Australian Government

AUSTRALIA'S LONG-TERM EMISSIONS REDUCTION PLAN

A whole-of-economy Plan to achieve net zero emissions by 2050

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Australian Government

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A whole-of-economy Plan to achieve net zero emissions by 2050

FOREWORD

When it comes to reducing emissions, Australia's story so far is one of consistent achievement.

Since 2005, we have reduced emissions by more than 20 per cent – faster than every other major commodity exporting nation – while our economy has grown by 45 per cent.

We have beaten our Kyoto-era targets by 459 million tonnes and expect to beat our 2030 Paris target by up to 343 million tonnes.

Australia is now forecast to achieve a similar or greater reduction in per capita emissions by 2030 than many other major developed economies including Canada, the European Union, Japan and the United States.

The Morrison Government's Long-Term Emissions Reduction Plan sets out the responsible, practical steps we will take over the next 30 years to reduce Australia's emissions to net zero by 2050, while growing our economy and jobs.

Our Plan is built on five key principles, the most important of which is technology not taxes.

Our Plan won't impose new costs on households, businesses or regions. It won't raise the price of energy, or reduce the competitiveness of our industries, which would destroy jobs. Not one job will be lost as a result of the Government's actions or policies under the Plan.

We will respect Australian households and businesses' right to choose rather than enforce mandates on what people can do or buy.

Instead, this is a Plan for prosperity and for our regions to excel. Under our Plan, 62,000 new regional jobs in mining and heavy industry will be created.

Accelerating a portfolio of low emissions technologies to cost competitiveness with existing approaches will have a global impact, supporting industry through the power of technology and economics.

Our Plan will continue the policies and initiatives that we have already put in place and that have proven to be successful, reducing emissions and energy costs at the same time as manufacturing employment has risen.

Our priority technologies, enabled by the Plan, will see Australia reduce its emissions by 85 per cent by 2050. Over time, we are confident that emerging technologies will deliver the remaining abatement necessary to reach net zero without hurting the economy and jobs.

We will remain transparent and accountable for progress, regularly reviewing and refining our Plan.

This is a Plan built on practical action, not empty symbolism. It's a Plan with a uniquely Australian approach, harnessing our strengths to shape our future.

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

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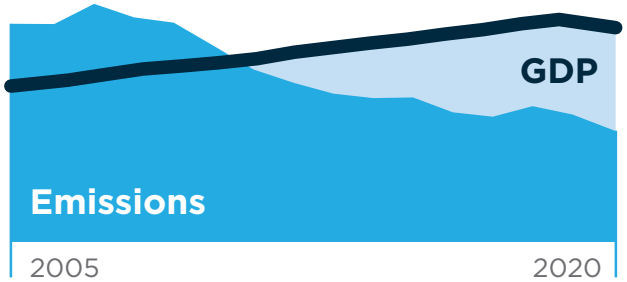
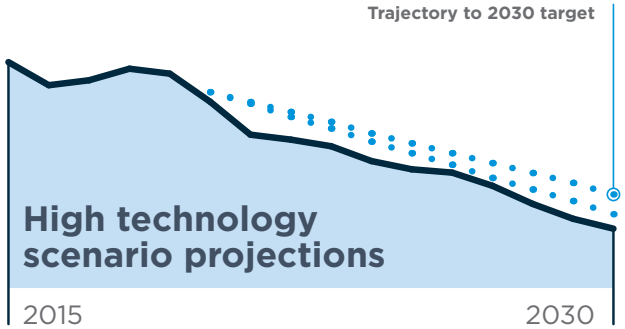
At a glance – Australia's achievements

Australia has reduced emissions and met its 2020 target while keeping the economy strong, and this will continue.

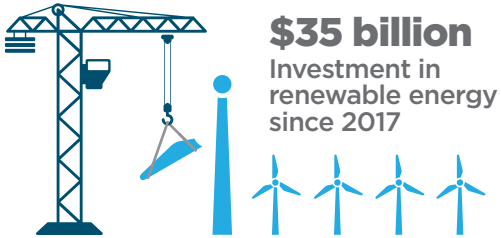
We have reduced emissions by over 20% since 2005, while our economy grew by 45%. Our emissions have fallen 1.6% per year on average since 2010, even as global emissions have increased by 1.4% per year.



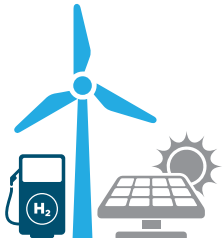
Through technology we are on track to beat our 2030 target



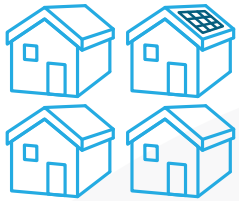
And we have become a leader in low emissions technology.



$35 billion
Investment in renewable energy since 2017



We adopt low emissions tech **8 times faster** than the global average for new renewable energy installations in 2020



Over 1 in 4 Australian homes have solar panels; the world's highest uptake

We are building **three of the world's largest hydrogen electrolysers**

90% of commercial solar cells globally use Australian technology

Snowy 2.0
is the largest energy storage project in the southern hemisphere

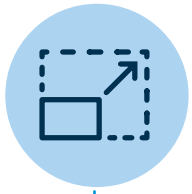
At a glance – Australia's Plan

Driving down technology costs

Unlocking growth of priority technologies by driving down costs:

- Clean hydrogen
- Ultra low-cost solar
- Energy storage
- Low emissions steel and aluminium
- Carbon capture and storage
- Soil carbon

Emerging technologies, such as livestock feed to reduce methane emissions



Enabling deployment at scale

Incentivising businesses to adopt low emissions technologies

Building voluntary carbon markets

Helping consumers with information, knowledge sharing and certification

Building essential infrastructure such as Snowy 2.0, EV charging networks and expanded electricity transmission networks

Planning to ensure the right infrastructure is in place as sectors decarbonise

Aligning efforts with the states and territories through bilateral support agreements and energy market reforms

Seizing opportunities in new and traditional markets

Expanding markets for minerals & metals that will be needed in low emissions economies, such as copper, nickel and lithium

Building a clean hydrogen export industry and shaping global certification standards

Exporting low emissions fuels, including LNG and uranium

Realising opportunities for low emissions manufacturing and clean energy equipment and services

Growing our agricultural sector and communities

Building our workforce by investing in skills and training

Continuing to invest in our regional communities

Fostering global collaboration

Building International partnerships to accelerate innovation and drive investment

Engaging through multilateral technology initiatives

Establishing a high integrity Indo-Pacific Carbon Offset Scheme

AUSTRALIA'S TECHNOLOGY-LED APPROACH

Over $1.4 billion committed to the **Australian Renewable Energy Agency** (ARENA) over the next 10 years, with an additional $75 million allocated to low emissions technologies like EV charging

The **Clean Energy Finance Corporation** (CEFC) is investing $10 billion to catalyse private sector investment in low emissions technology

Investing with our partners overseas, including $565 million for **international low emissions technology partnerships**

$2.5 billion for projects through the **Emissions Reduction Fund** - Australia's carbon offset scheme - and $2 billion for further abatement through the **Climate Solutions Fund**

Over **$1.2 billion** committed to supporting clean hydrogen so far, including up to **7 Clean Hydrogen Industrial Hubs**

Over $300 million for **Carbon Capture Use and Storage** (CCUS) hubs and technologies

$280 million to support industrial facilities to further reduce emissions using the new **Safeguard Crediting Mechanism**

The **Technology Investment Roadmap** will guide more than **$20 billion** of government investment in low emissions technology to 2030

More than **$80 billion** leveraged from government and private sector by 2030 | **160,000 jobs** in low emissions technology by 2030

EXECUTIVE SUMMARY

Australia's whole-of-economy Long-Term Emissions Reduction Plan (the Plan) sets out how Australia will achieve net zero emissions by 2050. The Plan is focused on 'the how', on practical action to convert ambition into achievemment, because a target without a plan is meaningless.

We will achieve net zero emissions by 2050 in a practical, responsible way that will take advantage of new economic opportunities while continuing to serve our traditional export markets. This Plan does not rely on taxes and it will not put industries, regions or jobs at risk. No Australian jobs will be lost as a result of the Commonwealth Government's actions or policies under the Plan.

Our Plan is the right one for Australia. It does not impose new costs on households or businesses. At its core, it recognises that reducing the cost of low emissions technologies is key to unlocking widespread deployment, and that global technology trends will drive demand shifts at home and abroad. It will not raise the price of our energy or reduce the competitiveness of our export industries.

Our Plan will create the enabling environment for investment in Australia, which will ensure regional communities can capture the opportunities of the new energy economy and unlock new sources of growth. It will not shut down coal or gas production or require displacement of productive agricultural land. Australia will remain a trusted commodity producer and a leading energy exporter. We will continue to meet the needs of our customer countries overseas, particularly in our Indo-Pacific region.

Our Plan is the best economic choice for Australia. Our modelling shows it will increase our national income per person by almost $2,000[1] in 2050 compared to a 'no policy change' scenario. By regularly reviewing our Plan, we will allow for future advancements in technology and avoid locking in high costs now. The Plan and its technology investments build on our long commitment to global action on climate change and working with our allies to reduce global emissions.

Our Plan recognises that acting to reduce emissions is in our national interest. If we don't act, decisions by customer countries will impact our traditional exports, costing jobs and exports. Failing to act increases the risk Australian businesses will face a higher cost of capital. By setting out a Plan to achieve net zero emissions by 2050, Australia can build on our existing industries and supply chains and capitalise on new export opportunities, protecting regional industries and the jobs and livelihoods they support.

Australia has a track record we can be proud of. Australia has reduced emissions by 20% between 2005 and 2020, with our emissions per capita falling by 36%.[2] However, our economy (real GDP, chain volume measures) has grown by 45% over the same period, with GDP per capita increasing by 14%.[3] Our latest projections show that under a Technology Investment Roadmap-aligned scenario, Australia will reduce emissions by up to 35% by 2030. Our Plan builds upon this record of success.

Our Plan is based on five key principles, with an enabling role for government. These principles are:

1. **Technology not taxes** – no new costs for households or businesses,
2. **Expand choices, not mandates** – we will work to expand consumer choice, both domestically and with our trading partners,
3. **Drive down the cost of a range of new energy technologies** – bringing a portfolio of technologies to parity is the objective of Australia's Technology Investment Roadmap,
4. **Keep energy prices down with affordable and reliable power** – our Plan will consolidate our advantage in affordable and reliable energy, protecting the competitiveness of our industries and the jobs they support, and
5. **Be accountable for progress** – transparency is essential to converting ambition into achievement. Australia will continue to set ambitious yet achievable whole-of-economy goals, then beat them, consistent with our approach to our Kyoto-era and Paris Agreement targets.

The Government's technology based approach provides Australia with a pathway to net zero by 2050 that protects and strengthens our economy. Achieving the Technology Investment Roadmap economic stretch goals, coupled with global trends like electrifying transport, will put us within range of net zero emissions by 2050, while supporting existing industries, creating new jobs and export opportunities from low emissions technologies, and ensuring the ongoing prosperity of our regions.

Modelling undertaken for our Plan confirms it is the right plan for Australia. We estimate that more than 100,000 new jobs could be created in industries including critical minerals, clean hydrogen, renewable energy, green steel and alumina, many in Australia's regions. Australia's export-oriented sectors are projected to grow significantly in aggregate, with the value of Australian exports more than tripling between 2020 and 2050.

Our Plan takes a practical approach. It responds to global technology shifts, rather than imposing costs through taxes or other measures. It does not penalise traditional industries and does not rely on converting Australian farms to create offsets. We will continue to supply traditional markets while enabling the private sector to invest in new industries to ensure we can take advantage of emerging opportunities in sectors like hydrogen, clean liquefied natural gas (clean LNG) and critical minerals.

Our Plan will confirm our long commitment to global action on climate change and ensure Australia can continue to cooperate with key allies in seeking solutions to this challenge, including with our Pacific family. With partners in the region, including the Quad (which comprises of Australia, Japan, India and the United States), we will work to establish a high quality carbon credit scheme in the Indo-Pacific. Through the Quad, Australia will progress specific proposals to forge closer partnerships between our economies to build competitive and reliable clean energy supply chains. Our Plan will also help to ensure Australian exporters are not targeted by trade action, and Australian businesses do not face cost of capital premiums.

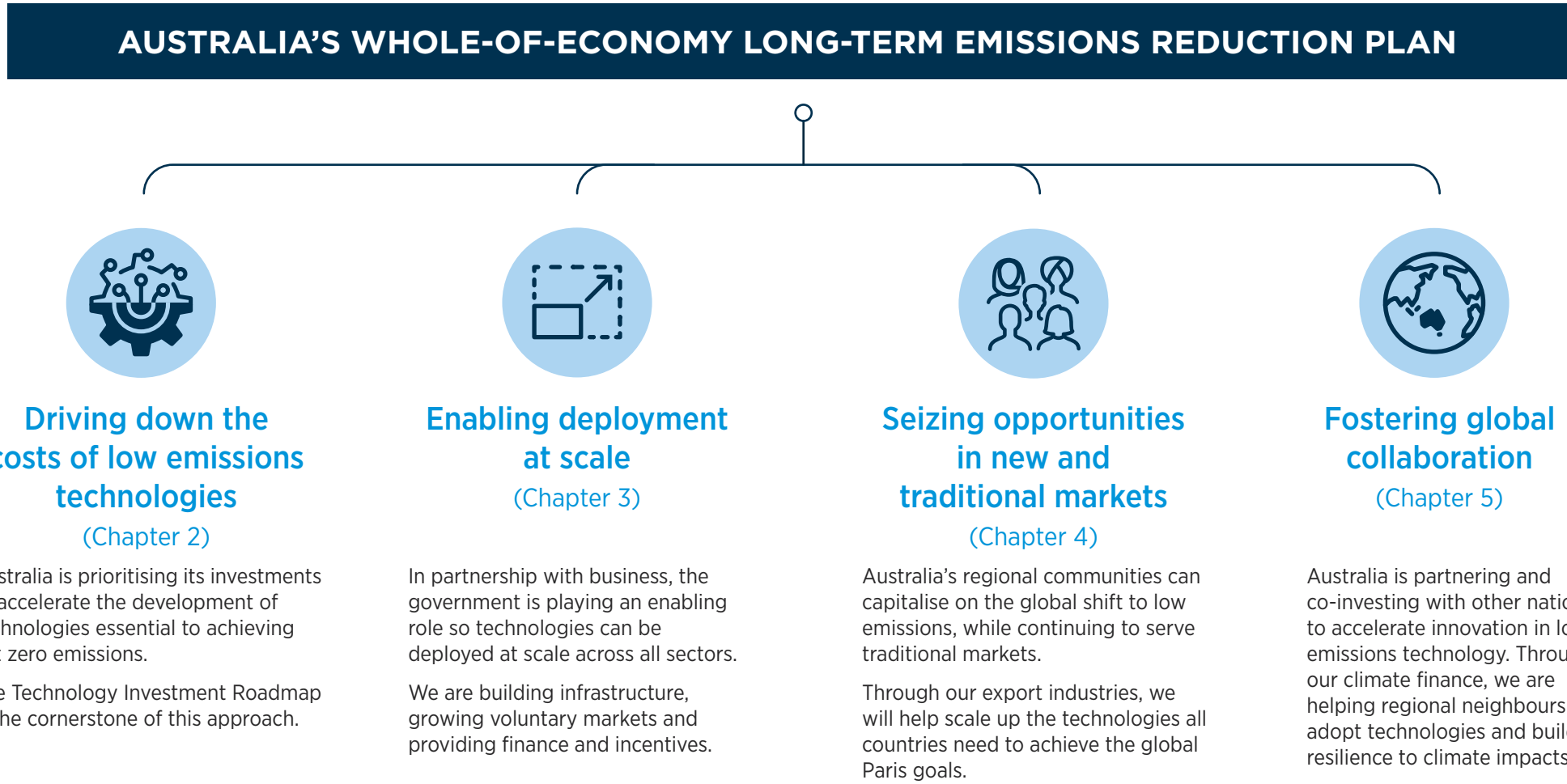
We will be accountable for progress under our Plan. Australia will continue to set the global benchmark for transparency and accountability in our emissions reporting so we can track our performance against our goals. Globally, Australia will continue to encourage the wide adoption of our world-leading approach to emissions measurement and inventory management.

