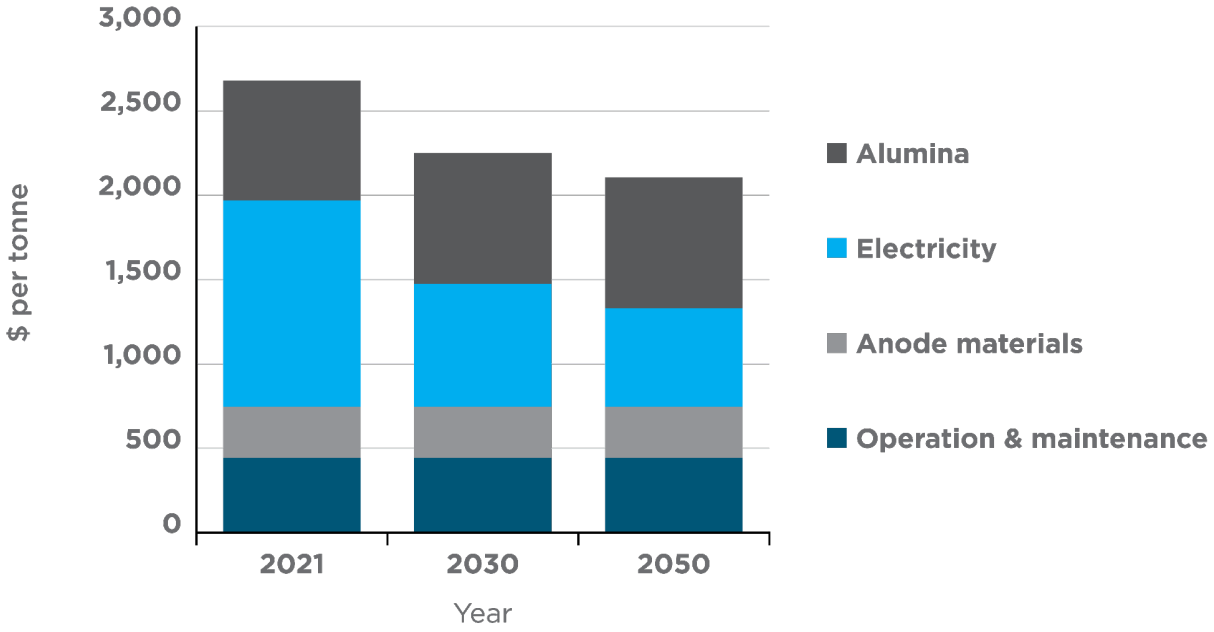
Alumina refining produced 14 million tonnes CO_2-e of domestic emissions in 2020.

Alumina refining offers significant opportunities to reduce emissions. Clean electricity or clean hydrogen could be used instead of fossil fuels to produce steam and heat.

With support from ARENA, the industry is investigating whether these technologies can be used at Australian refineries. But clean, cheap, reliable electricity is essential to make them economically viable.

Australia is already a major alumina exporter. Seizing these opportunities will help us capture future markets for low emissions alumina and aluminium.

Figure 16: *Low emissions aluminium cost breakdown under a high technology scenario*



Carbon capture and storage

Stretch goal: CO_2 compression, hub transport and storage for under $20 per tonne of CO_2.[54]

Potential for CCS in Australia

Large-scale CCS deployment in Australia would help decarbonise heavy industries and produce clean hydrogen.

