



Australian Government  
Department of Industry, Science,  
Energy and Resources

TECHNOLOGY INVESTMENT ROADMAP

# First Low Emissions Technology Statement – 2020

Global leadership in  
low emissions technologies





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# Minister's foreword

History shows that we solve hard problems through enterprise and innovation. The Newcomen steam engine, the Haber-Bosch process and the agricultural Green Revolution are all examples of overcoming great challenges through technological progress.

The global race to reduce emissions will be no exception.

That's why the Government's emissions reduction strategy is focussed on technology not taxes.

The *Technology Investment Roadmap* is first and foremost a research and development strategy.

Existing, proven technologies like coal, gas, solar and wind will play important roles in Australia's energy future, but are not the focus of the Roadmap. The Government will continue to invest in mature technologies where there is a clear market failure, like a shortage of dispatchable generation, or where these investments secure jobs in key industries.

But the Roadmap recognises that widespread deployment is primarily driven by the private sector, with a targeted role for public investment.

The Government's efforts will focus on new and emerging technologies with the potential for transformational economic and emissions outcomes, in Australia and globally.

We will enact change by:

1. Accelerating technology development through an investment and incentives framework that spans from research and development to pre-commercial deployment
2. Enabling our agencies to invest in the next generation of technologies through a legislative and regulatory reform package
3. Working together with our trading partners, because delivering global outcomes requires international collaboration.

Amara's law dictates that we tend to overestimate the impact of technology in the short term, yet underestimate it in the long run. That is why the Government will refine its approach over time through future *Low Emissions Technology Statements*.

These will be tabled in Parliament each year, detailing the impact of our investments and our progress towards clearly-defined priority technology stretch goals.

Getting these technologies right will create jobs, and preserve and expand our energy-intensive export industries. We will beat our 2030 emissions reduction target, with a platform for future emissions reductions beyond the next decade.

This technology-led approach won't compromise energy affordability or reliability, and will position Australia as a global technology leader.

I express my sincere appreciation to Australia's Chief Scientist, Dr Alan Finkel, and the other members of the Ministerial Reference Panel: Alison Watkins, Ben Wilson, Drew Clarke, Grant King, Shemara Wikramanayake and Jo Evans. This Statement benefitted greatly from their expert advice and insight.

**The Hon Angus Taylor MP**  
Minister for Energy and Emissions Reduction

# Message from the Chair

The *Technology Investment Roadmap* addresses the biggest global challenge of our era – to rapidly reduce emissions in a way that supports economic growth.

Technology is key to achieving this ambition. The *Low Emissions Technology Statement* is the first major milestone in the Roadmap. It identifies how emerging low emissions technologies can become economically competitive with and replace high emission incumbents, just as electric light bulbs replaced kerosene lamps, and are now being replaced by LEDs.

For the Roadmap, I am confident that the combination of Australian ingenuity and clearly articulated Government support will see these technologies rapidly become competitive.

I've been fortunate in recent years to contribute to the building blocks that are supporting an orderly transition to a low emissions future. In 2017, the review of the National Electricity Market set in motion important reforms that continue to be implemented through the work of the National Cabinet Energy Reform Committee. In 2019, the adoption of the *National Hydrogen Strategy* by all Australian governments stimulated domestic and international investor interest in the use of clean hydrogen as a chemical feedstock, for energy storage and for exporting renewable energy. And now, in 2020, the *Low Emissions Technology Statement* identifies the next steps required to accelerate the economically effective adoption of priority and enabling technologies through a principles-based investment framework.

I offer my sincere thanks to Minister Taylor for his engagement, insight and forward thinking, which gave direction to this project from start to finish, and I commend his key role in the development of the *National Hydrogen Strategy* last year. The Panel members Alison Watkins, Ben Wilson, Drew Clarke, Grant King, Jo Evans and Shemara Wikramanayake all have broad industry, policy and energy markets expertise that has enabled them to consider the technology challenges from the perspectives of industry, investment and shared benefits across the community. I thank them deeply for their wise counsel throughout.

I thank the leadership of the Department of Industry, Science, Energy and Resources for their guidance and support, and I extend my warm appreciation to the masterful taskforce that did all the hard work. Finally, it is my pleasure to note the broad engagement from the public during the consultation process. The workshops and the written submissions helped us greatly in formulating our advice to the Minister.

**Dr Alan Finkel AO**

Australia's Chief Scientist  
Chair, Ministerial Reference Panel

# At a glance

## Our vision

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

## Strategic intents

Accelerate the development of new and emerging technologies by making them economically competitive with established technologies, unlocking new opportunities across the country.

Build on our existing role as a trusted exporter of energy, resources and agricultural products, and secure continued prosperity in a low emissions global economy.

Realise our vision through a lasting partnership between industry, investors, researchers, governments and the broader community to:

- preserve and create jobs, capture new opportunities and revitalise Australia's regional economies
- lower household living expenses with abundant, clean and low-cost energy
- build competitiveness by leveraging our comparative advantages
- attract and retain the best minds in priority low emissions technology research fields.

# OUR VISION

A PROSPEROUS AUSTRALIA, RECOGNISED AS A GLOBAL  
LOW EMISSIONS TECHNOLOGY LEADER

## THE BIG TECHNOLOGY CHALLENGES



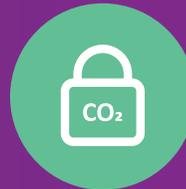
**Delivery of more affordable, clean and reliable energy to households and industry** for transportation, heating, production and power



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 permanent sequestration of CO<sub>2</sub>

GOVERNMENT INVESTMENT

PRIVATE INVESTMENT

## Highlights



### PRIORITY TECHNOLOGY STRETCH GOALS

**CLEAN HYDROGEN**  
under \$2 per kilogram

**ENERGY STORAGE**  
electricity from storage for firming under \$100 per MWh\*

**LOW CARBON MATERIALS**  
low emissions steel production under \$900 per tonne and low emissions aluminium under \$2,700 per tonne

**CCS – CO<sub>2</sub> COMPRESSION, HUB TRANSPORT AND STORAGE**  
under \$20 per tonne of CO<sub>2</sub>

**SOIL CARBON**  
measurement under \$3 per hectare per year

\* This would enable firm wind and solar at pricing at or below today's average wholesale electricity price



### ANTICIPATED IMPACTS FROM THE PRIORITIES

**OVERACHIEVE**  
on our Paris Agreement commitments, with a pathway to deeper emissions reductions beyond 2030

**SUPPORT OVER 130,000 JOBS BY 2030**  
with more than half in regional communities

**PRESERVE AND EXPAND EMPLOYMENT**  
in our energy-intensive manufacturing sectors

**AVOID IN THE ORDER OF 250 MILLION TONNES OF EMISSIONS PER YEAR BY 2040**  
through deployment of priority technologies at home and Australia's low emissions exports

**SIGNIFICANTLY REDUCE GLOBAL EMISSIONS**  
from energy, transport, industry and agriculture if priority technologies achieve widespread deployment. These sectors account for around 90% of emissions and emit approximately 45 billion tonnes of CO<sub>2</sub> each year.



### PUBLIC-PRIVATE PARTNERSHIP

**AIM TO CATALYSE \$3–\$5 OF NEW INVESTMENT FOR EACH DOLLAR OF COMMONWEALTH FUNDING**  
to achieve \$50 to \$100 billion in new investment domestically over the decade to 2030

**A TECHNOLOGY INVESTMENT FRAMEWORK**  
to improve coordination of delivery agencies – ARENA, the CEFC and CER – towards national technology priorities and expected Government investment of \$18 billion in low emissions technologies over the decade to 2030

**RETAIN ARENA ON THE FRONTLINE OF DIRECT GOVERNMENT INVESTMENT**  
in low emissions technologies, playing a central role in delivering Roadmap priorities. New funding for the CEFC to support grid reliability

**ARENA WORKING WITH THE CEFC AND OTHER AGENCIES**  
to develop a goal-oriented program for priority low emissions technologies like low emissions steel, low emissions aluminium, and energy storage

**ESTABLISH AUSTRALIA'S FIRST REGIONAL HYDROGEN HUB**  
co-locating domestic hydrogen users with an export focus to create global hydrogen supply chain linkages

**SCALE CCS**  
to support emissions reduction from power generation, oil and gas extraction, natural gas processing, industry or hydrogen production

## Government action towards our vision



### Investment and incentives framework

Stretch goals are a clear signal to the private sector on where the Government will focus its efforts.

The Government's investment and incentives framework spans from research and development to pre-commercial deployment: from ARENA to CEFC and through to the Emissions Reduction Fund.

Government will enter into international partnerships to collaborate on priority technologies.

Commonwealth-State deals will leverage greater co-investment towards *Low Emissions Technology Statement* priorities.