Our Plan is structured in six chapters:

1. Australia's approach and principles

Our Plan has the wellbeing and prosperity of Australia's regional communities at its core. It will not impose new costs on households, businesses or the broader economy. Our actions under the Plan will not lead to job losses or place burdens onto regional communities (Figure ES.1).

Figure ES.1 Australia's Whole-of-Economy Long-Term Emissions Reduction Plan



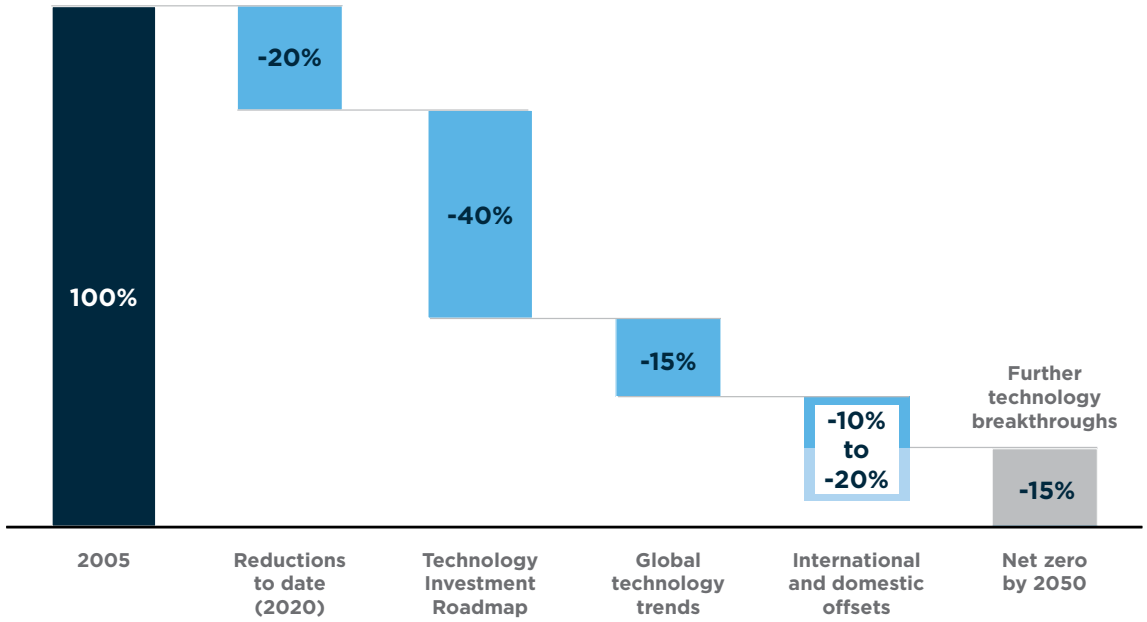
2. Driving down the costs of essential low emissions technologies

Affordable low emissions technologies are key to Australia achieving net zero emissions by 2050. The technologies prioritised through Australia's Technology Investment Roadmap can deliver approximately half the emissions reductions needed to achieve net zero emissions (Figure ES.2).

Our priorities are:

- clean hydrogen
- ultra low-cost solar
- energy storage for firming
- low emissions steel
- low emissions aluminium
- carbon capture and storage
- soil carbon.

Figure ES.2 Priority technology contribution to meeting Australia's net zero by 2050 goal



Source: *Based on McKinsey and DISER analysis. *Sources of offsets include voluntary soil carbon of up to 20%, depending on cost reductions in technology and voluntary demand.*[3]

The Technology Investment Roadmap is expected to guide at least $20 billion of Australian Government investment in low emissions technologies over the decade to 2030. The forthcoming LETS 2021 will examine deployment pathways for these priority technologies to ensure we meet our ambitious economic stretch goals.

Analysis to inform our Plan was commissioned from the Department of Industry, Science, Energy and Resources (DISER) and McKinsey & Company (McKinsey). This analysis shows that achieving the Technology Investment Roadmap stretch goals, coupled with other emerging global trends like electrification of transport, can reduce Australia's emissions by as much as 85% by 2050. Our Plan, with additional priority technologies over time, will close the gap.

We are already making the investments now to achieve this. The Government will invest more than $20 billion in low emissions technologies by 2030, helping to secure over $80 billion in total investment from the private sector and state governments.

Technology will evolve over the next three decades in ways that we can't yet imagine. This has been the lived experience with technologies like solar and batteries, where cost reductions have consistently exceeded forecasts. Trying to solve for every tonne of abatement now is not the right approach. Instead, our Plan sets our economy on a path to deliver a high percentage of the abatement needed without locking in high costs, and puts in place the right settings to adapt and refine our Plan as new technology options open up.

3. Enabling deployment at scale

Achieving net zero emissions by 2050 will require the deployment at scale of low emissions technologies across the economy. Lived experience shows there is an exponential relationship between falling technology costs and deployment. Despite significant research and deployment efforts since the early 1970s, it took until 2002 to deploy the first gigawatt (GW) of solar globally. Over the following decade (2002-12), 100 GW were deployed. By the end of 2022, more than 1,000 GW of solar will have been deployed globally.

Today, more than 90% of solar cells globally use Australian technology. We aim to replicate this success with our next generation of low emissions technologies.

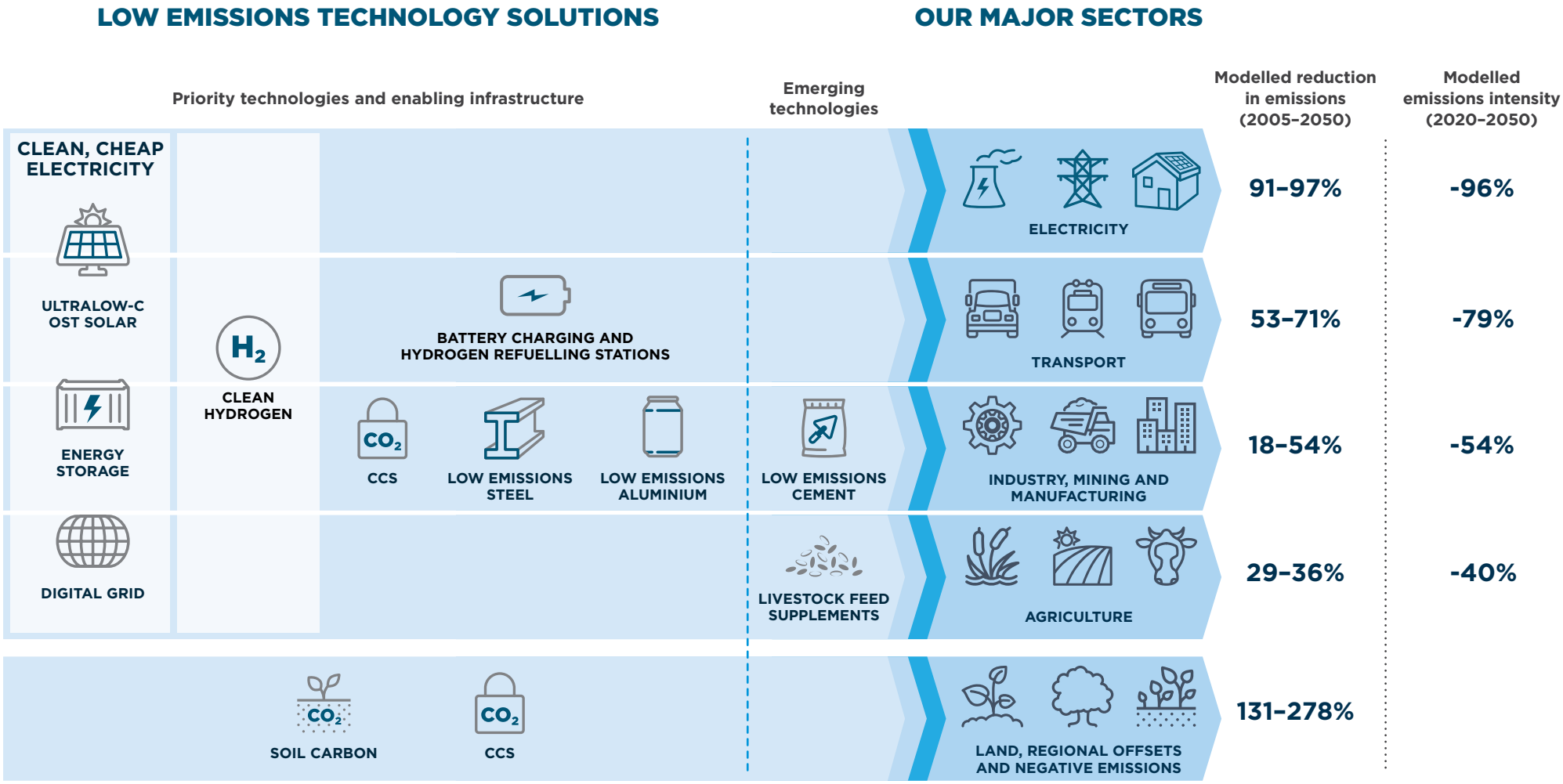
Australia is working not only to reduce technology costs, but also to remove barriers that may slow deployment across each economic sector. The Government is playing an enabling role to unlock investment and scale up technology deployment. This includes cross-cutting measures that apply across all sectors, and measures focused on overcoming barriers to technology deployment in individual sectors.

These measures include:

- planning for and building strategic and enabling infrastructure needed to unlock deployment, like electricity transmission and electric vehicle (EV) charging
- providing consumers and markets with the transparent information they need to de-risk technologies and make informed decisions, including developing a Hydrogen Guarantee of Origin certification scheme
- maintaining the high integrity accounting systems and trading infrastructure needed to grow Australia's voluntary carbon markets
- incentives and finance through the Emissions Reduction Fund, a new below-baseline Safeguard Crediting Mechanism and the CEFC that will accelerate technology adoption by firms.

Together, our efforts to reduce technology costs and enable deployment at scale drives emissions reduction across our economic sectors and puts Australia on a trajectory to net zero emissions by 2050 (Figure ES.3).

Figure ES.3 Reducing technology costs and enabling deployment drives emissions reductions across the economy



Source: *DISER analysis for the Plan (2021)* [4]

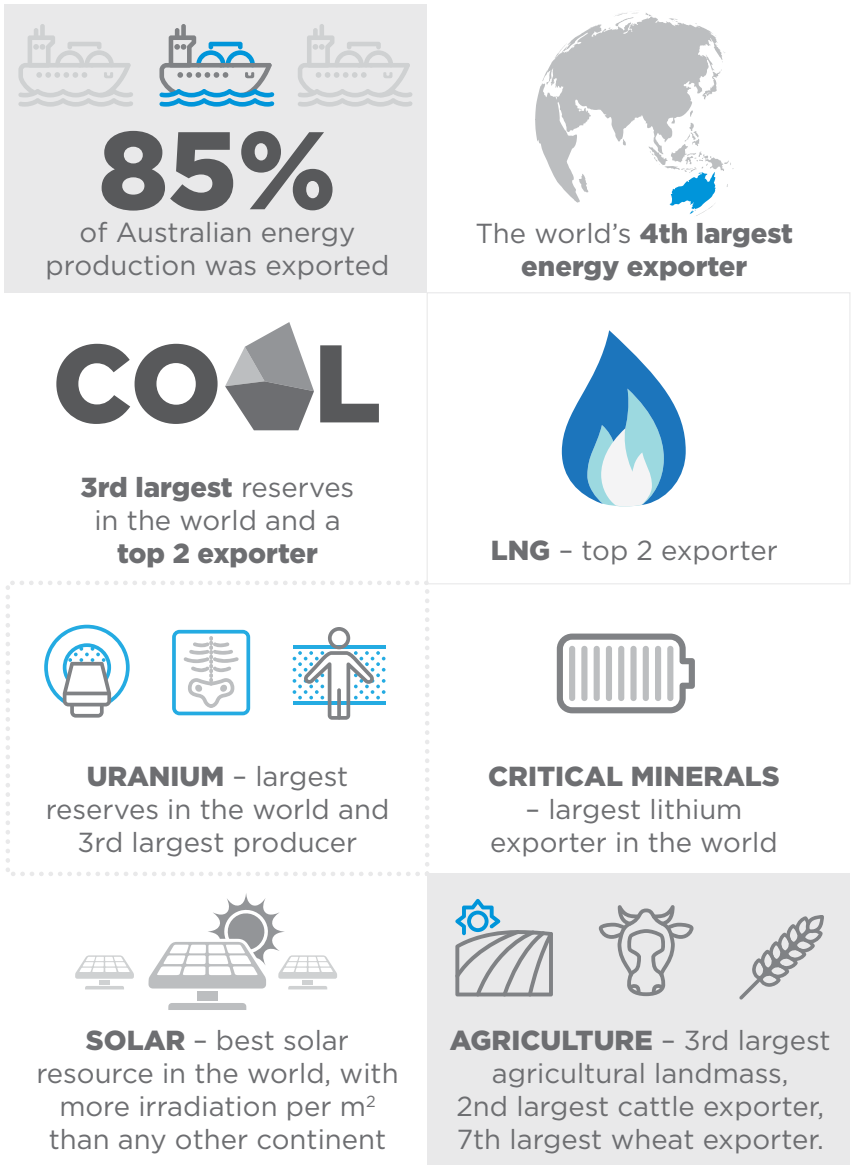
4. Seizing opportunities in new and traditional markets

Australia's regions have always powered the growth of our nation and the Government will continue to support our regions and traditional industries. Regional Australia is already home to one in three Australians, and more people will move to the regions as new low emissions industries grow and existing industries become stronger.

Regional industries have helped Australia's economy to specialise in the production of emissions-intensive exports and become the world's fourth largest energy exporter.

Australia is a global top three (or higher) exporter across a range of commodities (Figure ES.4), and is uniquely blessed with natural resources across traditional energy sources, emerging low emissions fuels and the new energy economy.

Figure ES.4 Australia's comparative advantages and natural endowments



Sources: *Geosciences Australia; Department of Industry; Science, Energy and Resources; Food and Agriculture Organization of the United Nations; World Bank.*

Changes in global demand for our energy exports and the actions of our trading partners will have implications for our regional communities. These changes will occur over several decades.

While most of our major sectors will grow strongly to 2050, even as the world decarbonises, some sectors will face global headwinds. We will continue to export our traditional energy exports for as long as our customers demand them. If we were to withdraw supply and reduce our exports, other countries would fill the gap in supply. Australia's coal and gas export industries will continue through to 2050 and beyond, supporting jobs and regional communities.

By building new industries like clean hydrogen, our Plan will create new export markets and jobs. These will benefit our regions, economy and jobs, and help other countries reduce their emissions faster. Analysis for the Plan shows that hydrogen, renewable energy and minerals like lithium could create more than 100,000 new direct jobs by 2050, many in Australia's regions. An Australian hydrogen industry could be worth more than $50 billion in 2050. Expanding production and processing of metals like lithium, nickel, copper and uranium could together be worth around $85 billion in exports in 2050.

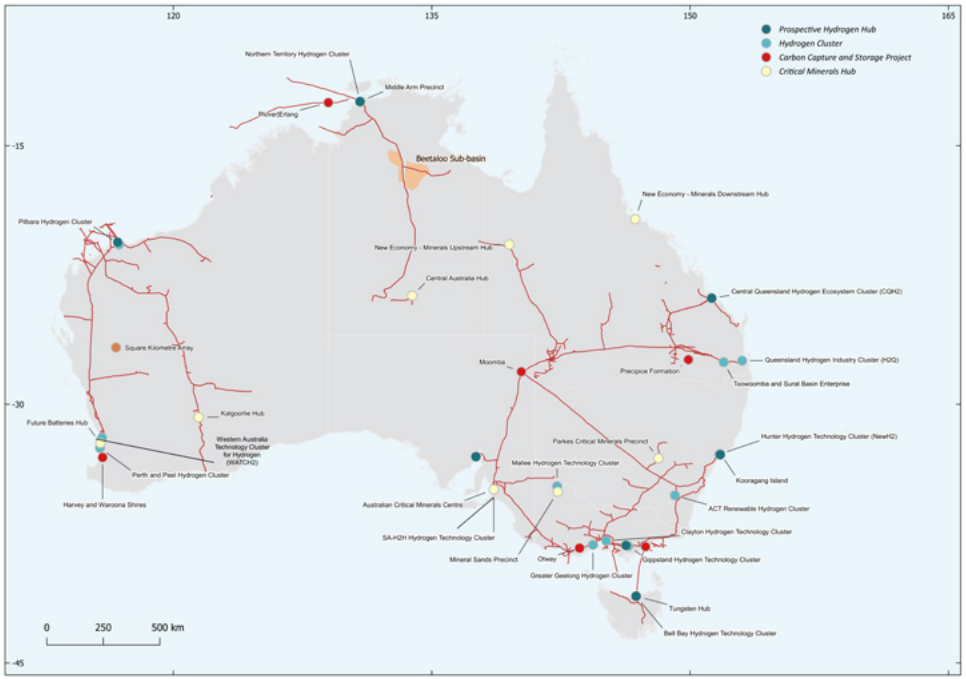
Australia will build on our comparative advantages to grow new and existing export industries for:

- critical minerals and metals used in clean technologies
- clean hydrogen
- low emissions fuels like LNG and uranium
- low emissions manufacturing (such as steel)
- innovative clean technologies
- agriculture.