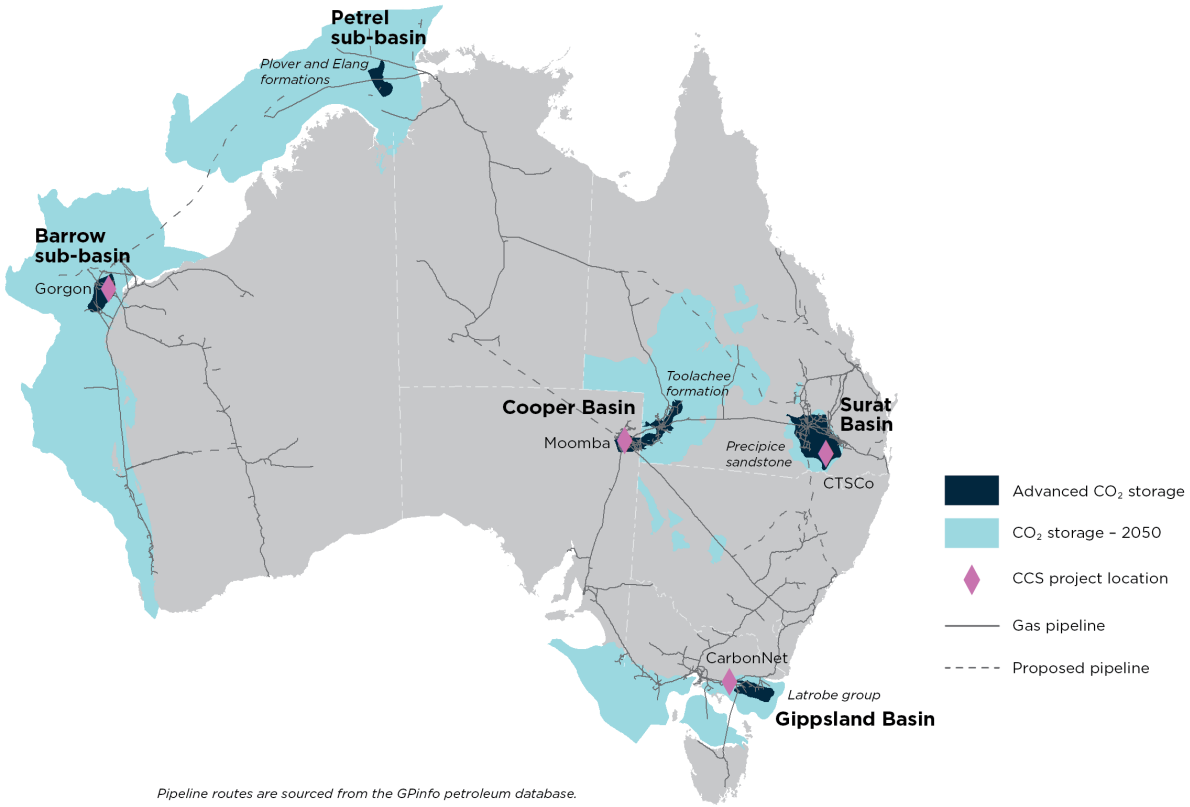
Australia's competitive advantage in CCS comes from our geological storage basins, many of which are close to industries that emit highly concentrated streams of pure CO_2. The Gippsland, Surat, and Cooper Basins, together with the Petrel and Barrow sub-basins host carbon storage sites at an advanced stage of development, and each have genuine industry interest and support (Figure 17). The combined storage capacity at four of these key locations (Gippsland, Surat, and Cooper Basins, and the Petrel sub-basin) is over 20 billion tonnes.[55]

The Australian Government is undertaking further analysis to inform Australia's potential to store CO_2 in our basins as this varies widely depending on basin characteristics and injection rates.

Analysis by the Intergovernmental Panel on Climate Change and the International Energy Agency concluded that the Paris goals won't be met without geological carbon dioxide storage.[56] The US and

[54] The stretch goal assumes CO_2 is transported within a hub distance of less than 100 km.
[55] Estimates by Geoscience Australia.
[56] Intergovernmental Panel on Climate Change 2019, *Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*, accessed 9 August 2021; International Energy Agency 2019, *Exploring Clean Energy Pathways: The role of CO_2 storage*, accessed 10 August 2021

Figure 17: *Prospective CO_2 storage sites in Australia*



UK governments are investing in carbon capture, use and storage (CCUS) technologies to support broader decarbonisation efforts.

The government recognises the importance of carbon capture and use (CCU) technologies in complementing CCS, supporting new industries and reducing emissions. CSIRO's CO_2 Utilisation Roadmap identifies opportunities in Australia's food and beverages industry, the creation of low emissions building products and materials, and the export of low emissions chemicals and fuels.[57]

CCU applications

Through its $50 million CCUS Development Fund, the Australian Government has invested in several innovative projects to capture process emissions and unlock commercial value and large potential markets, including:

- $14.6 million to Mineral Carbonation International. The company is building a mobile plant showcasing how CO_2 can be captured and used to produce manufacturing and construction materials, including components of cement and concrete. The plant will capture up to 3,000 tonnes of CO_2 per year from an industrial facility in Newcastle. The pilot project will demonstrate the commercial potential of CCU technology.
- $2.4 million to Boral to develop a cheap technology to capture and use CO_2. The project will use CO_2 to increase the quality and market value of construction materials like recycled concrete, masonry and steel slag aggregates.

[57] CSIRO 2021, *CO_2 Utilisation Roadmap*, accessed 24 August 2021

The Australian Government is investing over $250 million from 2021 to 2030 to:

- establish CCUS hubs
- support research, development and commercialisation of CCUS technologies.

This builds on $50 million CCUS Development Fund announced in the 2020-21 Budget.

CCS hubs are locations with a cluster of relevant industries. They encourage large-scale deployment of CCS by sharing infrastructure, helping reduce costs for industry.

Deployment pathways and cost drivers

The cost of CO_2 transport and storage depends on:

- distance to a suitable reservoir
- transport mode
- geological storage characteristics.

The cost of CO_2 compression, hub transport and storage could be close to $20 per tonne, if high volumes of concentrated streams of CO_2 are clustered within 100 km of well-developed reservoirs.[58]

Facilities that have started developing projects could implement CCS as early as 2025.[59]

Storage costs vary significantly based on reservoir characteristics, including:

- the level of existing geological data, and extent of additional appraisal drilling required
- geological complexity, such as permeability and porosity
- depth of formation, which affects construction costs.