### Legislative and regulatory reforms

Additional flexibility for ARENA and the CEFC will enable them to invest in the next generation of energy technologies and support emissions reductions across all sectors of the economy.

Actions to strengthen the enabling environment and remove regulatory barriers.

Government's approach to regulation will respect consumer choice and trust households and businesses to adopt new technologies as they approach parity.



### Institutions and governance

A permanent Technology Investment Advisory Council – including ARENA, the CEFC and CER – will advise on the preparation of future *Low Emissions Technology Statements*.

These Statements will be tabled in Parliament.

ARENA and the CEFC's investment mandates will be updated to reflect the Statement priorities.



### Monitoring, transparency and impact evaluation

Future *Low Emissions Technology Statements* will report on progress towards priority technology stretch goals.

Impact evaluation will be supported by regular reporting from key agencies.

Investment, regulatory and legislative frameworks will be reviewed annually to ensure their alignment with priority technologies.

# Technology Investment Roadmap

*Australia's Technology Investment Roadmap* (the 'Roadmap') is an enduring strategy to accelerate the development and commercialisation of new and emerging low emissions technologies.

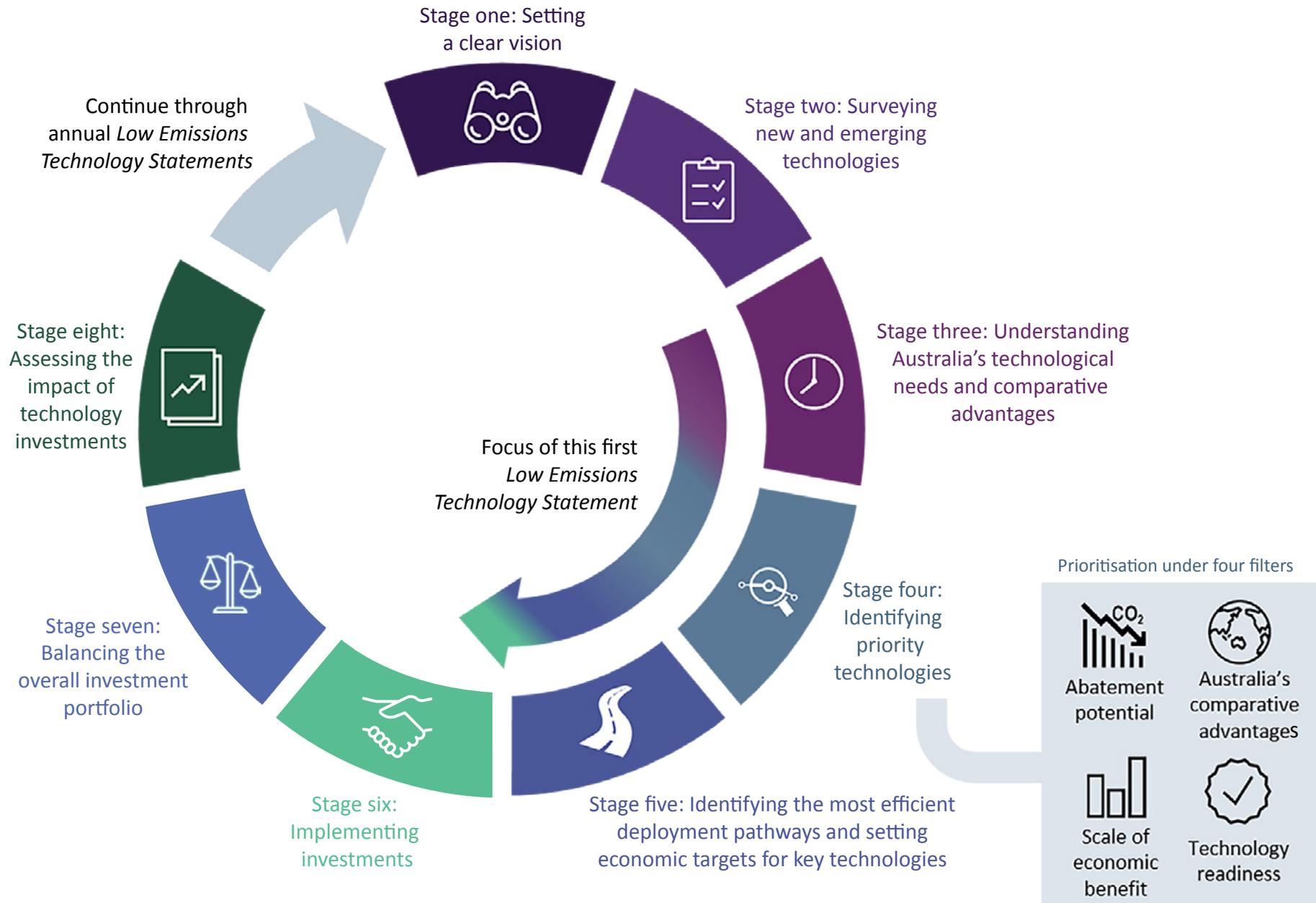
Key milestones of the Roadmap process are annual *Low Emissions Technology Statements* (the 'Statement') that will prioritise low emissions technologies with the potential to deliver the strongest economic and emissions reduction outcomes for Australia.

As we recover from COVID-19, the Roadmap will prioritise investments in new and emerging technologies that support jobs and economic recovery.

In May 2020, the Minister for Energy and Emissions Reduction published a discussion paper outlining the key stages of the Roadmap and commencing a survey of new and emerging technologies (**Figure 1**).<sup>1</sup>



**Figure 1: The Technology Investment Roadmap**



## Ministerial Reference Panel

A Ministerial Reference Panel, chaired by Australia's Chief Scientist, Dr Alan Finkel AO, and comprising industry, private investment, government and research leaders was established to advise the Minister in the preparation of the first *Low Emissions Technology Statement* (**Figure 2**). Recognising the Panel's ongoing role in supporting future Statements, the Panel will be formalised into a permanent Technology Investment Advisory Council. The Chairs of ARENA, the CEFC and the CER will also be appointed as *ex officio* members of the Council.

**Figure 2: Ministerial Reference Panel members**



## Consultation

The discussion paper opened a national conversation about Australia's future in a low emissions global economy. The Department of Industry, Science, Energy and Resources received around 500 written submissions and over 150 businesses, researchers, community organisations and associations participated in targeted industry workshops chaired by Dr Finkel, with participation by other members of the Ministerial Reference Panel. More than 400 people attended an online webinar led by Dr Finkel and several other Panel members.

A clear message from this outreach was that Australian industry, researchers and the broader community are ready to accelerate the development and commercialisation of low emissions technology to maintain and expand Australia's economic prosperity. Stakeholders want to capture the opportunities of the global low emissions economy, while ensuring that our existing industries remain strong.



*Australia has world-leading capabilities in several energy and emissions-intensive manufacturing industries, including aluminium, steel, chemicals, cement, building materials, pulp & paper and glass manufacturing. Preserving and strengthening those capabilities through the adoption of lower emissions technologies presents enormous opportunities for Australia, but must be approached in a way that maintains international competitiveness.*

**Manufacturing Australia**



*A technology-led approach involving a partnership between industry and government will be central to ensuring our heavy industry is well placed to prosper in a future carbon constrained global economy.*

**Energy Users Association of Australia**

## The first *Low Emissions Technology Statement*

This first, annual *Low Emissions Technology Statement* identifies Australia's **big technology challenges and opportunities, priority low emissions technologies, and economic stretch goals.**

The Statement also articulates the comprehensive investment framework that will guide technology investment agencies (ARENA, the CEFC and the CER) towards the Roadmap's priorities. For the first time, the investment framework includes rigorous impact evaluation that will ensure measurable outcomes from our investments.

The Statement's impact will be broader than the Government's direct investments through ARENA, the CEFC and the CER. The Statement will signal the Government's low emissions technology investment priorities to the broader research community, including CSIRO, CRCs and Australia's universities, as well as to industry, investors and community leaders. The Roadmap and Statement complement other emissions reduction policies including the *National Hydrogen Strategy*, ARENA's *Bioenergy Roadmap*, the *Critical Minerals Strategy*, AEMO's *Integrated System Plan*, the *National Waste Policy and Action Plan*, the *National Energy Productivity Plan*, and *Future Fuels Strategy* (**Figure 3**).



*...over the long term, Australia's technology investments should build new export-facing industries in the global low emissions economy.*

**National Farmers Federation**

State deals will also be guided by Roadmap priorities. The bilateral deal with NSW in January 2020 is the first of a series of agreements between the Australian Government and state and territory governments. These bilateral agreements will deliver initiatives to increase the supply of electricity and gas, improve grid security and reduce emissions.

The Roadmap and first *Low Emissions Technology Statement* will be the cornerstone of the *Long Term Emissions Reduction Strategy* Australia will take to COP26 in Glasgow.