Australia is making critical investments to build these regional industries right around the country (Figure ES.5). We are investing over $1.2 billion in Australia's hydrogen industry, including $464 million in 7 clean hydrogen industrial hubs. This will help grow a new hydrogen export industry and create local manufacturing jobs associated with low carbon products like ammonia, fertilizer, steel and aluminium. We are also investing over $300 million for carbon capture, use and storage (CCUS) technologies, projects and hubs.

ARENA and the CEFC will continue to support projects and employment in regional Australia – around half of the funds already invested by ARENA and almost a third of CEFC finance have been directed to regional areas.

Figure ES.5 Map of new energy export opportunities



5. Fostering global collaboration

Australia is partnering and co-investing with other nations to accelerate the technology transformations needed to decarbonise the world's economy, not just our own. Scaling up global production and supply chains will lower the costs of deploying the technologies all countries – including Australia – need.

Australia is also working with other countries, especially in our region, to access and adopt new technologies and build resilience to climate impacts. We are also working with our neighbours in the Indo-Pacific to build a high-integrity carbon offsets scheme.

6. An adaptive plan for the future

Australia's Plan will be flexible and adaptive. We will maintain a five yearly 'review and refine' cycle for the Plan, aligned with Australia's Nationally Determined Contributions (NDCs) under the Paris Agreement. This will allow Australia to evolve our policies as technology and market developments occur and prospective net zero pathways for sectors and applications become clearer. It will allow us to work with our regions over time to capture opportunities from new industries and to manage the impacts of global demand trends on traditional industries.

We will also review our progress towards the Technology Investment Roadmap stretch goals on an annual basis, through successive Low Emissions Technology Statements (LETS). We will also regularly review the economic impacts of Commonwealth, State and Territory emissions reduction policies, with the first of these to occur in 2023.

Australia will monitor and evaluate our progress towards net zero emissions, and will continue to be a leader in transparency and accountability. We will encourage the wide adoption of our world-leading approach to emissions measurement and reporting and we will continue to share our technical expertise in these areas to boost the capabilities of countries in our region.

PART A CONTEXT

1. AUSTRALIA'S APPROACH AND PRINCIPLES

Key points

- Practical global action on climate change is in Australia's national interest. This is why we have signed up to the Paris Agreement and are meeting and beating our ambitious emissions reduction targets.
- Achieving the Paris Agreement's global goals, including limiting warming to well below 2°C and reaching global net zero, will require practical action from all countries. Australia will play its part in the global effort to reach net zero emissions by 2050.
- Our Plan is to reduce the cost of low emissions technologies, accelerate their deployment at scale, and position our economy to take advantage of new and traditional markets. Modelling shows that, with this technology-led plan, Australia will prosper as we decarbonise. Our Plan will not cost Australian jobs.
- Australia is well placed to capture new employment and economic opportunities as the world shifts to low emissions technologies. Our Plan will support existing industries and workers to realise these benefits. Australian businesses are already taking practical action to reduce their emissions and emerging as global leaders in low emissions technology.
- Low emissions technologies are essential to achieving global decarbonisation and development goals. Australia's Plan focuses not only on reducing emissions domestically, but also on how we will play a global leadership role through our low emissions energy exports and contributions to innovation.
- Most major sectors will grow strongly to 2050, even as the world decarbonises, but some sectors will face global headwinds. By building new industries like clean hydrogen, Australia will create new export markets and jobs. This will help offset long-term impacts in sectors like thermal coal and natural gas which will be affected by falling global demand and the shifting choices of international consumers.
- This shift will unfold over decades, and these sectors (including coal and gas) will continue to provide jobs and underpin regional communities for many years to come.

1.1 Action on climate change and Australia's national interest

This Plan lays out how Australia will get to net zero emissions by 2050. It builds on our long standing commitment to make a significant contribution to the global effort to tackle climate change, as well as our strong record of achievement. It takes a practical, responsible approach that will take advantage of new economic opportunities while continuing to serve our traditional export markets. It will not put industries, regions or jobs at risk.

We are proud of our achievements to date. We have beaten our emissions reduction targets, kept our economy strong and become a low emissions technology leader (see 'At a Glance'). Compared to 2005 levels, our 2030 target will halve emissions per person and reduce the emissions intensity of our economy by two-thirds.

We have adopted this net zero by 2050 goal because practical global action on climate change is in Australia's national interest, and we must play our part.

Acting on climate change will help avoid the worst climate impacts on our communities, regions and natural environment. Australia is already experiencing climate impacts, and we are taking action to manage and adapt to these (Box 1.1). Avoiding further climate change will require global collaboration and deeper emissions reductions by all nations. Our technology-led approach is designed to achieve this by lowering the cost of low emissions alternatives.

Australia is uniquely enriched with an abundance of traditional and new energy and mineral resources. Our country will prosper over the coming decades as the world shifts to a cleaner global economy. Markets for low emissions technologies and commodities are emerging and will grow over time in Australia and around the world. These will grow both new and existing industries, creating jobs and boosting our economy.

Australia is already a low emissions technology leader thanks to our:

- world-leading deployment of renewable technologies and unmatched renewable energy resources
- exports of products that enable lower emissions, such as LNG, uranium, and lithium for batteries
- innovation in technologies like solar photovoltaics (PV) and hydrogen.

If managed well, we can build on these successes, enhance the competitiveness of our economic sectors, and further leverage our natural endowments and strong regional industries. This will enable us to capture the employment and economic opportunities of the global shift to low emissions, while continuing to serve traditional markets. For example, technologies such as carbon capture and storage (CCS) will provide low emissions options for some of our existing industries.

Australian businesses are already taking action to adopt new technologies and meet the growing demand for low emissions energy and products. This Plan outlines how the Australian Government is partnering with and supporting business so the benefits can be shared across our economy.

Box 1.1 Climate change impacts and adaptation

Australia's climate is changing – over the Australian landmass, average temperatures have increased by 1.44°C since 1910. Global temperatures have increased by over one degree since reliable records began in 1850.[5, 6]

Rising temperatures have led to more frequent and extreme heat events, as well as longer fire seasons with more extreme fire risk days.[7] The changing climate is also heating and acidifying the oceans.[8]

Even with rapid reductions in global emissions, temperature increases are already locked into the global climate system. These changes will further impact Australia's communities, regions, industries and ecosystems.

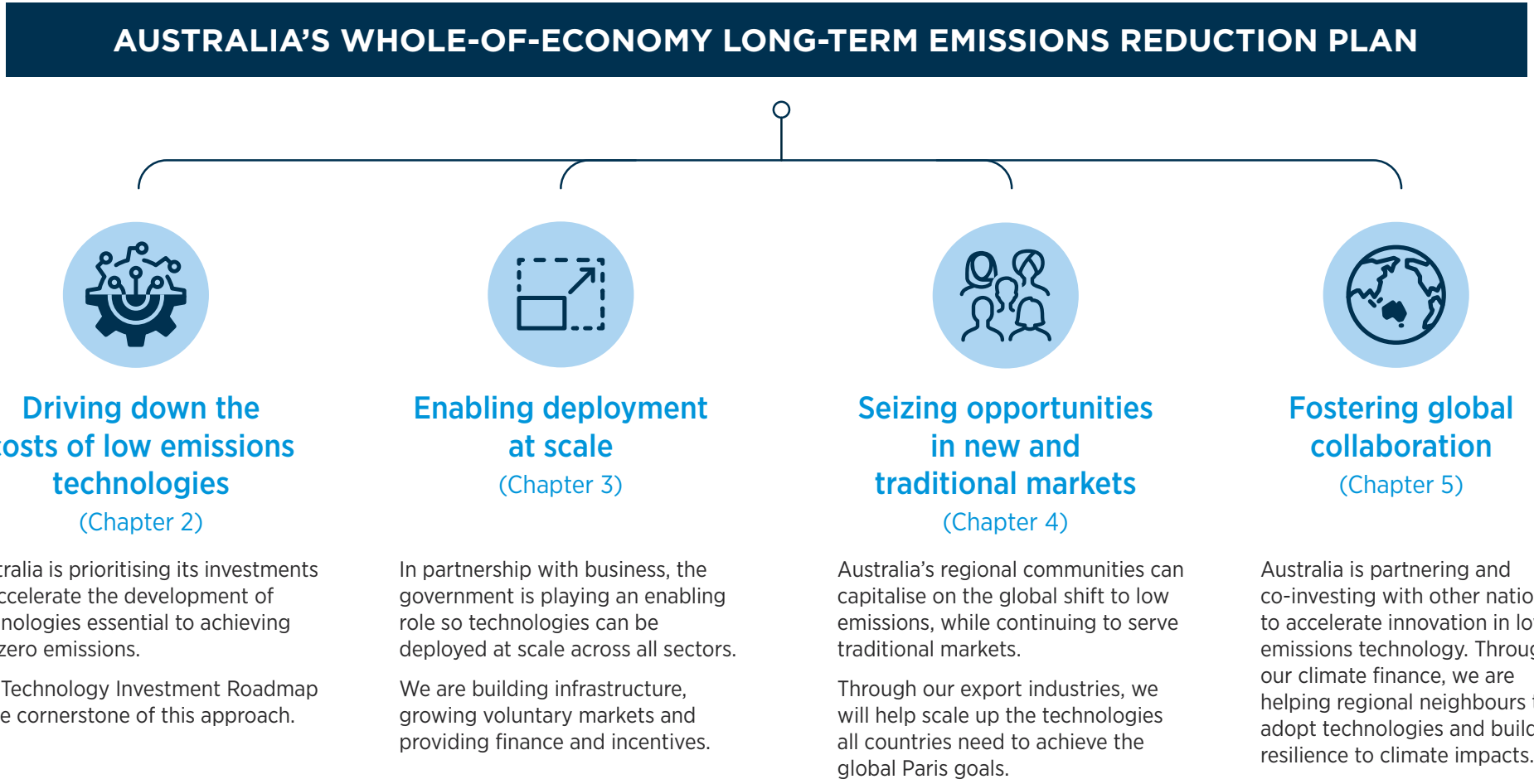
That's why Australia is refreshing its National Climate Resilience and Adaptation Strategy. This strategy focuses national adaptation and resilience-building efforts on:

- driving innovation, investment and adaptation action through collaborative partnerships
- providing climate information and services, so that we are better able to predict, manage and adapt to the physical risks of a changing climate
- tracking national adaptation progress through regular national climate risk assessments, monitoring and evaluation, to support learning and strengthen our collective adaptation response and adaptive capacity.

1.2 Australia's technology-led Plan

Australia's Plan will achieve net zero emissions by 2050 and position our economy to seize the opportunities of new and traditional markets (Figure 1.1). Our focus is on driving down technology costs, accelerating their deployment at scale, and building our regional economies.

Figure 1.1 Australia's whole-of-economy long-term emissions reduction Plan



The Plan brings together and builds on several existing sectoral strategies and investments (Figure 1.2), and draws on the analysis and stakeholder engagement from those processes.

Figure 1.2 Relationship between the Whole-of-Economy Long-Term Emissions Reduction Plan and other strategic processes

Our Plan has the wellbeing and prosperity of Australia's regional communities at its core. It recognises that a global transition towards low emissions technologies, fuels and commodities is now underway. This transition will unfold over the coming decades – not as an immediate and sudden shock. Nonetheless, shifting demands by our customers are likely to result in material declines in some of our major export commodities. The Government will not leave regional communities affected by this transition behind. We will support and partner with communities and businesses to capture new markets and help manage the transition.

Our Plan will not impose new costs on households, businesses or the broader economy. Our approach does not rely on levying taxes. No jobs will be lost as a result of Australian Government policies outlined in this plan.

The world is moving to reduce emissions, and these global efforts will have impacts on Australia. If we don't act to shape our future it will be determined for us by the actions of other countries. We can shape our own destiny, and through this Plan we will do so.

Markets are moving as governments, regulators, central banks and investors prepare for a lower emissions future. New international markets are emerging and will grow over the coming decades. Australian businesses are already adapting as countries around the world take action to decarbonise. Our analysis shows that retaliatory action, such as a capital premium levied on Australian firms, could be costly and disruptive. Our Plan makes sure Australia is well placed to take advantage of new economic opportunities presented by these shifts.

Our Plan confirms our long commitment to coordinated global action on climate change and ensures Australia can continue to cooperate with key allies in seeking solutions to this challenge, including with our Pacific family. With partners in the region, including the Quad, Australia will be working to establish a high quality carbon credit scheme in the Indo Pacific. Through the Quad, Australia will progress specific proposals to forge closer partnerships between our economies to build competitive and reliable clean energy supply chains. Our Plan will ensure Australian exporters are not targeted by trade action, and Australian businesses do not face cost of capital premiums.

Five core principles have guided the development of Australia's Plan. Taken together, these principles will ensure our shift to a net zero emissions economy by 2050 will be effective, fair and equitable, and that no sector of the economy will carry a disproportionate burden. These principles will continue to govern our long-term approach to reducing emissions.

Box 1.2 Australia's principles

Technology not taxes

Australia's technology-led approach will unlock the technologies needed to decarbonise our economy, enabling Australia to achieve our goals while growing our economy.

By investing in research, development and demonstration, Australia's technology-led approach will reduce the cost of new and emerging technologies, rather than tax our existing industries. It will make it easier for businesses to grow and compete. It will avoid regressive impacts on people who spend a higher proportion of their household bills on energy, including people on low incomes or in regional Australia.

Reducing and removing the price difference between current technologies and low or zero-emission solutions is the key to widespread global adoption. Australia is partnering and co-investing with other nations to foster a globally collaborative approach to technology and innovation.

Expand choices, not mandates

Australian businesses are embracing the emissions reduction task and emerging as global low emissions technology leaders.

Technology deployment must continue to be led by the private sector, with government supporting this by expanding and enabling consumer choice.

Under Australia's approach, government and businesses partner to unlock investment and accelerate technology deployment at scale. The Government's role is to remove barriers to deployment, including by:

- investing in enabling infrastructure
- ensuring transparency and knowledge sharing
- providing incentives and finance for firms to deploy emerging technologies.

Australia's approach respects consumer choice and trusts households and businesses to adopt new technologies as they become cheaper. The Government will not regulate technology adoption or impose new costs on consumers and businesses through mandated targets for technologies that are not able to compete on their own merits.

This applies both for Australian consumers and our international partners. We will expand the choices available in global markets by unlocking new energy sources like hydrogen and deepening global supply chains for critical minerals and other metals.

Drive down the cost of a range of new energy technologies

Achieving the global Paris goals requires transformative technologies to be deployed across the economy. There are no silver bullets – a portfolio of technologies will be needed across and within sectors.

Australia's approach prioritises the technologies that can open pathways to net zero by 2050 across all nations' economies. The six technologies prioritised through our Technology Investment Roadmap can reduce or capture emissions across all sectors, including from key hard-to-abate processes.

Australia's approach keeps all technologies on the table. We will monitor emerging technologies in the early stages of development, like small modular nuclear reactors. We are open to any low emissions technologies, including those that reduce the emissions from traditional fuels like gas or coal. We are open to any low emissions technologies that contribute to Australia's net zero future.

Keep energy prices down with affordable and reliable power

Australia has unrivalled energy resources: coal, natural gas, uranium and sun. These abundant resources have made us a global energy superpower. Reliable and affordable energy is a key foundation of our prosperity and underpins regional industries like mining and manufacturing.