Storage costs for offshore reservoirs are more expensive due to:

- higher exploration costs
- more complex engineering
- the complexity of servicing offshore operations.

Applications for CCS

Deployment of CCS is critical in applications like cement production, where there are few other solutions to completely eliminate emissions.

Other promising applications for CCS are:

- CO_2 removal in natural gas processing
- clean hydrogen from fossil fuels
- Allam cycle electricity generation from natural gas.

This is due to:

- high capture efficiencies at relatively low cost, due to concentrated streams of CO_2
- the potential to locate these applications in CCS hubs near a geological basin.

In the long term, providing long-term storage of CO_2 for Direct Air Capture and Removal is another promising application of CCS.

[58] Analysis by McKinsey & Company prepared for the Department of Industry, Science, Energy and Resources.
[59] Subject to securing offtake agreements and development approvals.

Soil carbon

Stretch goal: soil carbon measurement under $3 per hectare per year

Potential for soil carbon in Australia

Increasing organic carbon concentrations in soil can offset emissions from hard-to-abate sectors like agriculture, industry and aviation.

Soil carbon projects can generate offsets that provide additional income for farmers while improving agricultural productivity and soil resilience (Figure 18).

Australia is a world leader in soil carbon measurement. But soil carbon stocks vary with soil type, climate and management practices, even within a single paddock. With current information, it is difficult to predict the rate of soil carbon uptake for a given landscape and management practice.

Understanding this variability and accurately measuring soil carbon concentration currently requires expensive and labour-intensive physical sampling. Technologies that make it cheaper and easier to measure soil carbon concentration will encourage more sequestration activities.

Cheaper soil carbon measurement will also support best-practice land management and national soil carbon sequestration strategies.

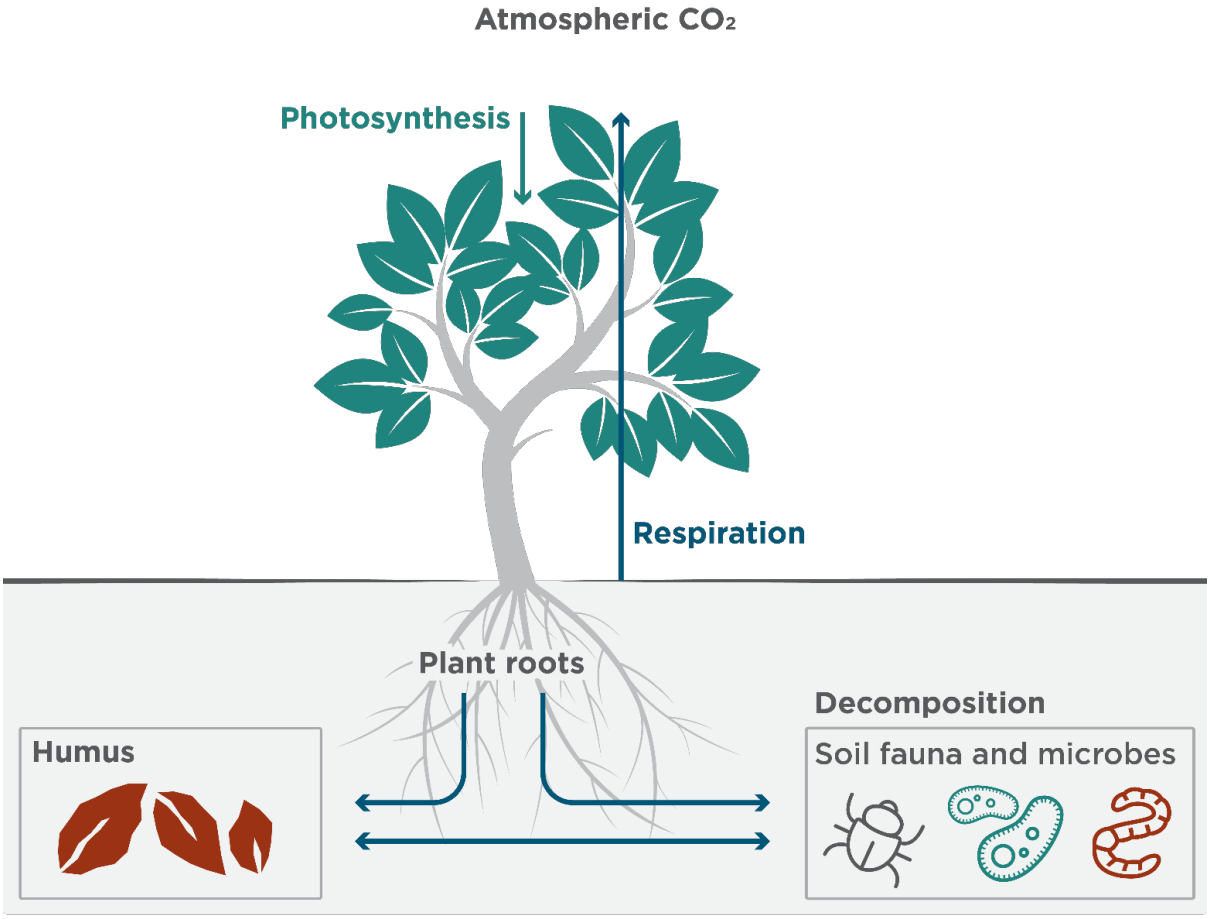
The government is accelerating the deployment of soil carbon measurement technologies by funding research and development:

- The $50 million National Soil Carbon Innovation Challenge will identify and fast-track low-cost, accurate technological solutions for measuring soil organic carbon.
- The $8 million Soil Carbon Data Program supports partnerships between scientists, industry and landholders to develop and validate measurement approaches.
- The $215 million National Soil Strategy is helping farmers monitor, understand and make better decisions about their soils' health, productivity and sequestration potential.
- The CEFC is investing in the agricultural technology sector to build the industry's capabilities. The CSIRO, rural research and development corporations, and the CRC for High Performance Soils are investing in agricultural innovations, including soil carbon measurement.

The ERF also provides incentives for soil carbon sequestration. To help ERF projects get started, payments of up to $5,000 are available to help with upfront costs of soil sampling. The Clean Energy Regulator is also developing a new soil carbon ERF method that lets projects supplement direct sampling with model-based approaches.

Deployment pathways and cost drivers

Figure 18: *Soil organic carbon is a balance of carbon inputs and outputs*



Soil organic carbon is made up of living organic matter such as roots, fauna and microbes, as well as organic matter at various stages of decomposition, including dead roots, humus and crop residues.

Technologies to measure soil organic carbon stocks include:

- physical measurement
- modelling
- remote sensing.

The most practical pathway to low-cost measurement will require an appropriate mixture of these technologies for the environmental and land management context.

Physical measurement

Labour-intensive field sampling followed by lab analysis is currently the standard soil carbon measurement method. But alternative in-field analysis involving technologies such as infra-red scanning are becoming more accessible. Developing tools that use these technologies will significantly lower the cost of physical measurement.

Modelling and remote sensing

Modelling and remote sensing technologies can be used to estimate soil carbon concentrations. As these non-contact approaches improve, the need for physical measurement to support precise measurement will reduce.

Achieving the stretch goal assumes that, with advances in modelling and remote sensing, reliable measurement will be possible with physical testing occurring as infrequently as once every 10 years. Assuming early deployment of modelling and remote sensing technologies, the cost of soil carbon measurement could be reduced to less than $3 per hectare per year before 2030. The stretch goal could be achieved as early as 2025 for land areas greater than 2000 hectares.

Australia's resources opportunity in a new energy economy

The Technology Investment Roadmap's mission is to identify and incentivise the development and deployment of technologies that reduce emissions or sequester hard-to-abate emissions.

The global deployment of zero emissions electricity and hydrogen, low emissions materials and energy storage solutions will depend on large-scale production of low emissions technologies such as batteries, electrolysers, fuel cells, solar panels, electric vehicles, electric motors and wind turbines.

These, in turn, will require the expansion of mining and processing to provide the materials from which they will be built.

This chapter is a complement to the main theme of the roadmap, to give consideration to the resources that are required to support the global transition to a new energy economy. It identifies the increased demand for metals and minerals required to produce low emissions technologies, and considers the opportunities for Australia therein.

Australia has large reserves of relevant metals and minerals, including:

- lithium
- nickel
- copper
- uranium
- cobalt
- manganese
- vanadium
- rare earths
- graphite
- bauxite.[60]

We also have a world-leading mining-equipment technology and services (METS) sector and are close to the growing Indo-Pacific market. This means Australia is well positioned to expand our resources and energy commodity export market as demand surges.

By carefully managing environmental and social impacts, Australia can build on existing industries and create new ones.

These industries will develop alongside Australia's existing energy and resource industries such as coal and liquefied natural gas (LNG), which are major contributors to our economy. Coal and gas will continue to have an important role in the world's energy mix for years to come.[61]

In June 2021, the Australian Government released Australia's Global Resources Statement, a milestone of its Global Resources Strategy. The Global Resources Statement promotes Australia's vision to further strengthen our resources and energy sectors by diversifying our export markets.

[60] Department of Industry, Science, Energy and Resources 2021, *Global Resources Statement*, accessed 5 August 2021

[61] International Energy Agency 2020, *World Energy Outlook 2020*, accessed 5 August 2021

The government is also ensuring the competitiveness of our critical minerals exports and downstream processing capabilities through:

- the Critical Minerals Facilitation Office
- the Modern Manufacturing Strategy.