**Figure 3: Technology deployment to complement other strategies which lower long-term emissions**



# Australia's big technology challenges and opportunities

To realise our vision, we need to tackle the big technology challenges and opportunities facing our country.

The opportunities we pursue should play to Australia's strengths. The challenges recognise issues affecting consumers and businesses globally, including supply of affordable energy and supporting transformation of energy-intensive industries.

A common theme during stakeholder outreach was that our natural endowments – unmatched renewable energy and mineral resources, vast landmass, suitable geology, and close proximity to emerging markets – will continue to be the foundation of our prosperity as a low emissions economy.



This Statement's priorities and approach are designed around these big technology challenges:

- **Delivering more affordable, clean and reliable energy to households and industry** for transportation, heating, production and power.
- 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** such that we provide globally significant permanent sequestration of CO<sub>2</sub>.

Addressing these challenges and opportunities in an integrated way will set us on the path towards our overarching vision.

Affordable, clean and reliable energy is the cornerstone of improved productivity, competitiveness and lower emissions from industry. Lower energy costs will reduce pressure on household budgets and improve Australian quality of life. Low-cost and reliable energy will encourage more onshore energy-intensive manufacturing. Improved productivity and reduced emissions intensity will help us capture new opportunities in a global low emissions economy.

Finally, large-scale geological and biological sequestration will reduce hard-to-abate emissions by safely storing more carbon in Australia's landscape. A strong focus by the Government on sequestration recognises these technologies can boost the productivity of Australia's agriculture sector and provide decarbonisation pathways for new and existing industries, which will preserve jobs.



*Australia's comparative advantages provide a basis for reducing Australian emissions and for helping our overseas partners to lower their emissions through our clean energy exports (particularly Japan, South Korea and China).*

APA Group



*Just as Australia is in an excellent position to lead the way in transforming energy systems to carbon-neutral methods, it could also do so for food production, leading to more sustainable and climate-smart systems.*

Australian Academy of Technology and Engineering

### BOX 1: LOW EMISSIONS EXPORT POTENTIAL

Low emissions technologies could position Australia for over \$30 billion a year of new export revenue from energy-intensive, low emissions products by 2040. This scenario would see Australia developing into a world-leading exporter of hydrogen and a significant international producer of low emissions metals and industrial products.

The Grattan Institute's recent *Start with steel* report estimated the potential for \$65 billion in export revenue, creating 25,000 manufacturing jobs in Queensland and New South Wales (assuming Australia captures 6.5% of the global steel market in 2050).<sup>2</sup>

# Australia's priority low emissions technologies

This Statement identifies four technology categories – priority low emissions technologies, emerging and enabling technologies, watching brief technologies, and mature technologies (**Figure 4**).

**Figure 4: Technology categories**

## **PRIORITY LOW EMISSIONS TECHNOLOGIES**

Potentially transformative economic and abatement impacts. They have high potential to reduce emissions both domestically and internationally across multiple sectors and applications. They are aligned with Australia's comparative advantages.

These technologies will be the focus of new public investment. The Government will strive to remove barriers to the development of these technologies.

## **EMERGING AND ENABLING TECHNOLOGIES**

Emerging technologies are those that have transformative potential, but require continued monitoring of global learning rates, research and investment trends, or are the focus of existing policies and institutions.

Enabling technologies include infrastructure, like charging and refuelling stations, energy management systems, digital infrastructure, energy efficiency, and market design activities required to overcome the challenges and realise the opportunities for priority low emissions technologies.

ARENA, the CEFC and the CER will continue to support these technologies.

## **WATCHING BRIEF TECHNOLOGIES**

Prospective technologies with transformative potential, perhaps where developments are currently driven primarily overseas.

International developments will be closely monitored and supporting infrastructure needs assessed.

## **MATURE TECHNOLOGIES**

Existing, proven technologies like coal, gas, solar and wind will play important roles in Australia's energy future, but are not the focus of the Roadmap.

The Government will continue to invest in mature technologies where there is a clear market failure, like a shortage of dispatchable generation, or where these investments secure jobs in key industries, but future deployment of mature technologies will primarily be driven by the private sector.

## BOX 2: MATURE TECHNOLOGIES SUPPORTING AUSTRALIA'S LOW EMISSIONS TRANSFORMATION

As new and emerging technologies develop and become more competitive, households and businesses will adopt them. This process will take time and depend on the continued operation of mature technologies.

Mature technologies include coal and gas, as well as renewable technologies like hydro, solar and wind that are already enjoying widespread commercialisation. While these technologies will play continuing roles in Australia's energy future, they are not the focus of the first *Low Emissions Technology Statement*, which concentrates on accelerating uptake of new and emerging technologies. Continued cost reductions and performance improvements for mature technologies will be needed to support some of the priority low emissions technologies in this Statement and overcome the key technology challenges outlined above.

Mature technologies comprise the overwhelming majority of Australia's electricity generation fleet – coal, gas and hydro, accompanied by rapid and world-leading investment in solar and wind. In 2019, fossil fuels contributed 79% of total electricity generation.<sup>3</sup> Many existing generators remain relatively early in their operating lifetimes, and will continue to provide reliable, secure and affordable electricity. For example, the existing coal fleet provides critical system stability as well as the

bulk of the low-cost power consumed by Australia's energy-intensive industries, while gas generators provide the stability and services needed to enable the integration of rapidly increasing solar and wind energy capacity.

Gas already provides much of the peaking capacity in Australia's electricity grids and its ability to flexibly ramp up output means it can provide firm power when solar and wind output drops. Gas-powered generation (GPG) has been valuable in enabling solar and wind build-up in several jurisdictions such as California (where 43% of annual in-state generation is from GPG), South Australia (49%) and Britain (41% from GPG and 17% from nuclear).<sup>4</sup>

For the most part, the Government will look to the private sector to lead investment in existing technologies, although there will be instances where it will make strategic investments, particularly where there is a clear market failure, like a shortage of dispatchable generation, or where these investments secure jobs in key industries. ARENA and the CEFC will also continue their important role in supporting the reliability and security of the current grid through their work on enabling technologies such as distributed energy management and energy efficiency.

## Priority low emissions technologies and economic stretch goals

**Priority low emissions technologies** are those expected to have a significant impact on Australia's big technological challenges and opportunities. These technologies have the highest abatement and economic potential in areas of comparative advantage for Australia. They are priorities where government investments can make a difference in reducing prices and improving technology readiness.

The priority low emissions technologies identified in this Statement are:

- clean hydrogen
- energy storage
- low carbon materials (steel and aluminium)
- carbon capture and storage
- soil carbon.

**Economic stretch goals** are ambitious but realistic goals to bring priority low emissions technologies to economic parity with existing mature technologies. Stretch goals have been set for each priority technology.

**Investors can have confidence** that identified priority low emissions technologies are of long-term strategic importance for the Government. We will report on progress towards these goals through annual *Low Emissions Technology Statements*. We will be responsive to local and global technology developments, and add or alter priority low emissions technologies and goals with advice from the Technology Investment Advisory Council.

We will target **international partnerships** that support these economic stretch goals, including access to global markets and more competitive supply chains. We will also prioritise partnerships that focus on critical research, development and deployment challenges for economically important, hard-to-abate sectors.

Priority low emissions technologies and economic stretch goals are described further in the following sections. For all priority low emissions technologies, stretch goals have been set with reference to the current costs of today's incumbent technologies.

These priority low emissions technologies will offer emissions reduction opportunities across Australia's economic sectors, with sequestration technologies also providing additional decarbonisation pathways for key industries, while protecting and preserving jobs.

The Government's role in helping bring down technology costs towards the stretch goals is to influence and co-invest with the private sector and other levels of government and encourage a supportive enabling environment.

## ECONOMIC STRETCH GOALS FOR PRIORITY LOW EMISSIONS TECHNOLOGIES

- Clean hydrogen under \$2 per kilogram
- Energy storage — electricity from storage for firming under \$100 per MWh (this would enable firming wind and solar at pricing at or below today's average wholesale electricity price)
- Low carbon materials — low emissions steel under \$900 per tonne and low emissions aluminium under \$2,700 per tonne
- CCS — CO<sub>2</sub> compression, hub transport, and storage under \$20 per tonne of CO<sub>2</sub>
- Soil carbon measurement under \$3 per hectare per year

For all priority low emissions technologies, stretch goals have been set with reference to the current costs of today's incumbent technologies.

### Clean hydrogen under \$2 per kilogram

#### *Why is it a priority?*

Hydrogen is a transformative fuel. It 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 energy resources, extensive carbon storage reservoirs, and excellent reputation as a trusted energy exporter – mean we are well positioned to be a world leading hydrogen producer.