Australia will maintain this competitive advantage as we decarbonise our own economy and the world shifts to low emissions technologies.

We will continue to supply energy exports in the form our customers want it. Without affordable low emissions technologies, global demand for our existing energy exports will continue, and other countries will fill the gap if Australia is forced out of global markets early. Australia's approach is to develop technologies – like hydrogen and carbon capture and storage – for adoption here and overseas so they are ready as global demand changes for coal and gas.

This will ensure Australia's regions remain strong and capture new employment opportunities by supplying low emissions energy and commodities to the world.

Be accountable for progress

Ambition is important, but outcomes are what matter. Australia has a strong record of meeting and beating our emissions reduction commitments. We have done this by setting ambitious goals and putting plans in place to deliver them. This will continue.

Australia will continue to set the global benchmark for transparency and accountability in our emissions reporting, so we can track our performance against our goals.

1.3 Australia's Plan and the global context

Keeping the increase in global temperatures below 2°C requires global CO_2 emissions to fall by over 75% between 2017 and 2050, and reach net zero globally by around 2070. Meeting a 1.5°C goal requires global net zero CO_2 emissions by 2050. Substantial reductions are also needed for other greenhouse gases like methane.[9]

The global energy system will need to continue to evolve to meet these goals. Over a 30-year period, the International Energy Agency (IEA) has estimated that to achieve these goals:

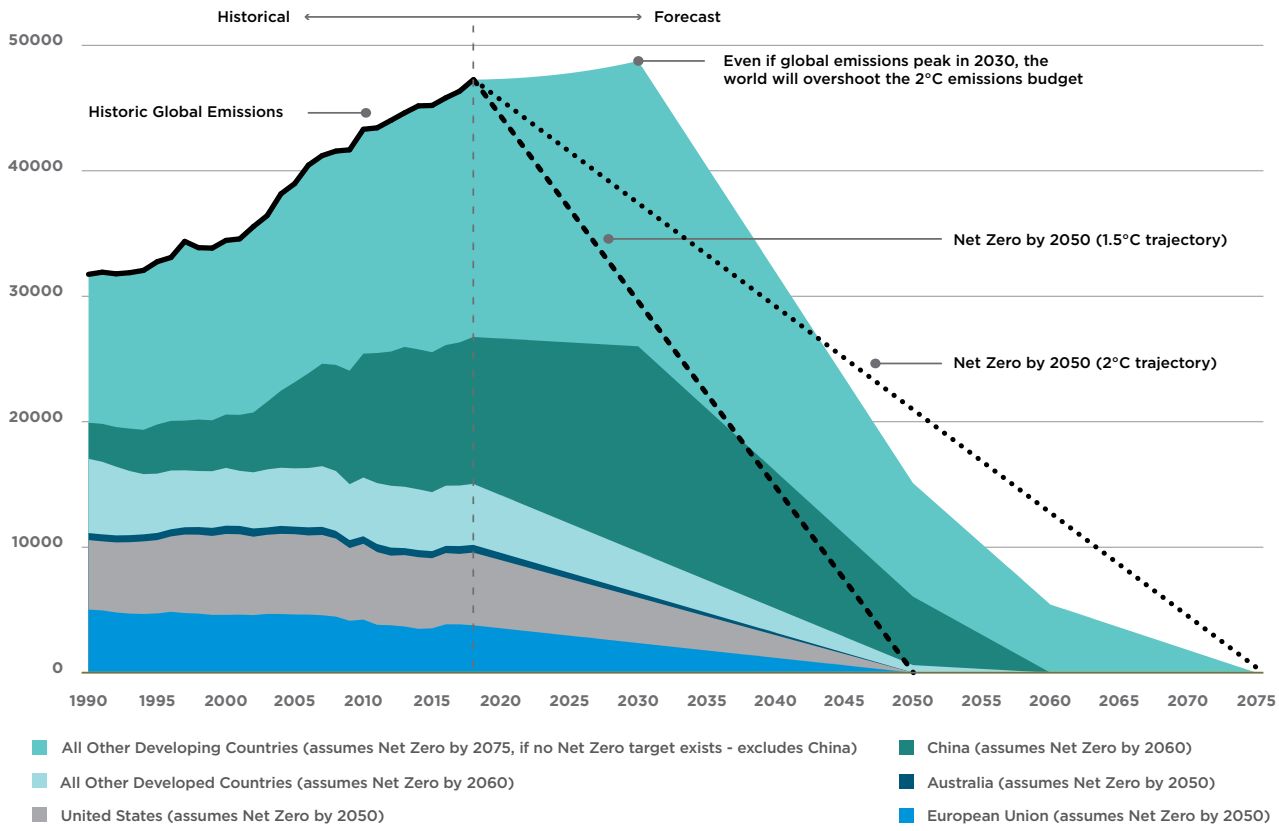
- Low emissions technologies – including solar, hydropower and nuclear – must grow from 29% of global power generation to 88% between 2020 and 2050.
- Hydrogen and CCUS technologies will need to grow to contribute around 50% of the emissions reductions in heavy industry.[10]

The global community is mobilising, but the task is significant and we must turn around the trends of recent decades. Despite the ambitions and efforts of many nations, global emissions have increased by an average of 1.8% every year since 1990 (Figure 1.3).[11] More than 60% of the CO_2 budget consistent with keeping temperature rise below 2°C was exhausted between the pre-industrial period (1850 to 1900) and the end of 2019.[12] Unless we can achieve deep reductions in global emissions, the remaining budget will be depleted. This would see the Paris temperature goals of well below 2°C exceeded by mid-century, and the 1.5°C threshold could be reached much earlier.[13]

Deep emissions reductions will require practical action by all major emitters – both developed and developing nations.

Achieving the global Paris goals needs to occur alongside an increasing world population and many nations' development aspirations. The energy sector accounts for around 75% of global emissions today. By 2050, it must be cleaner and more efficient while meeting the needs of an estimated 2 billion extra people and a global economy more than twice its current size.[14] South East Asia's electricity demand growth has been among the fastest in the world and is projected to continue growing into the future.

Figure 1.3 Historical global emissions trends (Mt CO_2-e)



Source: *DISER analysis based on NDCs lodged with the United Nations Framework Convention on Climate (UNFCCC) and other sources* [15]

The global approach to the Paris goals must recognise and accommodate nations' development needs and aspirations. An approach that seeks to reduce emissions by making existing technologies more expensive will not be durable or sustainable, and will not deliver the outcomes the world needs.

Technology is the key to balancing these global emissions and economic development objectives. Reducing technology costs means the world can reduce emissions rapidly, with smaller impacts on economic growth and without the need for sustained costly policies. Eliminating the price difference between incumbent technologies and low or zero carbon solutions – will enable net zero emissions growth to become mainstream.

We need a renewed global mission on technology. Almost half of the emissions reductions needed by 2050 depend on technologies currently in the demonstration or prototype phase and not yet available to the market.[16]

Australia recognises we must reduce emissions while accommodating countries' economic development goals, especially in the Asia-Pacific and Indo-Pacific regions. As well as reducing our own emissions, our plan focuses on how Australia can play a global leadership role through low emissions energy exports and contributions to innovation.

1.4 Australia's current emissions and recent trends

Australia has already reduced emissions by 20% since 2005 (Figure 1.4) with our emissions per person falling by 36%. We have reduced emissions faster than other major emitters, noting the average reduction across OECD countries was 7% between 2005 and 2018. Australia has reduced its emissions by 1.6% per year on average over the past decade, even as global emissions have increased 1.8% per year.

We have achieved these outcomes even as our economy has grown, with Australia's GDP per capita increasing 14% since 2005 and the emissions intensity of our economy improving by 44%. Emissions intensity has improved across major sectors, including:

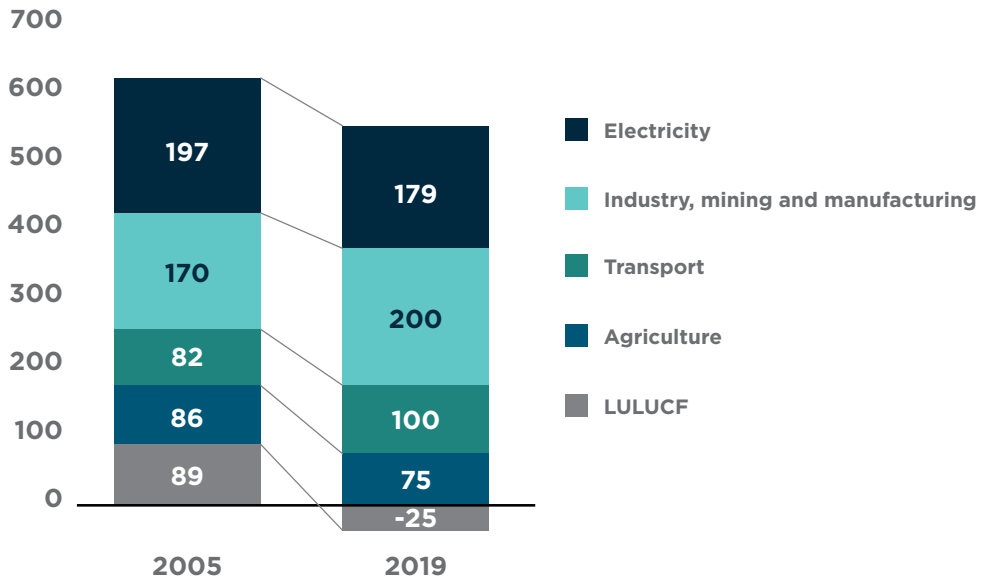
- agriculture and the land sector (nearly 60% improvement since 2005)
- construction (30%)
- utilities, including electricity generation (24%)
- mining (21%).[18]

Australia's farmers and regional communities have already been doing their share, playing a crucial role in these achievements. Emissions from the Land Use, Land Use Change and Forestry (LULUCF) sector have fallen by 114 Mt CO_2-e since 2005, and in 2019 the sector represented a 25 Mt CO_2-e sink for Australia (Box 1.3). Emissions from the electricity sector have also fallen significantly over this period, driven by the unprecedented rate at which large-scale renewables, household solar and energy efficient technologies have been adopted.

Australia has long been a supplier of low-cost energy to the world. Access to affordable energy has been a driver of poverty reduction and economic growth across the world and Australia will continue to be an important supplier of low-cost energy in the decades to come.

Around 40% of Australia's emissions are associated with export-facing sectors, while 60% of Australia's emissions are associated with domestic-facing sectors (Figure 1.5).

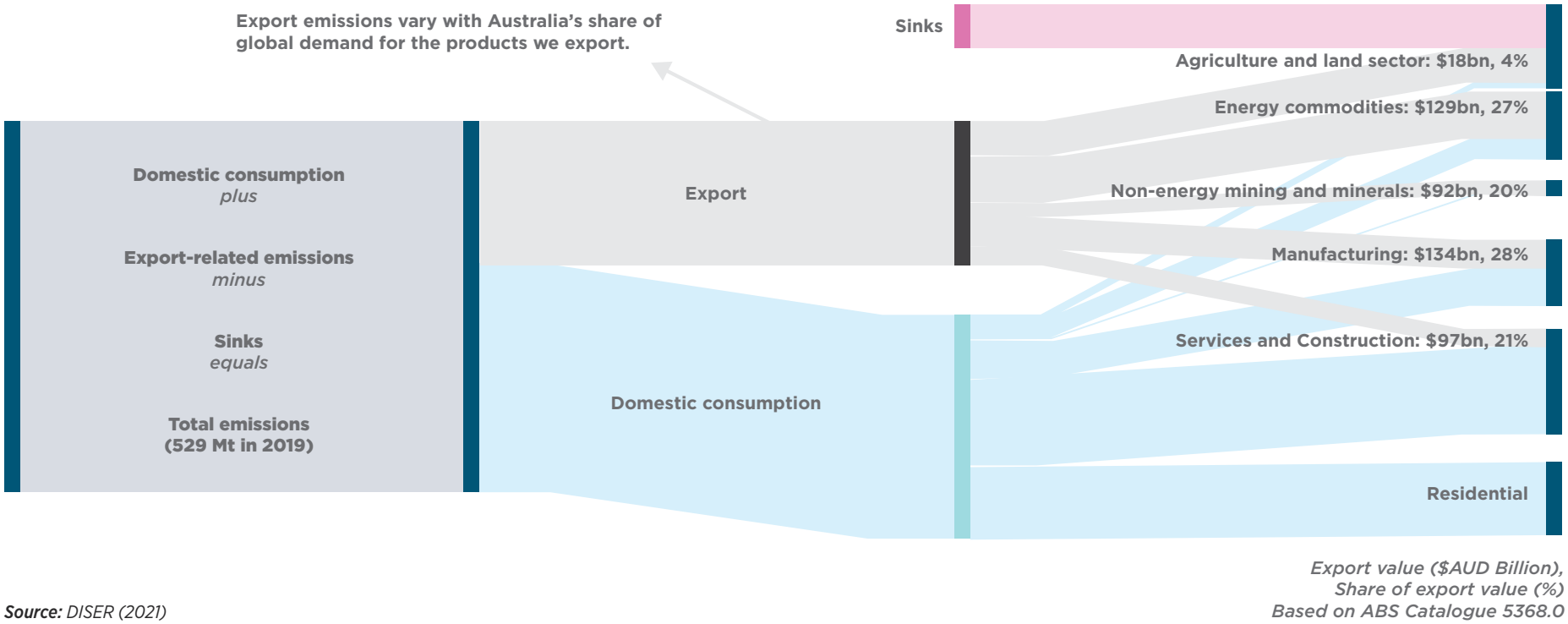
Figure 1.4 Change in Australian emissions by sector, 2005 to 2019 (Mt CO_2-e)



Source: *National Greenhouse Gas Inventory* [18]

This emissions profile creates challenges for Australia not shared by many other nations. Emissions associated with the production of exports depend on both the emissions intensity of production and international demand for the product – Australia can influence the former, but not the latter. Furthermore, low-cost abatement technologies do not yet exist for many applications across Australia's export-facing processes. As a result of these factors, Australia has reduced emissions by 33% since 2005 from its domestic-facing sectors, while emissions from its export-facing sectors have risen 50% (Figure 1.6).

Figure 1.5 Emissions from domestic-facing and export-facing sectors, 2019



Source: *DISER (2021)*

Box 1.3 Historical contribution by farmers and landholders to Australia's achievements

The Australian grazing industries have made among the most significant reductions in emissions of any major industry group in Australia. Between 1990 and 2019, emissions from Australian grazing (and grain cropping) industries have fallen by around 71% to 81 Mt CO_2-e.

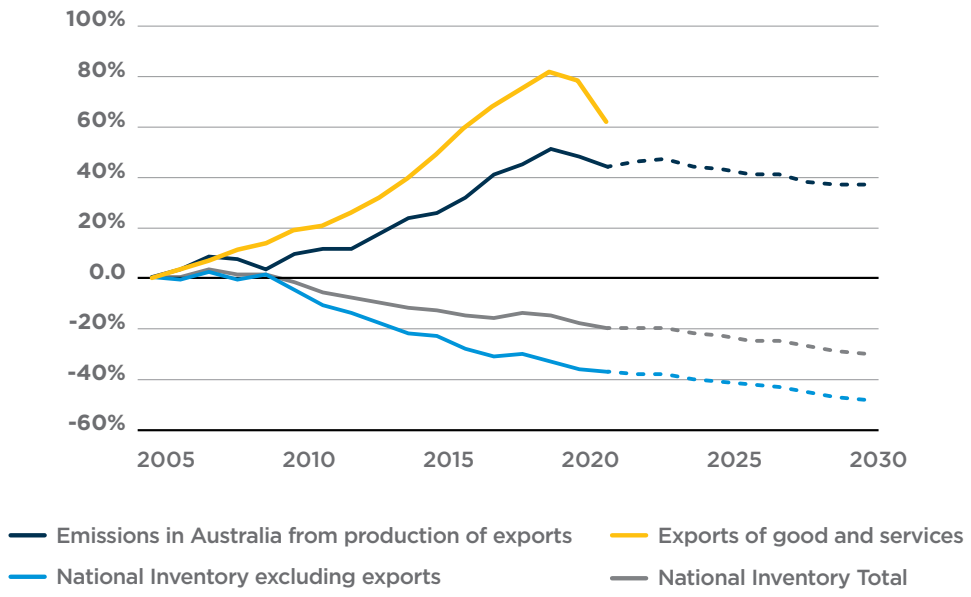
The decline in emissions from these industries has been mainly due to changes to land management practices, which have also had significant impacts on Australia's vegetation.