Future demand for minerals and low emissions fuels

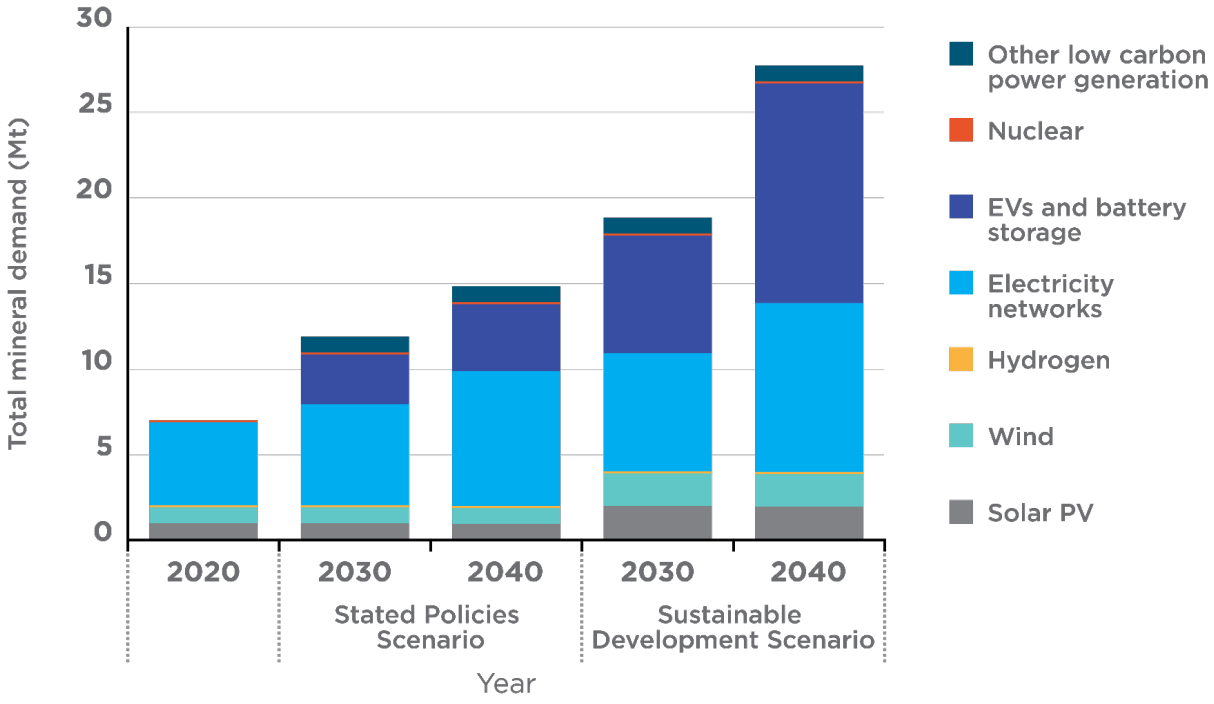
The International Energy Agency (IEA) has conducted modelling of emissions reductions using two key scenarios. The Stated Policies Scenario sets out the outcome of existing policy frameworks and today's announced policy intentions, whereas the Sustainable Development Scenario focusses on what would be required in a trajectory consistent with meeting the Paris Agreement goals.

The IEA predicted that under the Stated Policies Scenario, mineral requirements for low emissions technologies will double by 2040, and could almost quadruple in the same time period under the Sustainable Development Scenario (Figure 19).[62]

The IEA also projects increasing demand for low emissions fuels, including hydrogen, and uranium for nuclear electricity.[63]

Australia's export potential

Figure 19: *Total mineral demand to manufacture low emissions technologies under IEA's Stated Policies and Sustainable Development Scenarios*



Through Australia's Global Resources Strategy, the government is working to expand and strengthen our resources export markets. This includes seeking new trading opportunities with partners in our region though existing bilateral relationships, as well as forging new connections. Australia's new energy technologies and minerals resources will be key to facilitating the global energy transition.

[62] International Energy Agency 2021, *The role of critical minerals in the energy transition*, accessed 5 August 2021

[63] International Energy Agency 2021, *World Energy Outlook 2021*, accessed 21 October 2021

We are a reliable, responsible and ready player to support our partners to achieve their emissions reduction targets.

The Office of the Chief Economist of the Department of Industry, Science, Energy and Resources has analysed Australia's competitiveness in the evolving global market and our potential export revenues under the scenarios of gradual and rapid transition to low emissions technologies.[64]

The analysis shows that Australia is well positioned to supply a significant share of the global demand for minerals, metals and fuels, including:

- lithium
- nickel
- copper
- uranium
- clean hydrogen

Minerals and metals

Lithium

Lithium-ion batteries for electric vehicles and stationary storage may see demand for lithium increase 11-fold over the next 30 years.[65]

Australia is the world's largest lithium producer and has the world's second-largest lithium reserves. Chile and China are the next largest exporters, and Australia's lithium exports are larger than the sum of both.[66] Combined with cheap energy and large scale project expertise, our lithium reserves give Australia a competitive advantage in quickly scaling up lithium production.[67]