Conservative estimates developed for the *National Hydrogen Strategy* indicate a domestic industry could generate over 8,000 jobs and \$11 billion a year in GDP by 2050.<sup>5</sup>

#### *Setting the stretch goal*

Achieving 'H<sub>2</sub> under 2' at the site of production will be a key step in unlocking hydrogen industry growth. At \$2 per kilogram, clean hydrogen becomes competitive in applications such as producing ammonia, as a transport fuel and for firming electricity.

#### *Indicative deployment pathways*

To achieve this stretch goal, industry will need to scale up quickly and cost effectively while reducing input and capital costs.

Clean hydrogen from off-grid gas with CCS, and coal gasification with CCS might be the lowest cost clean production methods in the short-term, although renewable production methods will come down in cost as clean hydrogen demand grows.

Establishing domestic demand for hydrogen will help the industry to scale up and prepare Australia to be a global exporter to emerging international markets. Using clean hydrogen in heavy vehicles, as industrial feedstocks, blended into gas distribution networks, for export as clean ammonia, and for power generation at remote sites, offer early hydrogen growth opportunities. For example, cost-effectively deploying hydrogen in remote mine sites could avoid expensive supply of diesel and reduce associated emissions.

The *National Hydrogen Strategy* sets out the initial actions needed to support this emerging industry. A range of actions can accelerate industry growth, such as encouraging hydrogen hubs, developing international supply chains, ongoing research and investment in both proven and emerging production technologies, and domestic incentives to create hydrogen demand. The Government's new \$1.9 billion investment package in new energy technologies includes new commitments that will support hydrogen, including \$1.6 billion in new funding for ARENA, a \$74.5 million Future Fuels package, and a \$70.2 million to activate regional hydrogen export hubs. This will build on over \$500 million committed towards hydrogen projects by the Government at the launch of the *National Hydrogen Strategy* in 2019.

Establishing hydrogen as a priority technology and working towards this stretch goal will reinforce these commitments and ensure Australia can capture a significant share of the growing global export demand for this technology.



*....technologies to produce hydrogen are attractive because they support multiple sectors and applications, including transport, electricity generation and industrial processes that are difficult to decarbonise, opening opportunities to decarbonise that are not available through renewable electrification alone.*

**Woodside Energy Ltd**

## Energy storage – electricity from storage for firming under \$100 per MWh (enabling firming wind and solar at pricing at or below today's average wholesale electricity price)

### *Why is it a priority?*

Grid-scale electricity storage will be a critical element of Australia's future electricity system. Broad deployment of storage will facilitate more low-cost solar and wind electricity in the grid. Storage will also provide system security services and be a source of reliable, dispatchable electricity. It can reduce pressure on electricity prices by meeting peaks in consumer demand.

Low-cost backup and storage will enable more solar and wind electricity in the grid and has the potential to reduce Australia's cumulative emissions by over 700 Mt CO<sub>2</sub>-e to 2040.<sup>6</sup>

### *Setting the stretch goal*

This stretch goal is consistent with an average wholesale electricity price under \$70 per MWh and represents the cost at which low emissions electricity, available on demand for eight hours or more, will be competitive with conventional mid-merit gas generation in the National Electricity Market (NEM).<sup>7</sup> The market contracts firming services by way of capacity contracts. The stretch goal represents the capacity cost plus the short run marginal cost of mid-merit generation.

### *Indicative deployment pathways*

A mix of storage options will be needed to meet the needs of Australia's electricity system. Initially, the lowest cost storage option will likely be pumped hydro. Batteries and solar thermal energy storage (charged by solar thermal generation) will become increasingly cost competitive, and will be suitable in places where pumped hydro is unavailable or where other characteristics are valuable, such as the ability to provide frequency control or heat for industry. These are emerging technologies and there is scope for costs to fall as experience with them grows and global supply chains mature.

Governments and industry can pursue a range of actions to bring down technology costs, including ongoing investment in research and demonstration projects, de-risking projects through offtake agreements, deepening international supply chains for critical battery minerals, and electricity market reforms to recognise and value the strengths of emerging storage technologies.

The Australian Government has already invested over \$270 million in innovative energy storage projects since 2014-15.<sup>8</sup> In 2019, it committed \$25 million over six years for the Future Battery Industries CRC. The development of new battery mineral reserves is also being encouraged through the 2019 *Critical Minerals Strategy*.<sup>9</sup> Prioritising energy storage and working towards this stretch goal will further accelerate the development of this critical technology and its deployment in Australia's electricity system.



*As one of the world's largest per capita installed solar countries in the world, the impact from solar is limited without the addition of energy storage technologies, such as batteries, to support it.*

**Australian Battery Society**

### Low carbon materials – low emissions steel under \$900 per tonne and low emissions aluminium under \$2,700 per tonne

#### *Why is this a priority?*

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.

Low emissions steel and aluminium could reduce Australia's cumulative emissions by around 200 Mt CO<sub>2</sub>-e to 2040, while increasing economic activity and generating many thousands of new jobs in the long-term. If Australian low emissions steel and aluminium exports can meet a greater share of projected global demand for these metals, we could help to reduce international emissions cumulatively by over 500 Mt CO<sub>2</sub>-e over the period to 2040.

#### *Setting the stretch goal*

In the long-term, achieving stretch goals of \$900 per tonne for low emissions steel and \$2,700 per tonne for low emissions aluminium would retain cost-competitiveness with existing steel and aluminium production. These stretch goals are based on the three year average market price for steel and aluminium.<sup>10</sup>

The stretch goals would cover emissions associated with steel and aluminium production, including direct process emissions and supplied electricity emissions. While emerging technologies to reduce upstream emissions from iron ore mining and alumina production are not included in the stretch goal, the Government will continue to monitor global learnings, research and investment trends.

### *Indicative deployment pathways*

One possible pathway for low emissions steel is likely to be 'greenfield' developments involving direct reduction of iron (initially using natural gas and then clean hydrogen) and electric arc furnaces using low-cost renewable electricity. Direct reduced iron using natural gas may be commercially viable in Australia by 2030, with hydrogen steel-making available by 2040. Partially reducing emissions by optimising blast furnaces with hydrogen is also being explored internationally.

For low emissions aluminium, increasing supply of low-cost firm renewable electricity, more efficient smelter technology, and inert anodes that do not produce emissions will reduce direct emissions. There may also be ways to reduce the emissions in the supply chains (e.g. alumina production for aluminium).

Governments and businesses will need to work together to unlock and integrate new technologies while maintaining and expanding existing industries. Alongside ongoing research, development and demonstration investments, and building international partnerships, technology deployment will be accelerated where the regulatory environment recognises and rewards broader co-benefits. Electricity market reforms, such as pricing demand response to improve grid reliability and reduce costs for all users, will reward aluminium smelters for the services they provide and may enable the adoption of new production technologies.



*Efficient deployment of technological changes will support the transition of economically important industrial sectors such as alumina and aluminium, enabling a greater manufacturing sector.*

**Australian Aluminium Council**

## CCS – CO<sub>2</sub> compression, hub transport, and storage under \$20 per tonne of CO<sub>2</sub>

### *Why is this a priority?*

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. CCS currently offers strong potential where a facility produces a pure and high pressure CO<sub>2</sub> stream, as this negates the need for capture technology. Such processes include oil and gas extraction, natural gas processing, and coal gasification or methane reforming for hydrogen production.

Australia has a comparative advantage in CO<sub>2</sub> transport and storage, with a number of sources of CO<sub>2</sub> located close to suitable geological storage basins and with established pipeline easements between the two. Australian CCS projects could also play an important long-term role in storing CO<sub>2</sub> drawn down from the atmosphere, likely to be crucial in global efforts to meet the Paris Agreement's temperature goals (**Box 3**).

### *Setting the stretch goal*

Achieving a stretch goal of under \$20 per tonne for CO<sub>2</sub> compression, hub transport (in the vicinity of 100 km) and storage would position CCS to be competitive over the long term with other forms of abatement supported by the Emissions Reduction Fund.

The stretch goal covers CO<sub>2</sub> compression, hub transport and storage, but does not cover capture processes, noting the cost of capture technologies varies between applications and depends on factors such as the relative concentration of CO<sub>2</sub> produced by an industrial process.



### *Indicative deployment pathways*

Collaboration and partnerships between governments, industries and communities will be necessary to enable large-scale CCS development and deployment in Australia. Governments play a role through investments in research, development and demonstration and by providing targeted incentives for technology adoption. CCS hubs and shared pipeline and storage infrastructure could provide pathways to scale and lower costs, and enable emissions to be safely stored from a range of sources including hydrogen production, power generation, gas and oil production, and hard-to-abate industrial processes.