Reductions in vegetation clearing, especially primary forest clearing (clearing of forest that has not been previously cleared), the fostering of vegetation growth and the use of shelter belts have all contributed to improved carbon stock outcomes on Australia's grazing lands. [19]

Australia's outcomes have been exceptional. From 2010 to 2020, Australia had the largest net gain in forest area out of all OECD countries.

Carbon sinks are an important part of reducing global emissions and reaching net zero, and the Government recognises the contribution of Australia's farmers over this period. It is notable that over this same period Australia's farmers have continued to supply food and fibre to Australians and the world.

Figure 1.6 Emissions reductions from domestic and export-facing sectors, 2005–19



Source: *DISER economic modelling for the Plan (2021)*

Australia's success in reducing emissions has been driven by policies put in place by governments over the past two decades and the choices of consumers and industries (Box 1.4).

Australia's experience has highlighted the different policies and levers that can be applied to reduce emissions. Australia introduced a carbon tax in 2011, but repealed it in 2014. The Government considers that carbon taxes are regressive, with significant costs borne by people with least capacity to pay. Carbon taxes also apply to every tonne of emissions covered by the scheme, not just those that are responsive to a price mechanism. In contrast the Emissions Reduction Fund (ERF), which commenced in Australia in 2015, targets voluntary reductions in emissions.

Australia has continued to improve and refine its emissions reduction policies. The King Review was commissioned in 2019 to examine how Australia could build on the ERF to unlock additional sources of abatement. While the ERF has been very successful in driving abatement from the land sector, the King Review recommended improvements to the ERF and a greater focus on voluntary action and technology to achieve abatement from a broader range of sources.

Co-design of new and expanded methods (including for CCS) and reducing transaction costs for participants will create more opportunities to participate in the ERF. As part of its response to the King Review, the Government is implementing a below-baseline crediting mechanism under the Safeguard Mechanism, backed by $280 million in new funding. This will create more opportunities to drive abatement, especially in the industrial sector.

As observed by the King Review and confirmed in analytical work for this plan, achieving deep emissions reductions in the future will require an approach that enables emissions reductions by all sectors. Australia's technology-led approach is designed to achieve this.

Box 1.4 Major milestones and policy achievements

- The United Nations Framework Convention on Climate Change (UNFCCC) is agreed at the UN Conference in Rio de Janeiro, Brazil (4 June 1992). Australia ratifies the UNFCCC (30 December 1992)
- Creation of the Australian Greenhouse Office (1998)
- The *Renewable Energy (Electricity) Act 2000* (Cth) sets the framework for the Mandatory Renewable Energy Target (MRET)
- The *National Greenhouse and Energy Reporting Act 2007* (Cth) established a single national framework for reporting and dissemination of company information about greenhouse gas emissions, energy production, energy consumption and other information.
- Australia ratifies the Kyoto Protocol (12 December 2007)
- Passing of the *Clean Energy Act 2011* (Cth) including a carbon tax, which was repealed in 2014.
- MRET replaced with the Renewable Energy Target (RET) in 2009 to establish a target for 2020 and provide support for both small and large scale renewables; revised onto a sustainable footing in 2015.
- ARENA established on 1 July 2012.
- CEFC established on 3 August 2012.
- Climate Change Authority is established to provide independent expert advice to government (2012)
- The *Carbon Credits (Carbon Farming Initiative) Act 2011* established the ERF in 2015 and has been the cornerstone of the policies that enabled Australia to meet and beat its 2020 target.
- The Australian, state and territory governments agreed the National Energy Productivity Plan in 2015.
- Australia ratifies the Paris Agreement and the Doha Amendment to the Kyoto Protocol (9 November 2016)
- Independent Review into the Future Security of the National Electricity Market (The Finkel Review) (2017)
- In 2019, the Government committed a further $2 billion through the Climate Solutions Fund to build on the ERF's success and invest in additional low-cost abatement.
- Australia's National Hydrogen Strategy (2019)
- Snowy Hydro Limited (Snowy Hydro) approved to proceed with Snowy 2.0 (2019)
- The final report of the Expert Panel, chaired by Mr Grant King, examining additional sources of low-cost abatement (the King Review, 2020)
- Australia overachieved on its Kyoto-era targets by 459 million tonnes (30 June 2020)
- Technology Investment Roadmap and first Low Emissions Technology Statement (2020)
- Appointment of the Special Adviser to the Australian Government on Low Emissions Technology (2020)
- Amendments to ARENA and CEFC mandates to support the priorities of the Low Emissions Technology Roadmap (2021)
- Carbon Capture, Use and Storage Development Fund launched (2020)
- Australia's Whole-of-Economy Long-Term Emissions Reduction Plan (2021)
- Second Low Emissions Technology Statement (2021)

1.5 Achieving net zero emissions by 2050

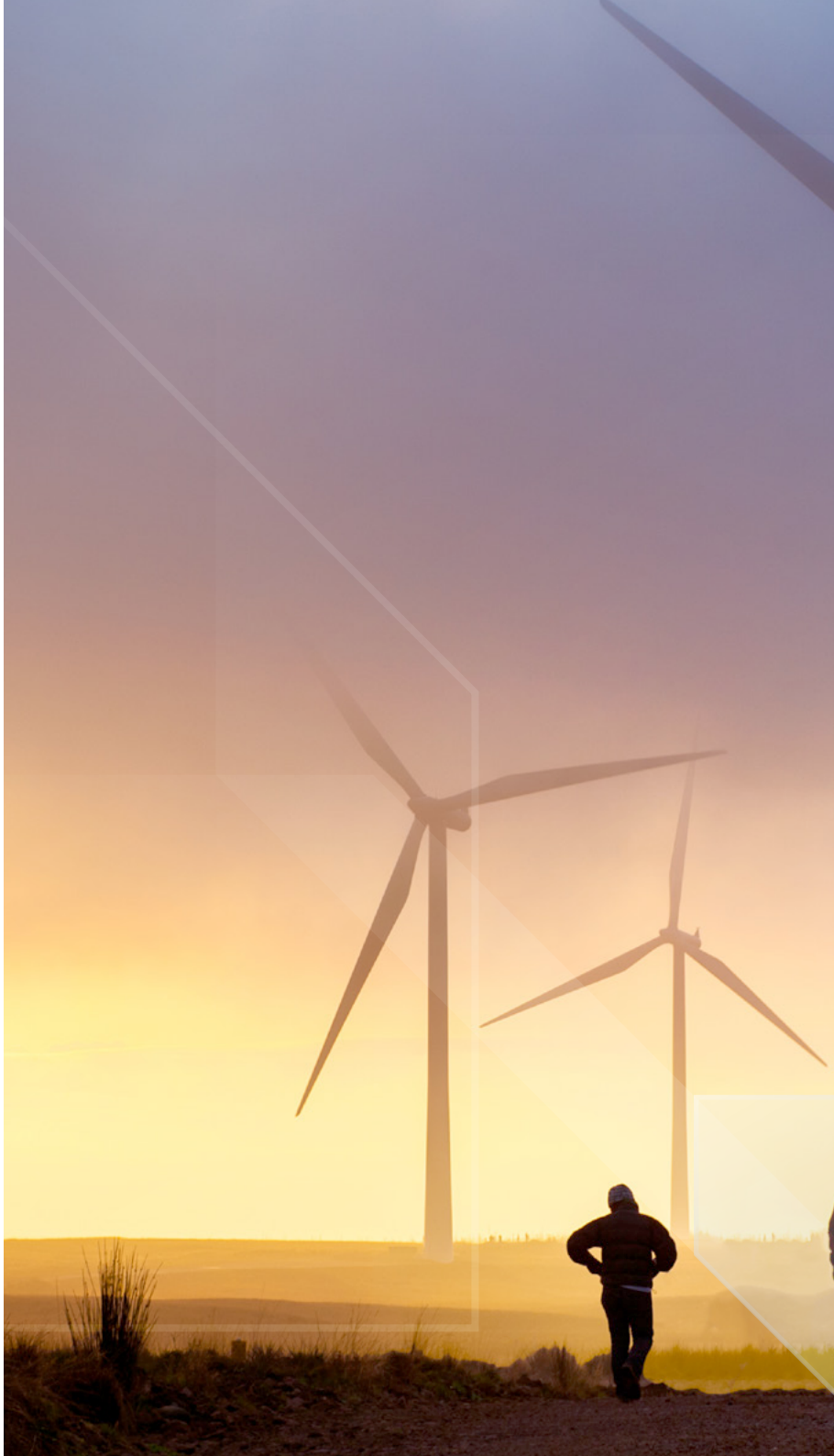
1.5.1 Economic implications at the national level and policy choices

Australia's Plan has been informed by detailed modelling and analysis. This analysis has built on the work undertaken for the 2020 Low Emissions Technology Statement (LETS) to assess customer and technology trends and identify priority technologies for Australia, as well as subsequent work for the forthcoming LETS 2021 to understand how far and how soon the costs of those technologies could fall. Two complementary analytical approaches – top-down economic modelling and bottom-up analysis by McKinsey – were then used to understand the potential economic impacts that could follow. This approach has helped us evaluate how close we can get to net zero emissions through an agenda that reduces technology costs and shapes and expands the choices available to consumers.

The analysis shows that it is possible for Australia to get to net zero emissions by 2050 and that the costs will be significantly lower if we adopt a technology-based approach to reducing emissions. In a scenario where we succeed in driving down technology costs and accelerating their deployment at scale across all sectors, Australia can get within range of net zero by 2050 with a voluntary incentive of less than $25 per tonne CO_2-e in 2050.[20] This is comparable to costs observed in voluntary markets today.

Our modelling finds that, with our technology-led plan, Australia can continue to prosper even as we reduce our own emissions to net zero and global demand shifts towards low emissions technologies, fuels and commodities. The modelling projects that Australia's economy will continue to grow and Australians will enjoy sustained growth in material living standards, with our Plan expected to increase our national income per person by almost $2000 in 2050, compared with no policy action.. Employment remains strong, and our regional industries keep exporting energy to the world.

A technology not taxes approach is a must have. In contrast, if we fail to unlock new technologies then net zero by 2050 is only achievable for Australia at much higher marginal costs (about $100 to $170 per tonne CO_2-e) and with heavy reliance on carbon offsets from Australia's productive agricultural land or from overseas.

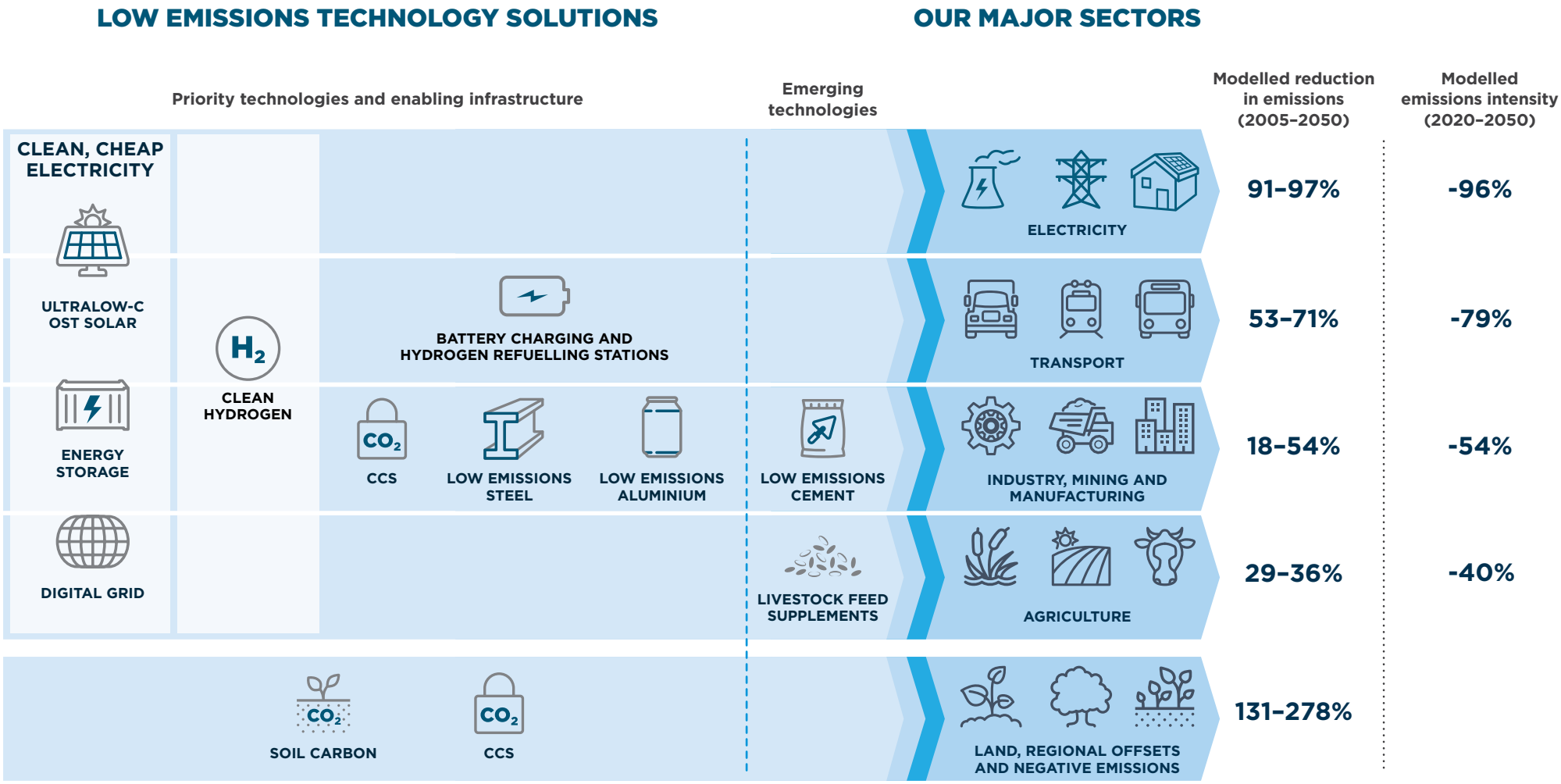


The analysis shows that policy choices are important and directly impact the future wellbeing and prosperity of Australians. This is why the Government has adopted a balanced approach to deliver a pathway to net zero by 2050 that does not rely on:

- high carbon prices
- conversion of productive farming land to carbon sequestration
- excessive use of international units.

It is a balanced approach that will ensure Australia plays its role in the global effort to reach net zero by 2050 without threatening our prosperity or our regions.

Figure 1.7 Change in output across Australia's sectors



Source: *A, B, C, E, F, G and H, DISER economic modelling for the Plan (2021); and D, F and G McKinsey data.* [23]

1.5.2 Economic implications at the sectoral level

As noted in Australia's 2021 Intergenerational Report, the shift to lower greenhouse gas emissions globally will mean that some sectors will need to adjust to falling demand for some exports, while new opportunities will be created in other sectors.[21]

Our modelling shows that Australia's export-oriented industries grow strongly even as global demand shifts towards low emissions products and we reduce our own emissions.

Our analysis shows most sectors, including mining and manufacturing, will continue to prosper in a low emissions global economy. New industries create new export markets and jobs that more than offset impacts in other sectors, like thermal coal and natural gas, affected by falling global demand. Australia's hydrogen sector could grow rapidly to provide around 10% of global supply in 2050, generating substantial export revenues in coming decades.

Overall, the value of our exports is projected to more than triple between 2020 and 2050. Most sectors will remain competitive in a global economy that increasingly values low emissions fuels and products due to our:

- world-class renewable energy and mineral resources
- low energy costs
- low emissions intensity of traditional industries like agriculture.

With industries like mining, heavy manufacturing and agriculture primarily based in regional areas, regional communities will be major beneficiaries. McKinsey analysis found that Australia's comparative advantages and proactive policy choices could mean that job gains can far outweigh job losses driven by shifting customer demand, particularly in regional areas. Growth in the mining and heavy industry sectors alone could create as many as 62,000 new jobs by 2050, mostly in regional areas.