Under a scenario of gradual transition to low emissions technologies, Australia could grow its estimated annual revenue from lithium exports by more than 12-fold on 2020 levels to $14 billion by 2050. Under a rapid transition scenario, annual revenue could grow more than 17-fold to $19 billion by 2050.[68] This would amount to 62% of a $31 billion global export industry. Australia's annual revenue could grow further to as much as $34 billion by 2050 if current high commodity spot prices are maintained and Australia further refines all the lithium it produces.[69]

Nickel

Nickel's increasing global demand is mainly due to its use in the production of lithium-ion batteries. Demand for nickel is projected to increase fivefold over the next 30 years.[70]

Australia is the world's sixth largest producer of nickel and has the world's second-largest nickel reserves. Indonesia, the Philippines and Russia are the three largest exporters of nickel.[71] Given the

[64] Analysis assumes rapid uptake of low emissions technologies, consistent with an average temperature rise limited to 2°C in the IEA's 2020 World Energy Outlook Sustainable Development Scenario.
[65] Bloomberg New Energy Finance 2021
[66] United States Geological Survey 2021, *Mineral Commodity Summaries 2021*, accessed 9 August 2021
[67] United States Geological Survey 2020, *Mineral Commodity Summaries 2020*, accessed 5 August 2021
[68] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis. Figures are in real 2020 dollar terms.
[69] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis. Figures are in real 2020 dollar terms.
[70] Bloomberg New Energy Finance 2021
[71] United States Geological Survey 2020, *Mineral Commodity Summaries 2020*, accessed 5 August 2021

limited nickel reserves around the world, Australia is well placed to capture a larger share of the global market.

Australia's annual nickel export revenue is projected to increase three-fold to $12 billion under a scenario of gradual transition to low emissions technologies, or five-fold to $22 billion by 2050 under a rapid transition scenario.[72] The latter would make up 15% of a $150 billion global export industry. If current high spot prices were to persist over the outlook, Australia's annual revenue could grow to as much as $31 billion by 2050.[73]

Copper

Copper's conductivity makes it essential for the wires and components in:

- electricity networks
- stationary storage
- electric vehicles
- solar and wind power generation.

Australia has the world's second-largest copper reserves.[74] Australia is currently the third-largest exporter of copper, after Chile and Peru.[75]

The already wide scale of copper use across infrastructure and technology, means that any growth in copper demand stemming from low emissions technologies is not expected to be as large as that for other materials. Additionally, due to high recycling rates, increases in the demand for mined copper is likely to be moderate.

Australia is expected to remain globally competitive, with higher export volumes compensating for lower export prices. Under both gradual and rapid transition scenarios, Australia could grow its estimated annual revenue from mined copper exports to around $8 billion by 2050.[76] This would amount to 10% of an $80 billion global export industry. If current high spot prices were to persist over the outlook, Australia's annual revenue would grow to $19 billion by 2050.[77]

Other minerals and metals

Australia will continue to be a major exporter of iron ore, alumina and aluminium. Demand for aluminium will grow due to the need for lightweight material in electric vehicles and the support structures for solar panels.[78]

Australia is currently the world's largest exporter of iron ore, with Brazil and South Africa being the next largest.[79]

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[72] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis.
[73] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis. Figures are in real 2020 dollar terms.
[74] Geoscience Australia 2021, *Australia's Identified Mineral Resources 2020*, accessed 15 October 2021
[75] Department of Industry, Science, Energy and Resources 2021, *Resources and Energy Quarterly, June 2021*, accessed 9 August 2021
[76] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis.
[77] Department of Industry, Science, Energy and Resources 2021, Office of the Chief Economist analysis. Figures are in real 2020 dollar terms.
[78] Department of Industry, Science, Energy and Resources 2021, *Resources and Energy Quarterly, June 2021*, accessed 9 August 2021
[79] Department of Industry, Science, Energy and Resources 2021, *Resources and Energy Quarterly, June 2021*, accessed 9 August 2021

Large quantities of steel will be required for construction of low emissions facilities. As an example, it has been estimated that steel represents up to 80% of all the material mass used to construct a wind turbine.[80] The largest global steel exporters are China, Russia, and Japan.[81]

Australia could also see strong growth in the export of rare earth elements like cobalt, graphite and vanadium.[82]

Fuels

The IEA predicts that natural gas, coal and oil will be an important part of the world's fuel mix for many years.[83] In particular, global natural gas demand is projected to increase in the coming years.[84]

Australia is an established global supplier of LNG and coal.[85] Many of our gas producers and exporters are exploring solutions to reduce emissions across their supply chains. This means Australia is well positioned to remain a supplier of choice for natural gas.

Meanwhile, growing demand for low emissions fuels creates the potential for our resources sector to diversify our exports by supplying clean hydrogen and uranium.

Australian Industry Energy Transitions Initiative

Supported by a $2 million ARENA grant, and convened by ClimateWorks Australia and Climate-KIC Australia, the Australian Industry Energy Transitions Initiative is made up of 16 major industrial and finance companies. They include:

- Australian Gas Infrastructure Group
- BHP
- BlueScope Steel
- BP Australia
- Fortescue Metals Group
- RioTinto
- Wesfarmers Chemicals Energy and Fertilisers
- Woodside.