The Australian Government has begun work on a new method for CCS to incentivise adoption through the Emissions Reduction Fund. Recommendations of the King Review, such as below-baseline crediting under the Safeguard Mechanism and a technology neutral remit for ARENA and the CEFC, will also encourage technology development and adoption in industry.<sup>11</sup> Establishing CCS as a priority technology and working towards this stretch goal will build on and reinforce these commitments, and accelerate the development of this critical technology as a potential decarbonisation pathway for key industries.

### BOX 3: ROLE OF NEGATIVE EMISSIONS TECHNOLOGIES, INCLUDING CCS, IN ACHIEVING THE PARIS AGREEMENT'S GLOBAL GOALS

As outlined in the King Review, global institutions such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) have concluded the Paris goals cannot be achieved without carbon sequestration deployed at scale. Over 90% of the IPCC's scenarios consistent with a 66% chance of avoiding a 2°C temperature rise rely on negative emissions technologies, including bioenergy coupled with carbon capture and storage (BECCS) and afforestation and reforestation. All scenarios consistent with a 50% chance of keeping temperatures within 1.5°C require negative emissions in addition to deep emission reductions.



*CCS is a critical factor in de-carbonising industry and in the development and scale-up of the hydrogen industry.*

**Hydrogen Energy Supply Chain Project Partners**

## Soil carbon measurement under \$3 per hectare per year

### *Why is this a priority?*

Australia has untapped potential as a globally significant source of carbon sequestration in our soils. Improving land management practices on a quarter of Australia's crop and grazing lands could draw between 35 and 90 million tonnes of CO<sub>2</sub> per annum from the atmosphere while improving agricultural productivity and soil resilience.<sup>12</sup> Offsets created by soil carbon projects can provide a valuable additional revenue stream for farmers, and provide decarbonisation pathways for new and existing industries, which will preserve jobs.

Increasing the soil carbon concentration (in the form of organic material) can improve farm productivity and crop yields through better nutrient and water retention, and boost resilience to drought and erosion. Realising the sequestration potential of Australia's soils would deliver positive economic outcomes and exploit a powerful competitive advantage for our nation, and help position our agriculture sector to meet its aspiration to exceed \$100 billion in farm-gate output by 2030.<sup>13</sup> However, the current cost of accurately measuring changes in soil carbon is a barrier to widespread adoption of practices that would unlock soil carbon sequestration on a broad scale.

### Setting the stretch goal

Industry experts confirm that achieving a stretch goal for soil carbon measurement of under \$3 per hectare per year would transform the economics of soil carbon projects for Australian farmers. It would remove measurement as a barrier to participation in Emissions Reduction Fund soil carbon projects, and enable farmers to be credited for the emissions reductions these projects would achieve.

Currently, soil carbon measurement for Emissions Reduction Fund projects cost around \$30 per hectare per year.<sup>14</sup>



*With the seventh largest land mass globally, approximately half of which is agricultural lands, Australia's ability to sequester carbon through land-based projects is a clear competitive advantage.*

**Climate Friendly**



*Rural and regional communities are well positioned to play a key role in our energy future. Low emissions technologies provide opportunity for growth in jobs and income in regions.*

**Ag Energy Taskforce**

### Indicative deployment pathways

Options proposed by industry and researchers involve the expanded use of remote and proximal sensing technologies, improved national soil carbon datasets and the development of the next generation of soil carbon computer models.

If successfully developed and deployed, these measurement approaches would enable farmers and other landholders to reduce the number of direct physical measurements needed to understand soil carbon changes, while maintaining accuracy.

The Government will explore opportunities to partner with industry and researchers to improve soil carbon measurement. Based on this early work, a **competitive challenge-based** approach, where industry and researchers put forward proposals for meeting the stretch goal, is likely to be the best approach to revealing an effective development pathway.

This will complement the actions the Government is already taking to encourage and incentivise soil carbon projects. Incentives for soil carbon are available through the Emissions Reduction Fund, and the Government is progressing reforms recommended by the King Review to encourage greater participation. The CEFC is investing in the agricultural technology sector to build the industry's capabilities. Through the *National Soil Strategy*, the Government is exploring how it can help farmers to make better decisions about soil health and identify the productivity benefits of replenishing soil carbon on their properties.

## Emerging and enabling technologies

Many other technologies have a strong transformative potential and are likely to play an important role in Australia's transition to lower emissions (**Table 1**). This includes helping to realise the potential and intended impact of priority low emissions technologies.

Many of these technologies are already the focus of existing policies and institutions. For example, delivery of the *National Hydrogen Strategy* will support development of hydrogen refuelling, low emissions ammonia, low emissions building and industrial heating, and hydrogen enabled appliances.

The Government will continue to monitor global learning rates, research, and investment trends for these technologies. ARENA and the CEFC will continue to work with these technologies consistent with their legislative mandates and their efforts to achieve stretch goals for priority low emissions technologies. The Government welcomes stakeholder engagement on these technologies prior to the second *Low Emissions Technology Statement* in late 2021, particularly to aid consideration of whether any emerging and enabling technologies should be elevated to become priority low emissions technologies.

**Table 1: Emerging technologies**

Technology Group	Description
Vehicle charging and refuelling infrastructure	Technologies that enable the rapid, convenient and widespread refuelling of battery-electric and hydrogen-electric vehicles
Generation enablers	Technologies that support the grid to integrate more renewable generation (e.g. virtual power plants, vehicle to grid, micro grids, and synthetic inertia)
Innovative generation	Hybrid systems for off-grid or fringe-of-grid uses in agriculture or mining, solar thermal for use in manufacturing and mining
Energy efficiency	Providing the same service with less energy
Next generation solar PV	Higher efficiency solar PV, enabling the same power to be delivered at substantially lower deployment cost
Abatement of fugitive methane	Capturing the emissions being ventilated from underground coal mines
Low emissions heat	Methods of producing heat with low emissions such as solar thermal, heat pumps and hybrid systems in mining and manufacturing
Demand response	Moving the demand for electricity to times when low cost and low emissions supply is plentiful, without impacting on the service the energy provides
Carbon capture and use	Using CO <sub>2</sub> emissions to produce products such as methanol
Low carbon materials	Products that are produced with fewer emissions compared to an alternative product
Waste-to-energy and recycling	Reducing landfill by recycling and using waste to generate electricity
Low emissions ammonia	Made from clean hydrogen and renewable electricity powered processing plants, is expected to be a vector for hydrogen exports
Low emissions cement	Cement that uses alternatives to limestone or carbon capture and storage to reduce emissions from the cement process
Livestock feed technologies	Forage feeds and feed supplements that reduce methane from cows and sheep
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

## Enabling technologies and markets

Achieving large-scale deployment of the priority and emerging technologies will require a range of enabling technologies and activities. These technologies include:

- smart meters, smart appliances, energy management systems and better sensors that allow consumers to make wiser choices about how they use energy and other carbon-intensive products
- inverters, power conversion and demand management systems that allow every device that is connected to the electricity system to operate efficiently as part of an integrated system
- HVDC, micro grids and standalone power systems (SAPS) that allow the long distance transmission of renewable energy and provide remote and regional industries and communities with reliable, competitively priced energy.

Other enablers include electricity market design (e.g. to incentivise demand response technologies), skills development, digitalisation, process integration, monitoring and evaluation, and infrastructure planning. Many of these enablers cut across all of the priority low emissions technologies.

The Government has also recently introduced amendments to the *Clean Energy Finance Corporation Act 2012* to establish a \$1 billion *Grid Reliability Fund*, to firm and enable continued world-leading investment in renewable energy without compromising energy affordability or reliability. This additional funding will enable investment in energy storage projects (such as pumped hydro and batteries), electricity generation, transmission and distribution, and grid stabilising technologies.

## Efficiency

Energy efficiency is a crucial element of the enabling environment. It is not a single technology but a characteristic of every technology and process. Through their technology investments, governments can help de-risk and bring down the upfront costs of new and emerging energy efficient technologies, so consumers can capture the ongoing savings they offer. These technology investments sit alongside broader enabling policies (such as minimum standards, building codes and consumer information and benchmarking), helping to overcome specific barriers to energy efficiency.

Improvements in energy efficiency are an important element of increasing productivity, particularly in industry. However, increasing productivity and competitiveness can increase output and total energy use – reinforcing the need to unlock new technologies that directly reduce emissions, as well as those that improve efficiency.



*Australia has an opportunity to develop these new products and services such as peer-to-peer trading platforms, community energy platforms, energy management, smart inverters (particularly retro-fitting smart meters to unsmart older inverters), provision of services, metering and network visibility. Australia is an ideal test bed for these new approaches given its world-leading deployment of distributed energy resources.*

**Energy Networks Australia**



*Energy management and digitization are crucial to achieving a low carbon economy. Digital technologies are set to make energy systems around the world more connected, intelligent, efficient, reliable and sustainable.*

**Schneider Electric Australia**

## Watching brief technologies

Through consultation with industry and researchers, and technical work for this Statement, a range of prospective low emissions technologies and enablers were identified that could play an important role over the long-term. Generally, these technologies are at a very early stage of development.