Australia's adoption and integration of new technologies will create further benefits for the nation. McKinsey analysis suggests that technology could enable economy-wide energy productivity improvements over the next 30 years, with energy consumption per dollar of GDP falling by half in per capita terms by 2050. This is substantially driven by the projected substitution of oil by electricity in transport as the share of electric vehicles EVs grows. This would also increase Australia's energy self-sufficiency and help reduce the cost of Australia's energy as a share of GDP from 8% to 2%.

Building the new low emissions electricity generation needed to support electrification in transport and industry could also create around 35,000 new jobs by 2050, many in regional areas.

1.5.3 Economy-wide pathways to net zero emissions by 2050

Analysis undertaken for Australia's Plan illustrate there are a range of technology pathways that could put Australia on a trajectory to net zero emissions by 2050 (Figure 1.7). These analyses converge in key areas, such as the central role of low emissions electricity and electrification of transport, but diverge in others. Taken together, however, they underscore that technology can underpin deep cuts in emissions across all sectors of the economy, and that complementary measures, such as modest levels of land sector sequestration and regional offset trading, put us within range of net zero.

The analysis illustrates the outcomes that can be expected if we are successful in achieving our substantial reductions in the costs of low emissions technologies consistent Technology Investment Roadmap. It shows that if the costs of firmed renewables substantially decline, we can expect Australia's electricity sector to reduce emissions by around 90% between 2005 and 2050. Low emissions electricity, along with the increased availability of low-cost hydrogen and other technologies, will enable Australia to reduce emissions across other sectors. By 2050:

- industrial, manufacturing and mining emissions will have fallen to 140 Mt CO_2-e (a reduction of almost 20% on 2005 levels)
- agriculture emissions will have fallen to 55 Mt CO_2-e (36% reduction on 2005 levels)
- transport emissions will have fallen to 39 Mt CO_2-e (more than 50% reduction on 2005 levels).

Technology enables emissions intensity to fall across all sectors, meaning that emissions fall even as sectors grow and increase their output.

The modelling shows that, with our technology-led approach, Australia can reduce its emissions by two-thirds, to 215 Mt CO_2-e by 2050, before offsets. This outcome can be achieved at marginal costs comparable to those observed in voluntary markets today (below $25 per tonne CO_2-e).

The scenario analysed by McKinsey also underscores the importance of technology. In a scenario with strong global momentum towards the Paris goals, McKinsey has assessed that falling technology costs and a voluntary incentive of $25 per tonne CO_2-e could enable Australia's emissions to fall to 164 Mt CO_2-e in 2050, before offsets. By increasing the deployment of priority and other emerging technologies, deep emissions reductions can be achieved across all sectors, particularly in electricity (97% reduction on 2005 levels in 2050), transport (71%) and buildings (near 100%). As discussed further in Chapter 2, the priority technologies contribute around 40% of the abatement needed to achieve net zero in 2050.

Offsets will play a crucial role in closing the gap towards net zero. Our modelling shows that modest contributions from land sector sequestration and targeted purchases of international offsets allow Australia to reduce its net emissions to 94 Mt CO_2-e in 2050, around 85% below 2005 levels. In the scenario analysed by McKinsey, including land sector sequestration allows Australia to reduce its net emissions to 111 Mt CO_2-e in 2050, 82% below 2005 levels. [23]

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.

This has been the lived experience with technologies like solar and batteries, where cost reductions have consistently exceeded forecasts. Other analyses have highlighted that, for some important technologies, there is potential for higher abatement than has been assumed in the Plan. For example, the LETS 2020 noted the potential for improved management of one quarter of Australia's crop and grazing lands to secure as much as 35–90 million tonnes per annum through soil carbon, at least twice the level of accredited land sequestration used in the analysis for the Plan.

Our analysis for the Plan is also relatively conservative about how quickly emissions in the transport sector will fall.

Our technology-led approach is iterative and adaptive, meaning we can close this remaining gap over time by prioritising ongoing technology breakthroughs and other sources of abatement.

In summary, our analysis shows that net zero emissions by 2050 is achievable for Australia. Realising this outcome will depend on our success in reducing the costs of low emissions technologies and accelerating their deployment at scale across all sectors. Chapters 2 and 3 of this plan detail the practical actions Australia is taking to achieve this. Reducing our domestic emissions will also be aided by deeper international supply chains for low emissions technologies and fuels, which Australia is supporting by building our new and traditional export industries (Chapter 4) and by helping to foster global collaboration on technology and climate change (Chapter 5).

Targeted voluntary purchases of international offsets, domestic land sector sequestration and prioritising new technology breakthroughs, including negative emissions technologies, are all credible options for closing the gap to net zero, but each has costs and benefits. The exact balance between these options is a choice Australia can make over the coming decades. Chapter 6 outlines the adaptive and flexible approach Australia will take on this issue.

PART B AUSTRALIA'S PLAN

2. DRIVING DOWN THE COSTS OF LOW EMISSIONS TECHNOLOGIES

Key points

- Australia has identified and prioritised low emissions technologies that will open net zero pathways for our economic sectors.
- The Government is working with business, researchers and other nations to reduce the cost of these technologies so they become the rational choice for business and consumers.
- The technologies prioritised through Australia's Technology Investment Roadmap can contribute and enable around half the emissions reductions needed to achieve net zero. They are:
  - clean hydrogen
  - ultra low-cost solar
  - energy storage
  - low emissions steel and aluminium
  - carbon capture and storage
  - soil carbon.
- The roadmap is expected to guide at least $20 billion of Australian Government investment in low emissions technologies over the decade to 2030. National agencies including ARENA, the CEFC and the Clean Energy Regulator, as well as other targeted programs and initiatives, have been aligned with the roadmap and are investing in priority technologies. They also support the development of other high-potential emerging technologies like livestock feed technologies to reduce methane emissions.
- Australia is partnering and co-investing with other nations to foster a globally collaborative approach to low emissions technologies.

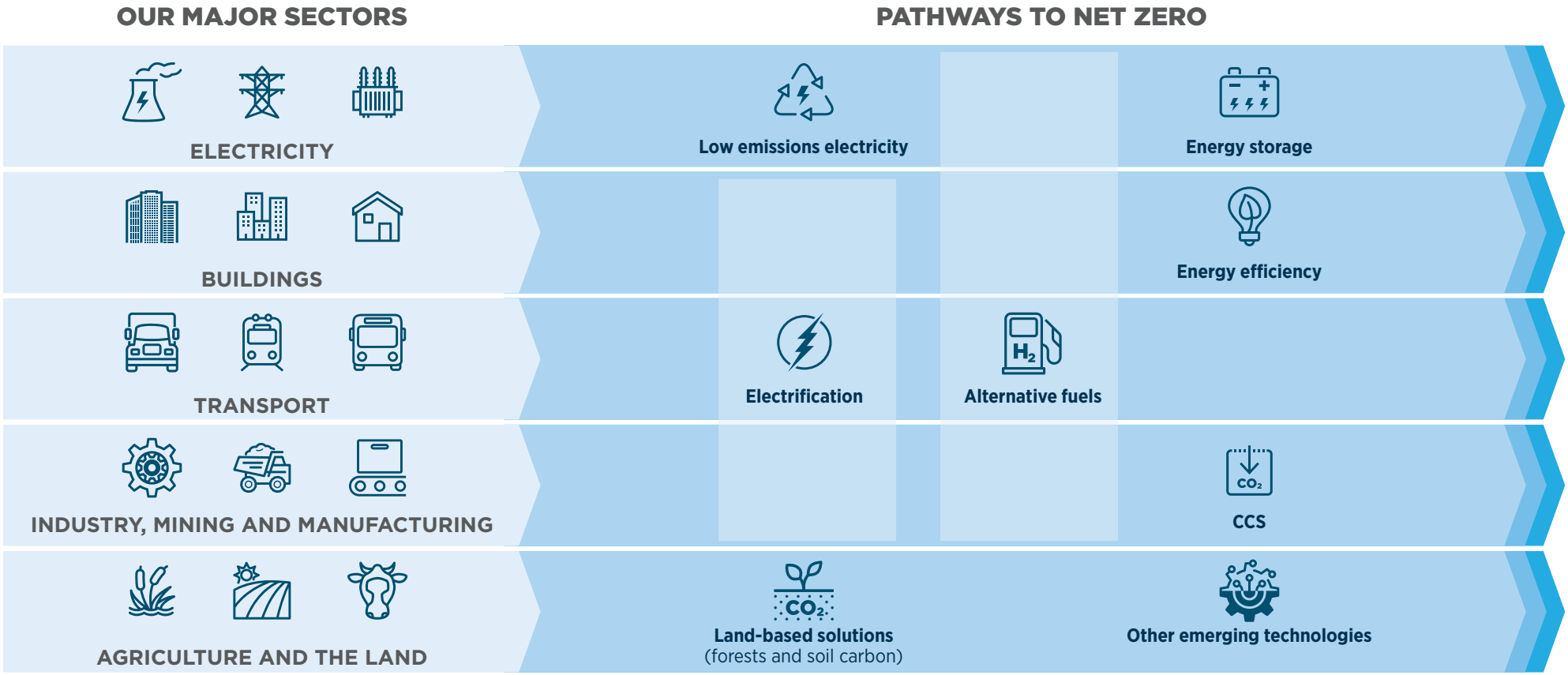
2.1 Critical pathways to net zero for Australia's economic sectors

There is no silver bullet to achieving Australia's net zero by 2050 goal. Our modelling underscores that emissions reductions must be achieved across all sectors, and that a set of critical pathways must be unlocked to achieve this (Figure 2.1).

Our policies are focussed on the technologies that can open these critical pathways. A portfolio of technologies will be needed, including cross-cutting 'platform' technologies (like hydrogen) and technologies tailored to specific and niche applications within individual sectors.

The Government's technology-led approach is closely targeting this challenge (Box 2.1). By investing in research, development and demonstration, the Plan will drive down the cost of these key technologies and achieve their economic stretch goals, unlocking their use across the economy. The Technology Investment Roadmap is the cornerstone of this approach.

Figure 2.1 Critical pathways to net zero for Australia's economic sectors



Note: *This Figure illustrates some of the more critical pathways, but many technologies will find application across many sectors.*

Box 2.1 Unlocking the critical pathways to net zero by 2050 for Australia's economic sectors

Low emissions electricity

Australia is already on a path towards low emissions electricity.

Solar, wind and other renewable technologies are being installed at a world-leading rate. These technologies are projected to provide half of Australia's total generation by 2030.[24] Led by ultra low-cost solar (Section 2.3.2), an increased share of renewables will be the foundation for a near zero emissions grid by 2050.

The challenge is to ensure our electricity system remains secure, reliable and affordable as the share of variable renewables grows. Storage technologies, like batteries, are already providing short-term firming and other system services.[25] Low-cost, long-duration storage will enable very high shares of renewables and ensure security and reliability (Section 2.3.3). In the meantime, while these technologies mature our existing thermal generation assets will continue to play an important and necessary role in providing affordable and reliable power.

Electrification and efficiency

Firmed renewables and other types of low emissions electricity will enable other sectors to decarbonise via electrification and energy efficiency. These sectors include transport, buildings, manufacturing and mining.

Global trends are making battery EVs more accessible and affordable. But these will need to be charged from low emissions electricity to be emissions free.

Efficient electric heat pump technologies can be used for space and water heating in buildings. They can also produce industrial heat for some low-temperature applications, like food manufacturing.

Electrification is also feasible for some mining applications, like surface transport.

Alternative fuels

Alternative fuels like hydrogen (Section 2.3.1) and biofuels will be needed where electrification is not viable or consumers choose alternative zero emissions technologies.

In transport – particularly heavy road freight, aviation and shipping – hydrogen, ammonia, biofuels and synthetic fuels will provide additional and alternative pathways.

In industry, alternative fuels will also be needed for the high temperature heat used in sectors such as alumina production. Clean hydrogen could be used to make low emissions steel through direct reduction of iron ore (Section 2.3.4). Plastics and fertiliser production will require zero emissions feedstocks like clean ammonia (made using clean hydrogen) or bioenergy.

Carbon capture and storage (CCS)

CCS (Section 2.3.5) can help decarbonise industrial sectors including steel, cement and natural gas. It can also provide a pathway to produce clean hydrogen using natural gas or coal.

In the future, CCS coupled with bioenergy or direct air capture technologies will likely play an important role in drawing carbon from the atmosphere. This will help achieve the Paris Agreement temperature goals.

Land-based solutions

Storing carbon in vegetation and soils (Section 2.3.6) can offset residual emissions from hard-to-abate sectors like agriculture, industry and heavy transport. Voluntary land-based offsets also provide new revenue streams for farmers and improve agricultural productivity. Our modelling shows this can occur with minimal land use change.

Tailored solutions

Tailored technology solutions will be needed for specific sectors, like livestock (Section 2.4) and aluminium (Section 2.3.4).

2.2 Technology Investment Roadmap and Low Emissions Technology Statements

Australia's Technology Investment Roadmap, consisting of annual Low Emissions Technology Statements (LETS), outlines the role the Australian Government will play in reducing the costs of low emissions technologies. The Government is doing this by investing in innovation through ARENA, the CEFC, the Clean Energy Regulator (CER) and other programs.

The roadmap is an enduring process for identifying low emissions technologies that:

- will have the biggest impact in reducing emissions in Australia and globally
- have significant economic potential
- build on Australia's competitive advantages
- government investment can help develop and deploy.

The Technology Investment Advisory Council comprises experts from industry, research, government and finance. The council advises the Government on its annual LETS. This allows the Government to refine its investment priorities in response to technology and market developments.

Through LETS 2020 and the forthcoming LETS 2021, the Government has:

- outlined a vision for a prosperous nation recognised as a low emissions technology leader
- identified key technology challenges to help guide and prioritise Australia's technology investments
- introduced and refined low emissions technology categories to guide government investment (Figure 2.2).

Through LETS 2020, the Government established a clear, principles-based Technology Investment Framework for guiding its investments in low emissions technologies. As part of this framework, national agencies including ARENA and the CEFC, as well as other targeted programs and initiatives, have been aligned with the roadmap and are helping drive down the costs of its priority technologies.

Figure 2.2 Technology Investment Roadmap technology categories

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

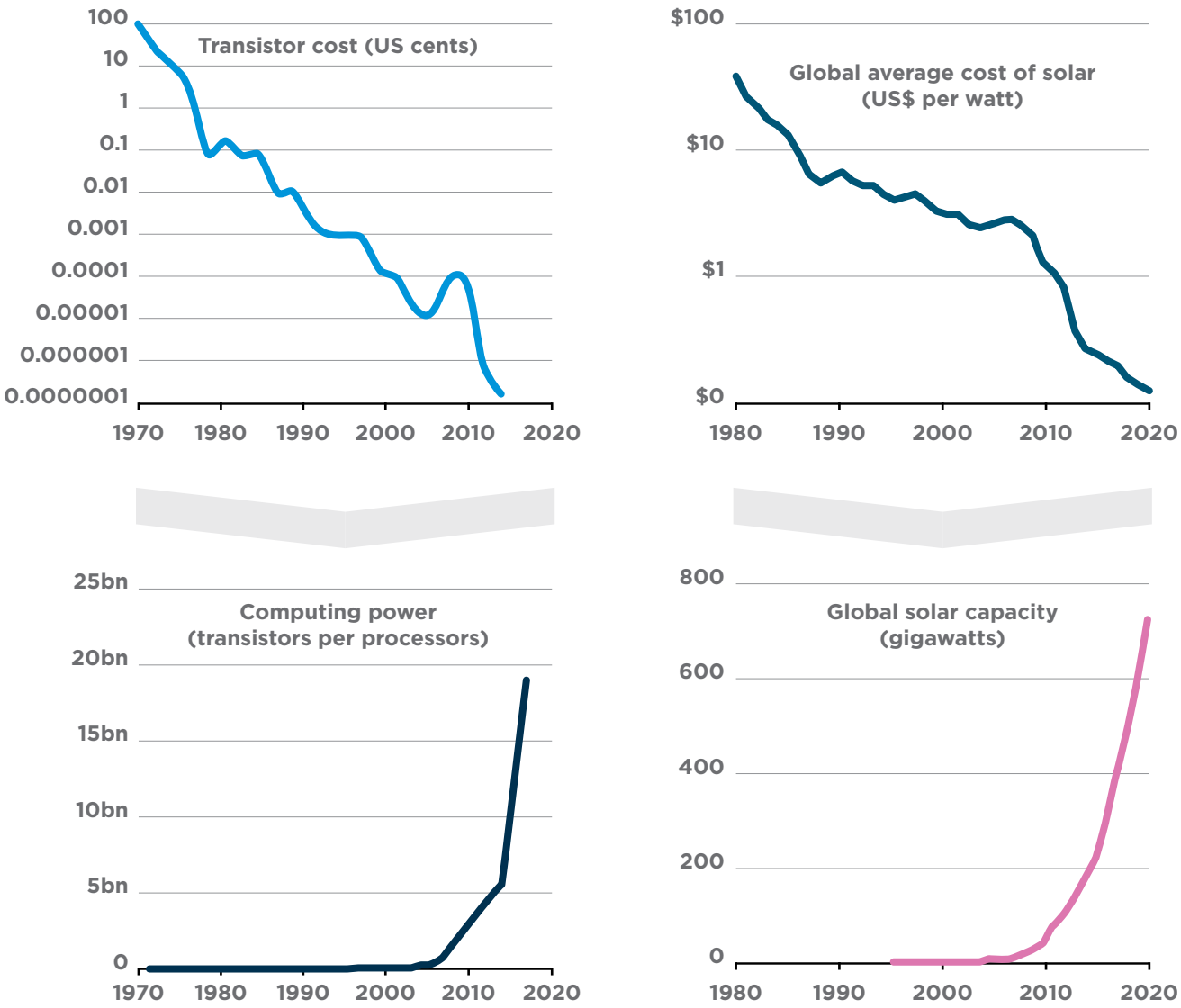
Infrastructure that is critical for enabling commercial deployment of low emissions technologies. The government's first enabling infrastructure priorities are battery charging and hydrogen refuelling stations to support consumer choice in electric vehicles, and a digital grid with enhanced management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

Emerging technologies

Emerging technologies have transformative potential, but require continual 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.