Its goal is to reduce supply chain emissions in some of our most important, but hardest to abate, industrial sectors, including: liquefied natural gas, chemicals, steel, aluminium, and other metals like copper, nickel and lithium.

The companies are identifying how their sectors can transition to net-zero emissions. The group's early research shows that existing or emerging technologies can address almost all of the emissions in these industries' supply chains.

By sharing knowledge and collaborating on action, this initiative will help Australia's heavy industries be global leaders in the shift to a net-zero economy.

[80] POSCO 2016, *Steel Solutions in Wind Power*, accessed 1 September 2021
[81] World Steel Association 2021, *2021 World Steel in Figures*, accessed 9 August 2021
[82] Department of Industry, Science, Energy and Resources 2021, *Outlook for Selected Critical Minerals in Australia*, accessed 9 August 2021
[83] International Energy Agency 2021, *World Energy Outlook 2021*, accessed 21 October 2021
[84] International Energy Agency 2021, *World Energy Outlook 2021*, accessed 21 October 2021
[85] Department of Industry, Science, Energy and Resources 2021, *Global Resources Statement*, accessed 5 August 2021

Uranium

All uranium produced in Australia is exported. It used as fuel for nuclear power plants.

Nuclear power can help zero-emissions electrification by complementing high levels of solar and wind generation.

The IEA estimates that nuclear power generation will need to double over the next 30 years to achieve net zero emissions. Attainment of this target will be determined by policy decisions among countries currently considering nuclear energy programs, as well as by potential improvements in nuclear power technology. Increased demand for uranium will likely be driven by the deployment of small modular reactors. Nuclear plants need a relatively small amount of uranium to run, so the world's known uranium reserves can fulfil the anticipated demand.[86]

Australia has the largest reserves of uranium, with around one-third of the world's uranium reserves, and is the third-largest producer after Kazakhstan and Canada.[87] We also have multiple mines under review or in development. This means Australia can expand its market share and export value. Our annual revenue from uranium exports is expected to increase from $0.8 billion now to just under $900 million by 2050 under a gradual transition scenario, or $1.3 billion by 2050 under a rapid transition scenario.[88] The latter is 13% of a $10 billion global uranium mining industry.

Clean hydrogen

Clean hydrogen and clean ammonia can reduce emissions when energy needs can't easily be met by electricity.

Australia is well placed to become a hydrogen superpower. In a recent analysis, Wood MacKenzie estimated Australia's hydrogen export industry to be between $70 and $130 billion (US$50–US$90 billion) by 2050.[89]

Value-adding opportunities

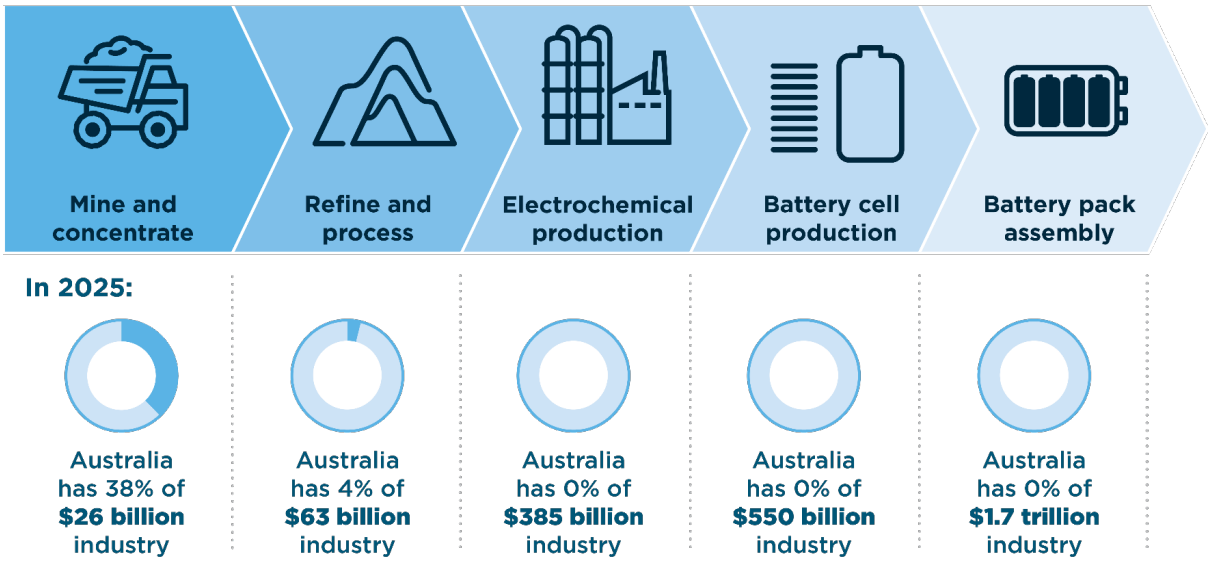
Most minerals have a complex value chain. They go through several stages of processing and conversion between the mine site and the point they are used.