This category also includes technologies where Australia will more likely be the recipient of technological advances and lower costs driven by overseas developments. Many technologies in the transport sector fall into this group, including battery, hybrid and plug-in hybrid electric vehicles and more efficient internal combustion engine vehicles.

Examples of technologies in the watching brief are outlined in **Table 2**. The Government will continue to monitor international developments and ensure Australian households and businesses are able to exercise consumer choice and adopt the latest technologies, where it makes sense for them to do so.

**Table 2: Watching brief technologies**

Sectors	Examples
Electricity	Small modular reactors (SMRs), ultra-low-cost transmission, next generation Allam Cycle generation technologies
Transport	More efficiency and zero emissions drivetrains, mode shift technologies, and low emissions aircraft
Buildings	Low carbon building materials, building integrated PV (e.g. solar PV tiles), and new refrigerants
Other sectors	Range of early-stage negative emissions technologies (e.g. direct air capture)



# The Roadmap's Technology Investment Framework

The Roadmap will bring a sharp focus to the Government's investments in priority low emissions technologies. Clear principles will guide our approach to investments and encourage partnerships with industry, researchers and the community that play to our strengths and adapt to changing circumstances.



*Low-emissions technologies will be deployed when they are cost-competitive with existing technologies. The role for governments in technology deployment should be to address market failures and remove barriers such as outdated regulations.*

**Grattan Institute**

## GUIDING PRINCIPLES FOR GOVERNMENT SUPPORT OF LOW EMISSIONS TECHNOLOGY

### A Technology-led approach

A **technology-led approach** lowers the cost of new and emerging low emissions technologies to achieve economic competitiveness with existing business methods.

The ultimate goal is the substitution of existing higher emission technologies and practices with cleaner, more efficient and lower cost technologies.

Ultimately, the Roadmap will help new and emerging technologies become the rational choice of economic actors. The Roadmap prioritises technologies that have potential to out-compete existing alternatives (not just reach cost parity) in the short, medium and long-term.

The Government sees enhanced economic outcomes in expanding rather than limiting the choices of consumers and businesses. Our approach is to reduce the cost of new and emerging technologies rather than raising the cost of existing processes or technologies, or adding to the costs consumers and businesses face. The Government will respect consumer choice and trust households and businesses to adopt new technologies as they approach parity. The Government will not seek to regulate these outcomes through mandated deployment targets or taxation mechanisms.

A technology-led approach delivers the lowest cost abatement and the best economic outcomes. **Technology neutrality** is fundamental to this approach.

This means that all available technologies need to be on the table for Australia to achieve global climate goals. Investments are prioritised through a transparent and system-wide process that does not exclude any technologies at the outset.

Some crucially important low emissions technologies, including some of the priorities identified in this Statement, such as CCS, may add to costs compared to incumbent technologies. These technologies may need targeted government support, incentives (such as through the Emissions Reduction Fund) and increased market demand for low emissions products to achieve deployment at scale.

The Government has a role in creating the right **enabling environment, including critical enabling technologies and infrastructure**, to achieve large-scale deployment of priority low emissions technologies.

### Play to our strengths

Investments should focus where Australia has a defined **comparative advantage or research edge**, building on our reputation as a reliable supplier of energy, food, fibre, and materials to global markets.

Investing in **skills and capabilities**, and leveraging the knowledge and experience of our existing industries and institutions, will prepare Australia's communities and businesses for a dynamic future.

We will build on **existing institutions**, rather than starting from scratch. **ARENA**, the **CEFC** and the **CER** will remain the key delivery agencies for the Roadmap. Through these institutions, Government support for technologies will extend across the full cycle from early and applied research and development, through to commercialisation, deployment and diffusion.

**CSIRO**, **CRCs** and **Australia's universities** will continue to pursue low emissions technology breakthroughs and the Roadmap will provide a clear signal for their investments.

### Partner with the private sector

The **private sector drives technology deployment** and the Government's role is to remove roadblocks, enable consumer choice and support the emergence of the **best enabling environment**. Government should invite the private sector to bring forward solutions to solve our technology challenges.

Government should never **crowd out** private investment, and deployment of commercially mature technologies should be left to the private sector. Ergo, agencies' focus will need to evolve over time. Incentives should be designed to help de-risk priority low emissions technologies that add costs to existing processes (such as CCS).

## GUIDING PRINCIPLES FOR GOVERNMENT SUPPORT OF LOW EMISSIONS TECHNOLOGY (CONTINUED)

In these cases, the Government will support voluntary emissions reductions, including through the Emissions Reduction Fund.

**Demand can be catalysed** through activities such as offtake agreements, procurement of certain technologies, and incentivising uptake of priority low emissions technologies through ARENA, CEFC and CER funding.

**Investor confidence** will be strengthened by clear policy directions, regulatory certainty, an enduring investment framework, and institutional continuity. These factors support revenue certainty for businesses and will help attract investment in priority low emissions technologies at the scale necessary to meet the economic stretch goals.

The Government will work with our international partners to **support access to global markets** for Australian low emissions businesses. Open trade and investment settings provide pathways for technology deployment in Australia and globally, helping make low emissions technologies commercial.

Strategic direction can be provided by the **Technology Investment Advisory Council** comprising industry, private investment, government, and research leaders.

### Adaptive pathways

The global technology and energy landscapes are changing rapidly. Annual Statements like this one will help to position Australia as a leading nation at the cutting edge of innovation.

The Roadmap is a comprehensive and enduring investment framework. It is an **analytical, transparent and system-wide** approach to targeting the Government's technology investments and actions.

Coordinated **impact evaluation** will measure the impact of investments, identify underperformance and enable the Government to fine tune its investment portfolio over time.



*Australian research has underpinned the world's development of silicon PV and is driving next-generation tandem silicon improvements helping further reduce energy costs.*

**ANU Research School of Electrical, Energy and Materials Engineering**



## Investment and incentives

Additional funding has been provided so **ARENA** can remain on the frontline of direct government investment in low emissions technologies.

In line with a recommendation of the King Review (**Box 4**), the Government will task ARENA to work with the CEFC and other relevant agencies to develop a **goal-oriented program** targeting a number of the priority low emissions technologies such as low emissions steel, low emissions aluminium, or energy storage. Industry and state governments will be consulted to co-design the programs, and to determine interest in co-funding.

Low emissions steel and aluminium are suitable targets for co-investment programs as they are hard-to-abate sectors with long-term, strategic funding required. Initial funding will focus on the first stages (e.g. research and development, feasibility and demonstration) required as part of a longer term program. Energy storage technologies would also be suitable targets, focussing more on later stage development (demonstration and commercialisation).

### BOX 4: THE KING REVIEW

The Expert Panel, chaired by Grant King, was tasked with examining options for unlocking additional abatement across the economy, with a particular focus on hard-to-abate sectors including industry, transport and agriculture, and energy efficiency.

The King Review was released in early 2020. In its response, the Government indicated it would progress two key recommendations through the *Technology Investment Roadmap* process:

- Establish a goal-oriented technology co-investment program to accelerate the uptake of transformative, high abatement potential technologies that are not currently cost competitive (*recommendation 10.1*).
- Provide ARENA and the CEFC with an expanded, technology neutral remit so they can support key low emissions technologies across all sectors and be involved in the delivery of the goal-oriented co-investment program (*recommendation 10.2*).

The Government will invite expressions of interest from industry and state government to establish a **regional hydrogen export hub**. This will be a region in Australia where clean hydrogen users and exporters are co-located, creating efficiencies in supply and focal points for innovation and skills development.

Government funding for this hub will help to provide the clean hydrogen demand to complement ARENA's current support for clean hydrogen supply technologies. It will complement the finance for hubs currently available from the CEFC. It will also help to attract international investment and build global hydrogen supply chain linkages.

In addition to hub support, funding will also be provided to support hydrogen related studies and international research collaborations. These will help to reduce costs, enable rapid industry scale-up and build international supply chains.

The Government will make **\$50 million available to scale CCS** research and development projects into commercial operations, supporting emissions reductions in power generation, oil and gas extraction, natural gas processing, and coal gasification or methane reforming for hydrogen production and other activities.

The Government has introduced legislation to establish the **CEFC's Grid Reliability Fund**, to unlock private sector investment for projects that provide reliable, low-cost, and low emissions energy. The Grid Reliability Fund will enable the CEFC to invest in additional low emissions energy storage and generation technologies, as well as supporting transmission and distribution infrastructure, and grid stabilising technologies

The Government has agreed key recommendations of the King Review and will establish a **King Review Technology Co-Investment Fund** to address barriers to industry uptake of energy efficiency and create the enabling environment for low emissions technology investments by the private sector.