History has shown the non-linear relationship between technology cost and deployment (Figure 2.3). Our experience with globally significant technologies like transistors and solar has shown that falling costs and a concerted innovation effort can catalyse an exponential increase in deployment. Achieving this outcome for the priority technologies is the ultimate goal of the roadmap.

Figure 2.3 Historical trends in cost and deployment for transistors and solar[26]



Source: *Sarma, S. (2016), Our World in Data (2020), IRENA (2021)*[27]

2.3 Priority low emissions technologies

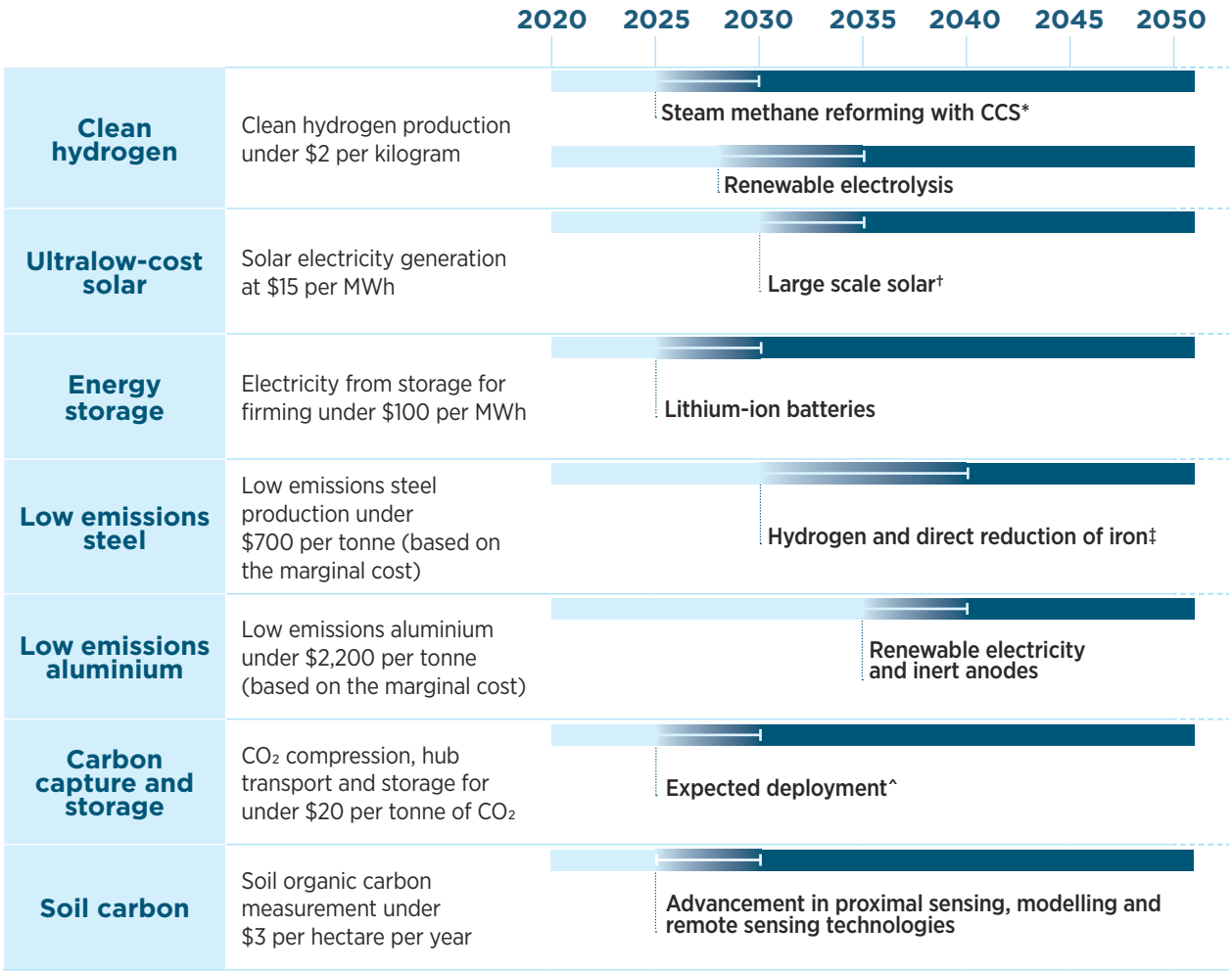
LETS 2020 and the forthcoming LETS 2021 have identified six priority low emissions technologies:

- clean hydrogen
- ultra low-cost solar
- energy storage for firming
- low emissions materials (steel and aluminium)
- carbon capture and storage
- soil carbon.

The statements have set ambitious but realistic economic stretch goals for each priority technology (Figure 2.4). The stretch goals aim to bring the priority technologies to cost parity with existing high emissions technologies.

The forthcoming LETS 2021 will examine deployment pathways for these priority technologies, with a focus on identifying cost reduction opportunities that would help achieve the economic stretch goals.

Figure 2.4 Priority technologies and economic stretch goals



* economically feasible now, but subject to offtake agreements, development approvals and the adoption of a hydrogen Guarantee of Origin scheme.

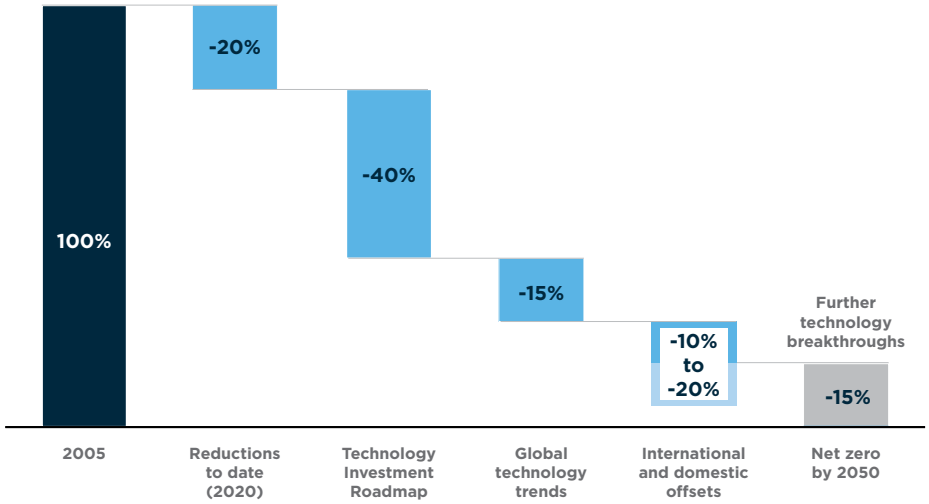
† the timeframe for achieving the ultra low-cost solar stretch goal does not yet underpin the electricity price assumptions used for achieving clean hydrogen, energy storage, and low emissions steel and aluminium stretch goals

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

^ subject to offtake agreements and development approvals

Analysis for this Plan shows that, if Australia is successful in realising its technology agenda, these technologies could unlock almost half of the abatement needed to achieve net zero emissions by 2050 (Figure 2-5). These technologies will also underpin further emissions reductions from global technology trends like EVs powered by zero emissions electricity or fuels.

Figure 2.5 Priority technology contribution to Australia achieving net zero emissions



Source: *Based on McKinsey and DISER analysis. *Sources of offsets include voluntary soil carbon of up to 20%, depending on cost reductions in technology and voluntary demand.*

2.3.1 Clean hydrogen

Stretch goal: Clean hydrogen production under $2 per kg

Potential for clean hydrogen

Australia is set to become a world-leading clean hydrogen producer and exporter.

Clean hydrogen will help decarbonise Australia's industry, transport and mining sectors. It can be used across a range of applications including:

- to power vehicles
- to generate heat and electricity
- as an industrial chemical feedstock for products such as ammonia and steel
- to globally trade clean energy

In the future, clean hydrogen could also help firm the electricity grid as renewables reach very high levels, and provide an important source of controllable energy demand to increase power system resilience.

McKinsey found fuel switching to hydrogen use, particularly across industry and heavy transport, could reduce Australia's emissions by around 50 Mt CO_2-e in 2050.

A future Australian clean hydrogen export industry can also make significant contributions to global emissions reductions, while creating jobs and income for regional communities (Chapter 4). Analysis by McKinsey found that an Australian clean hydrogen export industry providing a low emissions energy source and chemical feedstock for other countries, could drive international emissions reductions growing to almost 100 Mt CO_2-e per year by 2050.

Australian businesses are already mobilising to capture these opportunities. For example, Fortescue Future Industries is targeting 15 Mt year in Australian hydrogen production by 2030, building to 50 per year thereafter. It is also exploring how applications like steel and shipping can utilise hydrogen and its derivatives (like ammonia). The Australian Gas Infrastructure Group (AGIG) is investing in hydrogen and other renewable gas technologies with the aim to decarbonise its gas distribution networks as early as 2040, and will offer 100% renewable gas to new home estates by 2025.[29]

Government actions to unlock clean hydrogen

The Australian Government is working with the states and territories to deliver the National Hydrogen Strategy. The strategy envisions a clean, innovative and safe hydrogen industry that benefits all Australians and where Australia is a major global player by 2030.

The National Hydrogen Strategy has 57 actions that are the first steps to build Australia's hydrogen industry. These actions initially set the foundations for industry growth, ahead of supporting industry scale-up to service international and domestic markets as they emerge. Australia will track our progress and successes under the strategy, and adapt our approach as markets and technologies develop.

All levels of government are acting to deliver the strategy and are taking early actions to overcome the barriers facing the industry. So far, the Australian Government has:

- built international relationships, including major announcements on hydrogen cooperation with Germany, Japan, Singapore and the UK to build supply chains and advance technology research
- developed a domestic Hydrogen Guarantee of Origin scheme and helped shape the design of international methodologies for measuring hydrogen production emissions
- announced hydrogen funding programs, such as $464 million for the 'Activating a Regional Hydrogen Industry: Clean Hydrogen Industrial Hubs' program (Box 2.2)
- invested over $300 million to support development of CCS and CCUS projects
- awarded over $100 million to three 10 MW hydrogen electrolyser projects through ARENA
- fostered industry innovation, collaboration and knowledge sharing
- provided more than $300 million in funding for research, development and demonstration activities.

The Government has already committed more than $1.2 billion to building an Australian hydrogen industry.

State and territory governments are also helping to develop the hydrogen industry by implementing the National Hydrogen Strategy and their own hydrogen strategies. Together, the federal, state and territory governments have:

- started a review of legal and regulatory frameworks
- started an accelerated review of arrangements supporting blending of hydrogen into gas networks
- started the National Hydrogen Infrastructure Assessment
- commenced work on industry development, including skills and training
- supported analysis to help understand community attitudes towards hydrogen.

In addition, state and territory governments are undertaking activities in their jurisdictions to support the hydrogen industry, including:

- announcing funding for pilots, trials and demonstrations
- engaging with communities
- committing funding for hydrogen hubs
- supporting industry development
- participating in regional hydrogen technology clusters in partnership with National Energy Resources Australia (NERA)
- supporting trials for hydrogen vehicles and blending hydrogen into gas networks.

Through the forthcoming LETS 2021, the Australian Government will commit to develop a voluntary zero emissions gas market in Australia. This will increase early demand for clean hydrogen and other zero emissions gases and recognise consumers' voluntary purchase of zero emissions gas. Certification and standards (such as the Hydrogen Guarantee of Origin scheme) will provide the necessary transparency and traceability for this market.

Box 2.2 Clean Hydrogen Industrial Hubs

The Australian Government has announced $464 million over five years from 2021–22 for the Activating a Regional Hydrogen Industry: Clean Hydrogen Industrial Hubs program. This includes funding to support the early design works of hydrogen hubs, of which an estimated $30 million is available for Hydrogen Hub Development and Design Grants.

Hydrogen hubs will create economies of scale to drive down costs of production, unlocking further demand for hydrogen as costs fall. Hubs will also create efficiencies by leveraging and supporting the existing industrial capabilities and workforces in relevant regions. Hubs will stimulate innovation and increase workforce skills development, as well as support other existing industrial sectors in these regions to lower both emissions and costs in doing business.

The hubs will support direct and indirect employment in Australia's regions. This includes technicians, tradespeople, engineers and professionals associated with hydrogen production and export. Hubs could also create local manufacturing jobs associated with low-carbon products such as ammonia, fertiliser, steel and aluminium.

Australia's hubs program will build our 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.

2.3.2 Ultralow-cost solar

Stretch goal: solar electricity generation at $15 per megawatt hour (MWh)

Potential for solar

Cheap, clean electricity is integral to lowering emissions in the electricity sector and other industries in Australia. Australia has some of the best solar resources in the world, giving it a comparative advantage in utilising solar to supply clean electricity.

Australia is already experiencing high levels of investment in both grid-scale and rooftop solar. Australia has the highest solar capacity per person in the world,[30] and over 1 in 4 Australian homes now have rooftop solar. Solar contributed almost 10% of Australia's electricity generation in 2020 and is projected to contribute 27% in 2030.[31]

Lived experience shows there is an exponential relationship between falling technology costs and deployment. Despite significant research and deployment efforts since the early 1970s, it took until 2002 to deploy the first gigawatt (GW) of solar globally. Over the following decade 100 GW were deployed. By the end of 2022, more than 1000 GW of solar will have been deployed globally.

There is the potential for continued technology advances and breakthroughs to unlock ultra low cost solar. This would further reduce costs and emissions from Australia's electricity and help deliver the world's lowest cost clean electricity.

Reducing the costs of solar generation will also unlock the economic, employment and abatement potential of other priority low emissions technologies. Clean electricity at $15 per MWh would enable low-cost clean hydrogen production and increase our competitiveness in hydrogen export markets. It would also support cost-competitive production of low emissions steel and aluminium and emerging technologies like direct air capture of CO_2.

Modelling for the Plan shows that, if we can realise these cost reductions, solar could become the single largest source of Australia's electricity generation by 2050 (over 50% of total generation). Unlocking ultra low-cost solar is therefore crucial for Australia's electricity system to achieve near zero emissions.

Government actions for solar

ARENA, the CEFC and other Australian institutions will remain at the front line in developing solar technologies. They will build on their strong success in leading solar breakthroughs and deployment. To date, ARENA has provided $252 million since 2015 towards solar research, design and development (RD&D) to projects with a total value of $1.7 billion. The CEFC has committed over $1.1 billion towards large-scale solar projects with a total generating capacity of over 1.6 gigawatts (GW).