Each step significantly increases the value of the product. For example, it is estimated that in 2025 the global lithium mining production will be worth $26 billion, compared with the refining and processing industry worth $63 billion and battery pack assembly industry estimated to be worth $1.7 trillion (Figure 19). [90]

[86] International Energy Agency 2021, *World Energy Outlook 2021*, accessed 21 October 2021
[87] Nuclear Energy Agency and International Atomic Energy Agency 2020, *Uranium 2020: Resources, Production and Demand*, accessed 9 August 2021
[88] International Energy Agency 2021, *Net Zero by 2050*, accessed 9 August 2021
[89] Wood MacKenzie 2021, *Green pivot: Can Australia master the hydrogen trade*
[90] Future Battery Industries CRC 2020, *Li-ion battery cathode manufacture in Australia – a scene setting report*, accessed 6 September 2021

Global mineral processing and refining operations are generally heavily concentrated and vulnerable to disruption. With increasing concern about the risks of geographic concentration of supply chains, Australia offers security and reliability for customers looking to diversify their supply.

Figure 20: *Projected value of lithium battery value chain*



Australia's Critical Minerals Strategy highlights our potential to lead the world in critical mineral exploration, extraction, production and processing.[91]

According to the Future Charge report from Accenture, development of more onshore materials processing and upstream battery production has the potential to create over 34,000 jobs and contribute $7.4 billion annually to Australia's economy in 2030.[92]

In light of these strategic advantages and opportunities for our economy, resources technology and critical minerals processing has been identified as a National Manufacturing Priority under Australia's Modern Manufacturing Strategy.

The $1.3 billion Modern Manufacturing Initiative, a centrepiece of the strategy, will support the scaling up of local downstream processing and value adding of critical minerals, as well as commercialising and manufacturing cutting-edge technologies that drive productivity and sustainability of the resources sector.

[91] Department of Industry, Science, Energy and Resources 2019, *Australia's Critical Minerals Strategy*, accessed 9 August 2021

[92] Accenture 2021, *Future Charge – Building Australia's Battery Industries*, accessed 9 August 2021

Sovereign manufacturing capability in Australia

Australia produces many of the minerals needed for batteries, including cobalt, manganese and lithium. Combined with our outstanding manufacturing capabilities, this means Australia is well-placed to meet the world's increasing demand for battery storage.

Based in Perth, **Lithium Australia** wants to ethically and sustainably supply the global lithium battery industry. The company uses proprietary technologies to more efficiently extract lithium. It also produces cathode materials for batteries and is developing a way to recycle all the metals from old lithium-ion batteries.

On the other side of the country, NSW's **Energy Renaissance** designs and manufactures lithium-ion batteries optimised for hot climates. The company's tough, flexible 'superStorage' platform uses a proprietary battery management system for better efficiency, safety and security. All products are made at the 'Renaissance One' advanced manufacturing hub near Newcastle.

Impact evaluation framework

LETS 2020 committed to developing an impact evaluation framework for the Technology Investment Roadmap. The impact evaluation framework will:

- provide a clear and transparent way of tracking and reporting on the roadmap's progress
- inform government decisions to maximise the impact of policies and investments in low emissions technologies.

Figure 21 shows the pathway from the government's policies and investments to their intended impacts. The pathway has three stages, which align with the goals and targets in LETS 2020:

- **Enabling policies and investments**. These are government policies and investments that support low emissions technology development and deployment.
- **Co-investment and employment outcomes**. These include co-investment in government-funded projects from the private sector and other jurisdictions, as well as jobs supported.
- **Other technology, economic and abatement impacts**. Impacts the government aims to influence, but which are also influenced by external factors. These include:
  - technology deployment and costs
  - exports supported by priority technologies
  - reduced emissions.

The main long-term impact we will track is progress towards the economic stretch goals for priority technologies. Technology costs will take several years to reduce, so private sector co-investment is an important leading metric for progress in the meantime.

We aim to attract an average of over $3 of co-investment for every $1 of Australian Government investment over the decade to 2030, which is expected to be at least $20 billion. Lower co-investment may mean the private sector has less confidence in the technology or that policy settings need review. Significantly higher co-investment could mean technologies have become commercially mature. This would mean government investment could be prioritised elsewhere.

We will report our progress every year in annual statements, with individual metrics to be covered to the extent that data is available. To support this reporting, we will collect data from all relevant Australian Government agencies and also establish data supply agreements with core investment and regulatory agencies, including ARENA, CEFC and CER. The 'Australian Government investment' section of the introduction chapter includes progress updates on some metrics for the 12 months ending 30 June 2021.

The impact evaluation framework will be continually reviewed and refined in line with the roadmap's adaptive approach.

Figure 21: *Impact evaluation framework*

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