This Statement's technology priorities – particularly CCS and soil carbon – will also be supported by the **ERF**, administered by the CER.

Lastly, the Government is exploring the opportunities for Government investment to ensure the increased uptake of new vehicle technologies is planned and managed, through its **Future Fuels Strategy**. The Strategy will look to enable all technology choices, including hybrid vehicles, fuel cell electric vehicles and battery electric vehicles so Australians can choose to adopt new new vehicle technologies, where it makes sense for them to do so.

The future of transport in Australia will draw on a range of vehicle and fuel technologies. New vehicles that use electricity or hydrogen as a fuel represent discontinuous innovation (that is, technologies that require end users to change behaviour and change the dynamics of an industry as a result) for our transport system, requiring new infrastructure and integration with the existing electricity grid. While the early stage of deployment means there are currently barriers to the large-scale take up of these vehicles, there are also domestic opportunities to be explored, including the development and widespread rollout of rapid, convenient refuelling and charging solutions. Charging and refuelling technologies have been identified as important emerging and enabling technologies, and these will be considered as part of future *Low Emissions Technology Statements*. The **Future Fuels Strategy** will focus on practical actions to allow the private sector to commercially deploy these technologies.

## A broader toolkit for more effective investments

### Additional flexibility for ARENA and the CEFC

ARENA and the CEFC have a proven record of driving down costs of new and emerging low emissions technologies. The Government is exploring ways to give these agencies a broader range of tools to de-risk investments and accelerate commercial uptake of priority low emissions technologies.

In line with the King Review, the Government intends to **expand the remit of ARENA and the CEFC so they are able to support a broader range of technologies that reduce emissions across all sectors of the economy**. It is intended that both agencies can support energy efficiency technologies, low emissions technologies (including in the agriculture and land sectors) and renewable energy technologies. This will give those agencies the flexibility to align their investments with Statement priorities, noting they will continue to make their own investment decisions independently of government. Meeting our long-term emissions reduction goals requires new technologies to be adopted across the economy, so this will expand the toolkit available to the Government to unlock critical technologies in all sectors.

ARENA will also be encouraged to run challenge-based funding rounds to unlock technological and commercial barriers to realising priority challenges and opportunities.

### Regulatory barriers

Targeted regulatory actions can streamline the flow of private sector capital. This includes, for example, the Government's recent commitment to deliver a regulatory pathway for offshore clean energy projects, including transmission and wind energy. The Government will work with states and territories, industry and the broader community to remove regulatory barriers and identify targeted policy adjustments.

### Translating early-stage research to business opportunities

An ongoing priority area for the Government will be supporting the investment environment for early-stage research and development, particularly with respect to translating Australian research into new business opportunities. While Australia is strong in knowledge creation, we underperform in knowledge translation and research commercialisation. A relatively low proportion of Australian businesses introduce product or process innovations that arise from research and development activities.<sup>15</sup>

In addition to ARENA and the CEFC, a number of existing broad-based programs, such as the CSIRO Innovation Fund, the Early Stage Venture Capital Limited Partnerships, and the Tax Incentives for Early Stage Investors, are designed to address these issues by encouraging investment in innovative companies developing and commercialising new technologies.

## BOX 5: LEARNING FROM AUSTRALIA'S CONTRIBUTION TO SOLAR PV'S GLOBAL SUCCESS

Solar PV is the world's third-largest renewable electricity technology (after hydroelectricity and wind), and will be an increasingly important technology for lowering emissions.

Australian innovation is at the heart of solar PV's global success. Since the 1980s, solar researchers at the University of NSW have frequently broken world energy conversion efficiency records for solar PV. By some industry estimates, PV technology developed by the university is now used in almost 80% of today's global solar PV manufacturing.

There are lessons to learn – in both successes and failures – from solar PV's path to maturity if we want to bring technology's benefits to Australia.

First, the global demand for products is key to their ability to move down the cost curve. The Australian market, while important, is too small on its own to drive these results. A number of countries, notably Germany, used mandates to drive solar technology into their markets. Mandates for technology uptake in Australia are unlikely to make a material difference to cost reductions and are not consistent with the principle of driving down costs rather than imposing burdens on consumers. Increasing global demand is a key factor to consider when looking for technologies that we could support through a comparative advantage.

Second, while Australian universities have played an important role in developing solar PV, Australia has not reaped the full rewards that might have come from being more strategic in translating early stage research into commercial opportunities.

The *Low Emissions Technology Statement* is an opportunity to think strategically about how we can develop technologies to maximise advantages for Australia.

## Long-term investments in skills

Developing a workforce with the right skills and expertise is crucial to capturing the opportunities associated with low emissions technologies and global markets. Highly skilled workers will be needed to create, develop and implement technological solutions so Australia can realise its comparative advantages. New and expanded existing industries will need a workforce with general capabilities (e.g. communication, problem solving and digital literacy) along with discipline-specific skills in fields like construction, physical sciences, engineering, project management and data analytics.

The Government's \$585 million Skills Package – *Delivering skills for today and tomorrow* – is helping train highly skilled and qualified workers, including in regional areas, to meet the needs of businesses. As part of this package, the National Skills Commission has been established to oversee the Government's investment in vocational education and training, and drive research and analysis of future skills needs across industry.

## Trade and Investment

Most priority low emissions technologies depend on global supply chains to achieve scale. Targeted international collaboration to remove the trade and investment barriers facing those technologies, and achieve greater harmonisation of standards and certification, will help to accelerate the deployment of these technologies.



## Better information for investors regarding Australia's technology capabilities

The Government is developing a *Technology Investment Roadmap* data portal. The portal will encourage investment in low emissions technologies in Australia, providing high quality geospatial analysis tools and data for understanding Australia's low emissions technology potential. Focusing on the priority technology stretch goals, the online tool will use key national-scale datasets, such as locations of existing infrastructure, energy, and critical mineral resources, to support investment decisions.

“ *Maintaining and expanding the technical skill capability of our institutions and workforce must be a priority.*

Incitec Pivot

## Institutions and governance

Existing institutions, particularly ARENA, the CEFC and the CER, will play crucial roles in implementing the Technology Investment Framework.

The Minister for Energy and Emissions Reduction will issue new investment mandates for the CEFC and new statements of expectations for ARENA in line with annual *Low Emissions Technology Statements* to align their investment activities with Australia's technology priorities and stretch goals. The CER will continue to administer the ERF auction mechanism, supporting carbon offset projects and incentivising voluntary emissions reduction on a broad scale through uptake of commercially deployable technologies.

The Ministerial Reference Panel will be converted into an enduring institution – the Technology Investment Advisory Council – to advise the Minister on Australia's *Low Emissions Technology Statements*. The Chairs of ARENA, the CEFC and the CER will join the Council as *ex officio* members.

The *Technology Investment Roadmap* will be delivered in partnership with industry and the broader research community, including CSIRO, CRCs and Australia's universities. The Roadmap will help provide a signal to these institutions regarding national priorities. CSIRO recently announced it is working with governments, universities, industry and the community on a new \$100 million per year 'missions' program to bolster Australia's COVID-19 recovery and build long-term national resilience.

Among other things, CSIRO is working towards missions closely aligned with Australia's priority low emissions technologies, including:

- supporting the development of Australia's hydrogen industry to generate a new clean energy export industry
- supporting new industries to transform raw mineral commodities into higher-value products like critical energy metals, thereby building Australia's value-added product offerings, jobs and sovereign supply
- using technologies, such as CCS, systems modelling and grid integration technologies, to enable the transition of key industries to net zero emissions, without weakening our economy.

# Monitoring, transparency and impact evaluation

*Each Low Emissions Technology Statement will be an annual ministerial statement to Parliament.*

The Australian Government has been a significant investor in a wide range of low emissions technologies, having invested over \$10 billion on research, development, demonstration and commercialisation since 2014-15 (**Figure 5**). The biggest investments have been in solar (over \$3 billion), energy efficiency (almost \$3 billion) and wind (over \$1 billion). The bulk of this investment (more than 85%) has been aimed at commercialisation, mostly through finance from the CEFC. Around 5% has been invested in demonstration projects and around 9% has been invested in public research and development.<sup>16</sup>

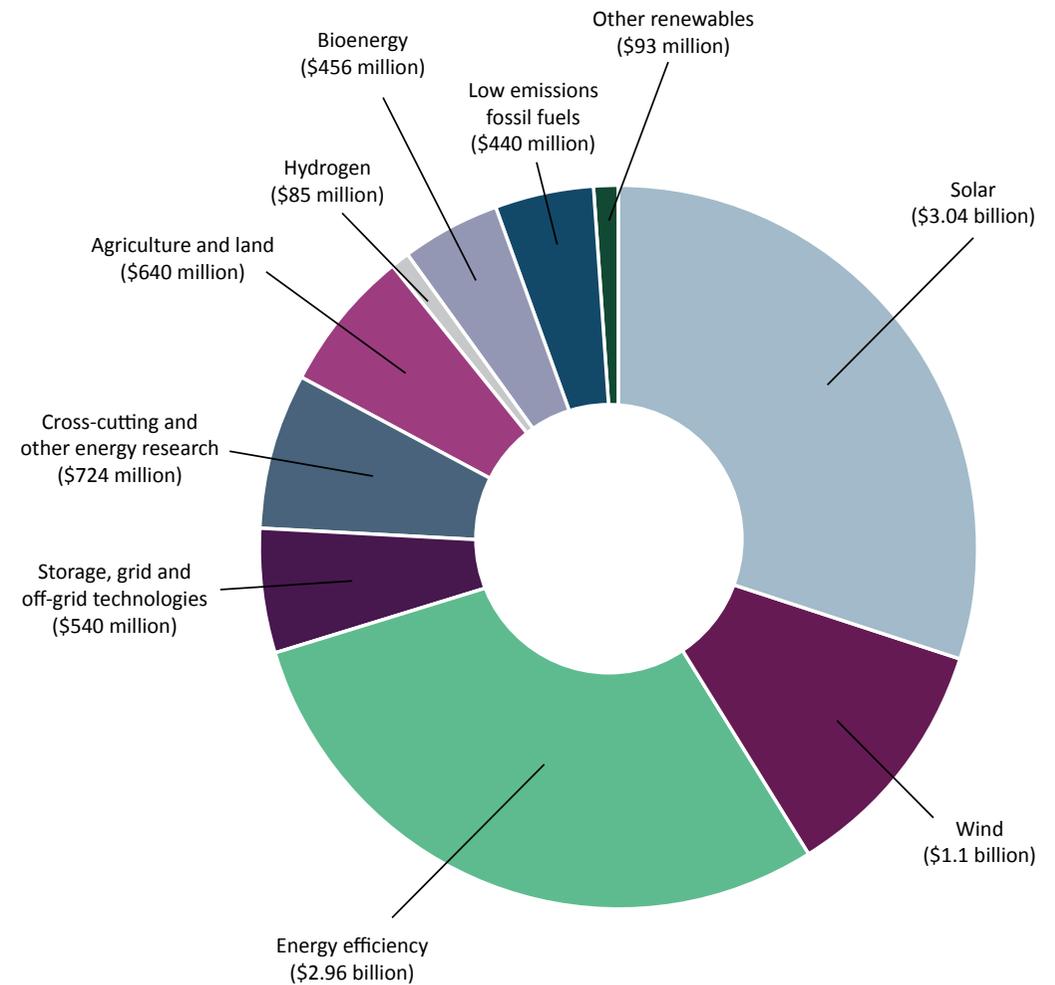
Looking ahead, all investments will be tracked against our overarching objectives and the impacts we aim to see. A key indicator will be the level of private sector investment in a particular technology. The Government will seek to leverage between \$3 and \$5 in new co-investment for every dollar it invests, on average, in low emissions technologies. Where public investment is not being multiplied by private sector spending, the Government will consider, through further Statements, the need to reprioritise that technology.

The Government expects to invest over \$18 billion in low emissions technologies over the decade to 2030. By leveraging additional co-investment the private sector and other levels of government, Australia could secure between \$50 and \$100 billion in total investment in low emissions technologies over the decade.<sup>17</sup>

The Minister for Energy and Emissions Reduction will meet regularly with the Chairs of the implementation agencies – ARENA, the CEFC and the CER – and those agencies will report quarterly to the Minister on Roadmap implementation and actions they are taking to support the stretch goals. The agencies’ annual reports will specifically report on Roadmap priorities.

Rigorous impact evaluation will be central to the Roadmap framework. An ongoing responsibility for the Department of Industry, Science, Energy and Resources will be to undertake this impact evaluation to support the Minister and the Council. This will require specific, measurable, achievable, relevant and time-bound (SMART) indicators to assess progress. A key focus of the second *Low Emissions Technology Statement* in 2021 will be establishing a robust approach to impact evaluation.

**Figure 5: Public spending on low emissions technology research, development, demonstration and commercialisation (2014–15 to 2019–20), by technology**



# Abbreviations and acronyms

Acronym	
AEMO	Australian Energy Market Operator
ARC	Australian Research Council
ARENA	Australian Renewable Energy Agency
CCS	Carbon Capture and Storage
CEFC	Clean Energy Finance Corporation
CER	Clean Energy Regulator
CO <sub>2</sub>	Carbon dioxide
CRCs	Co-operative Research Centres
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ERF	Emissions Reduction Fund
MWh	Megawatt hours

## Conventions:

All dollar amounts presented in this Statement are in Australian dollars, unless specified otherwise.

## Endnotes

1. Department of Industry, Science, Energy and Resources 2020, *Australia's Technology Investment Roadmap: Discussion Paper*, at: <https://consult.industry.gov.au/climate-change/technology-investment-roadmap/>
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5. COAG Energy Council 2020, *National Hydrogen Strategy*, at: <https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy>
6. Estimate by the Department of Industry, Science, Energy and Resources that includes over 200 Mt arising from renewable electricity dispatched from energy storage technologies to offset electricity generated by higher emitting sources, and around 500 Mt arising from energy storage technologies providing system security services that enable a greater penetration of variable renewable energy in the grid.
7. AEMO's 2019 *Wholesale Electricity Market: Electricity Statement of Opportunities* (page 18) defines 'mid-merit capacity' as Scheduled Generators that operate between 10% and 70% of the time.
8. The estimate of government investment in energy storage technologies includes non-transport energy storage technologies, such as batteries and pumped hydro, but does not include hydrogen or fuel cells.
9. Department of Industry, Science Energy and Resources 2019, *Critical Minerals Strategy*, at: <https://www.industry.gov.au/data-and-publications/australias-critical-minerals-strategy>
10. Steel (hot rolled coil) 3 year average price for 2017-2019 is estimated at \$878 per tonne derived using London Metal Exchange settlement prices and Bloomberg's Hot Rolled Coil Steel Index (HRCITOTL). The London Metal Exchange aluminium spot price three year average for 2017-2019 is \$2,599 per tonne. Currency conversion used RBA exchange rate data.

11. Department of Industry, Science, Energy and Resources 2020, *Final report of the Expert Panel examining additional sources of low cost abatement* (the King Review), at: <https://www.industry.gov.au/data-and-publications/examining-additional-sources-of-low-cost-abatement-expert-panel-report>
12. Based on an average sequestration rates for improved management of cropland and non-improved grazing land across Australia from Sanderman, Jonathan; Farquharson, Ryan; Baldock, Jeff. *Soil carbon sequestration potential: A review for Australian agriculture*. Urrbrae, S.A.: CSIRO; 2010, at: <https://publications.csiro.au/publications/#publication/PIcsiro:EP10121> and agricultural land area data from ABS, 2018, at: <https://www.abs.gov.au/statistics/industry/agriculture/land-management-and-farming-australia/latest-release>.
13. National Farmers Federation 2019, *2030 Roadmap: Australian Agriculture's Plan for a \$100 Billion Industry*, at: [https://nff.org.au/wp-content/uploads/2020/02/NFF\\_Roadmap\\_2030\\_FINAL.pdf](https://nff.org.au/wp-content/uploads/2020/02/NFF_Roadmap_2030_FINAL.pdf)
14. CSIRO estimate based on a land area of 300 hectares. CSIRO estimates current measurement costs would be lower for larger areas.
15. ABS, 2018. Available at: <https://www.abs.gov.au/statistics/industry/agriculture/land-management-and-farming-australia/latest-release> Department of Industry, Innovation and Science 2016, *Australian Innovation System Report 2016*, pp. 48-49, at: <https://www.industry.gov.au/data-and-publications/australian-innovation-system-report/australian-innovation-system-report-2016>
16. Spending described in Figure 5 is based on reporting by key Commonwealth science agencies, and includes research funding from the ARC, public contributions to CRCs, grant funding through ARENA, innovation activities by CSIRO, finance from the CEFC, direct purchasing of carbon abatement through the CER, and investments through the Industry portfolio in CCS.
17. Includes projected spending by ARENA (\$1.4 billion to 2030), the CEFC (\$1.3 billion per year, in line with average historical investment levels), and the CER (\$2.9 billion through the Emissions Reduction Fund and Climate Solutions Fund), as well as CSIRO, CRCs and the ARC (a combined total of around \$1 billion, being an extrapolation of historical investment by those organisations). Actual levels of investment by these agencies could be higher or lower depending on the pace of technology development and broader economic factors.

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