To support innovations in this area, the Australian Government has set an objective to achieve 30% module efficiency at 30 cents per installed watt by 2030 – the 'Solar 30 30 30' Initiative. Led by ARENA, the initiative will help drive down costs to meet the stretch goal for the newly prioritised technology.

ARENA, alongside other research institutions like the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Research Council, are also investing across a range of early-stage solar projects. These agencies have supported the world-leading Australian Centre for Advanced Photovoltaics headquartered at the University of New South Wales, where researchers have led solar breakthroughs and developed the passivated emitter rear cell (PERC) technology used in 90% of global solar production. ARENA is also supporting the commercialisation of an Australian National University patented technology enabling simpler, safer and cheaper fabrication of next-generation silicon solar cells.

ARENA and the CEFC have worked together to support early movers in large scale solar, helping de-risk the technology and generating lessons for industry growth. ARENA's $90 million Large-Scale Solar Round funded 12 projects, with 2 further projects signing up to ARENA's knowledge-sharing obligations. To provide financial certainty, the CEFC offered long-term debt finance to 8 of these projects, alongside ARENA's grant funding. These investments unlocked almost $1 billion of investment in the projects and laid the foundations for further large-scale solar deployment.

The Australian Government has also committed $68.5 million to the Reliable Affordable Clean Energy ('RACE for 2030') Cooperative Research Centre (CRC), which is focused on opportunities arising from low-cost renewable energy, network integration and smart energy management. Its research is aiming to:

- reduce energy costs
- cut carbon emissions
- increase customer load flexibility to allow increased penetration of renewables in the grid and increased reliability.

2.3.3 Energy storage

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

Potential for energy storage

Energy storage technologies are essential for Australia to shift to lower emissions electricity systems.

Capturing the full potential of Australia's renewable energy resources requires storage that can dispatch clean electricity on demand and provide critical system security services. Analysis for the Plan found that low-cost storage could enable a step change in the share of variable renewable generation, unlocking new opportunities for energy intensive exports.

The most pressing need for storage is for durations of several hours to manage daily variations in solar and wind output. But longer duration 'deep storage' technologies, along with expanded transmission networks, will also be needed as very high shares of renewables enter Australia's electricity grid. These will be required for seasonal storage and to mitigate the risk of weather events that last for days or weeks

Government actions for energy storage technologies

The Government is supporting emerging battery technologies through ARENA, the CEFC and other programs by:

- increasing access to capital to deploy early-stage, innovative technologies in Australia
- funding feasibility studies and demonstration projects
- supporting research to identify development opportunities in the battery supply chain.

For example, ARENA, the CEFC and the South Australian Government have co-invested up to $73 million towards expanding the Neoen Hornsdale Power Reserve. The Hornsdale Power Reserve is already the largest battery in the southern hemisphere, and this investment has increased its capacity by 50%. This will enhance the battery's ability to stabilise the grid, reduce the risk of blackouts and limit price volatility. The CEFC is also investing $160 million in a 300 MW Victorian Big Battery (VBB), providing a critical boost to the state's grid security while driving down power prices and supporting more renewable energy.

ARENA supports innovative battery projects such as a 30 MW grid-connected battery in Ballarat, Victoria. Capable of powering 20,000 homes for an hour, the battery will store energy when demand is low and use it during peak times. It will also examine other grid services like frequency control ancillary services. This project will demonstrate how batteries can provide grid stability and support on a congested transmission terminal, reducing the need to expand the substation.

ARENA, the CEFC and the Northern Australia Infrastructure Facility have also invested in the 250 MW Kidston Pumped Hydro Project in Queensland, an innovative project that will repurpose an abandoned gold mine site as a storage reservoir. These projects complement other pumped hydro investments, including the Snowy 2.0 and Battery of the Nation projects (Section 3.2).

The Australian Government has contributed around $300 million in battery-related research and development since 2015, including providing $25 million in funding for the Future Battery Industries Cooperative Research Centre (FBICRC). Established in 2019, the FBICRC is driving collaboration across industry and research organisations through an ambitious six year R&D program targeting all segments of the battery value chain.

2.3.4 Low emissions materials – steel and aluminium

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

Potential for low emissions materials

Low emissions technologies for steel and aluminium will provide a decarbonisation pathway for these globally significant but hard-to-abate sectors.

Decarbonising metal production has two parts:

- decarbonisation of the energy used in smelting
- reducing emissions from the chemical process of converting ore to metal.

Unlocking these technologies will help reduce Australian emissions. Modelling for the Plan projects that, by adopting new technologies, emissions from Australian steel production could fall by over a third by 2050, even as production volumes increase by about two-thirds. McKinsey's analysis suggests that even deeper reductions are possible if we can achieve substantial cost reductions for clean hydrogen and other technologies, with the potential to eliminate nearly all emissions from Australian steel production by 2050.

For aluminium, our modelling projects that emissions per unit of output could fall by around 60% while production and export volumes more than double. McKinsey's analysis shows with technology improvements could enable a 30% reduction in non-electricity emissions associated with aluminium and upstream alumina processing by 2050. Coupled with a deep reduction in Australia's electricity emissions, this has the potential to dramatically reduce emissions from production of these materials.

Unlocking these technologies would also reduce global emissions, as production of steel and aluminium together account for between 4 and 5 Gt CO_2-e worldwide.[32] Australia is well placed to help reduce these emissions by meeting growing future export demand for low emissions steel and aluminium, given our potential to draw on affordable firmed renewable electricity and clean hydrogen.

Government actions to support low emissions materials

Low emissions steel and aluminium production will become attractive in Australia as the costs of firmed renewable electricity and clean hydrogen fall. By driving down costs of clean hydrogen (Section 2.3.1), solar (Section 2.3.2) and energy storage (Section 2.3.3), the Government is laying the foundations for low emissions material manufacturing.

Funding and financing for low emissions materials are available through Australia's Cooperative Research Centres Program, ARENA and the CEFC. The Government, industry and universities are investing more than $200 million towards the Heavy Industry Low-carbon Transition Cooperative Research Centre.[33] The CSIRO is also investing in low emissions materials. It has developed an innovative self-sustaining pyrolysis process to produce 'designer biochar', which could be used to make high-end 'carbon lite' steel.[34]

As the largest producer of both iron ore and bauxite (most of which is exported in the form of alumina[35]), Australia is also focused on technologies that can reduce upstream supply chain emissions. CSIRO is investigating processes that improve iron ore quality and reduce energy consumption and emissions in ironmaking processes. ARENA is investigating if hydrogen and concentrated solar thermal energy can be used in alumina production, a process responsible for 14 Mt CO_2-e in 2020.

2.3.5 Carbon capture and storage (CCS) and carbon capture, use and storage (CCUS)

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

Potential for CCS and CCUS

Large-scale CCUS projects can underpin new low emissions industries (including clean hydrogen) and provide a potential decarbonisation pathway for hard-to-abate industries. CCUS is among the most prospective options for mitigating process emissions from many industrial processes including:

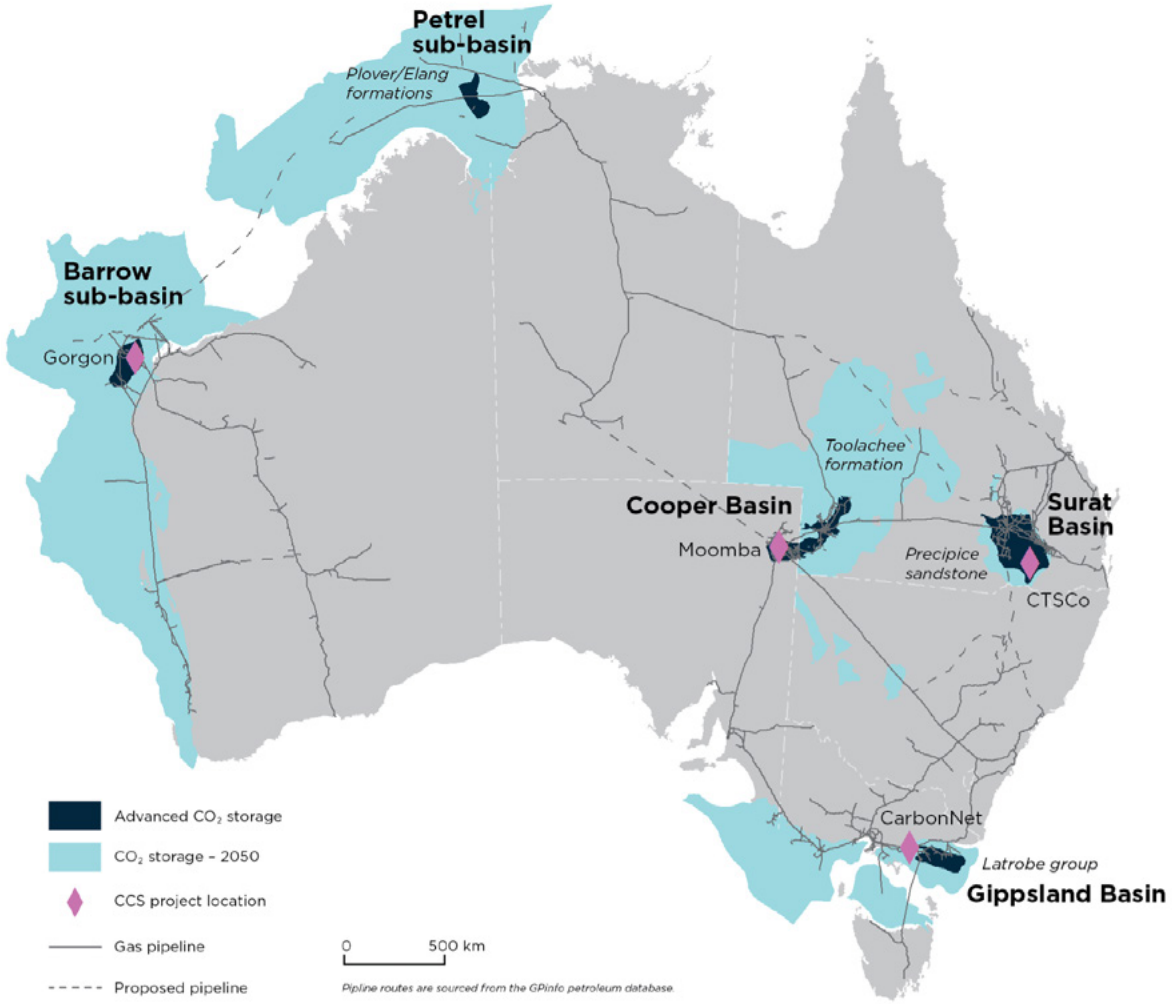
- natural gas processing
- cement production
- steel production
- fertiliser production
- power generation
- hydrogen production from fossil feedstocks.

Australian CCUS projects could also play an important long-term role in negative emissions projects that store CO_2 drawn down from the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has said negative emissions will be crucial in global efforts to meet the Paris Agreement's temperature goals.[36]

Australia's competitive advantage in CCUS comes from our abundant, world-class geological storage basins. Many of these basins are close to industries producing highly concentrated streams of CO_2 emissions.

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 2.6). 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.[37]

Figure 2.6 Prospective CO_2 storage sites in Australia



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.

Government actions to support CCUS

Australia is developing a National CCUS Technology Emissions Abatement Strategy to improve policy frameworks and coordinate the deployment of CCUS hubs and technologies. It is also investing an additional $250 million under the CCUS Hubs and Technologies Program over 10 years from 2021 to support research, development and commercialisation of CCUS technologies.

This builds on the $50 million CCUS Development Fund announced in 2020, which is supporting technologies including:

- direct air capture and removal
- capture and geological storage from power stations
- capture and use of CO_2 in the production of construction materials.

The Government has invested $790 million in CCUS and related low emissions technologies since 2008.

The Government has introduced reforms to ARENA and the CEFC to enable funding and investment in CCS. The Government has also introduced a new ERF method to incentivise CCS and has committed to develop a method for CCUS in 2022.

These opportunities are complemented by bilateral partnerships with key trading countries, including Japan and Singapore.

2.3.6 Soil carbon

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

Potential for soil carbon

Enriching soil carbon draws CO_2 out of the atmosphere, providing an additional way to offset emissions from hard-to-abate sectors such as agriculture, industry and heavy transport. In the modelling for this Plan, Australian soil carbon projects were estimated as having the potential to provide at least 17 Mt CO_2-e of accredited offsets in 2050, in addition to CO_2 drawn from the atmosphere without accreditation.

Offsets from soil carbon projects provide an additional revenue stream for farmers while improving agricultural productivity and soil resilience. Our modelling found landholders could earn around $400 million in additional revenue through the sale of accredited soil carbon sequestration in 2050. Some industry estimates suggest a greater soil carbon potential across Australian pasture and cropping lands, which if realised could offer substantially higher revenue for farmers (Box 2.4).

Government actions to unlock soil carbon's potential

The Government is accelerating the deployment of soil carbon measurement technologies through several research and development (R&D) funding mechanisms:

- The $36 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 is partnering with scientists, industry, landholders and other stakeholders to provide data that helps develop and validate measurement approaches, and can be used to improve models of soil carbon change.
- The $20 million National Soil Science Challenge grants program will help identify the best management practices to increase soil carbon and productivity.
- The CSIRO, rural research and development corporations, and the CRC for High Performance Soils are investing in agricultural innovations, including soil measurement.

The Government also provides incentives for soil carbon sequestration through the ERF. Advance payments of up to $5,000 are available to help with upfront costs of soil sampling. The CER is developing a new soil carbon ERF method that lets projects combine direct sampling with model-based approaches.

The CEFC is also investing in the agricultural technology sector to build the industry's capabilities. This includes a $1.7 million investment in the Soil Carbon Company, which is developing a microbial treatment for seeds that could increase soil carbon levels, enabling improved water retention and increasing the ability of crops to withstand extreme weather.

The National Soil Strategy is helping farmers and land managers monitor, understand and make better decisions about their soil health, productivity and sequestration potential.

This includes the $54.4 million National Soil Monitoring and Incentives Pilot to trial new measures to incentivise soil testing and data sharing. This will improve our understanding of Australia's soil condition and how our soil can be better managed. Soil data from land managers will also be used to validate soil carbon modelling and reporting.

Box 2.4 Potential revenue opportunities for farmers from soil carbon

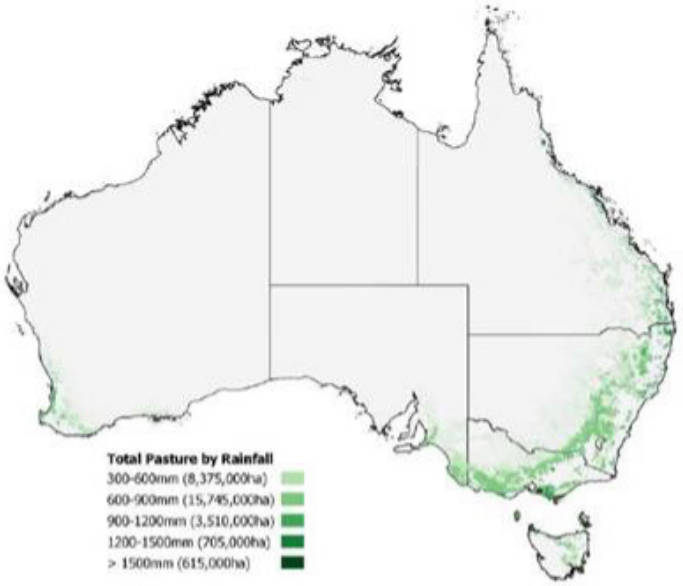
There is growing interest in increasing soil carbon levels on Australia's agricultural land, and the ERF has recently seen a rapid rise in adoption of soil carbon projects. Many new projects are still at an early stage, so there is limited data available on how much carbon these projects can store across Australia over time.

However, a range of estimates provide indications of the contribution soil carbon projects could make to reducing emissions. The 2020 Low Emissions Technology Statement drew on CSIRO analysis in noting the potential for improved management of one quarter of Australia's crop and grazing lands (including the extensive low-rainfall rangelands) to secure as much as 35-90 million tonnes per annum through soil carbon.

Other estimates indicate the potential could be higher. For example, leading soil carbon project developer Agriprove has conducted detailed analysis of soil carbon sequestration potential on cropping and grazing land across different rainfall zones. Agriprove's analysis indicated the national potential across cropping and grazing land (not including lower rainfall rangelands) could be at least 103 million Australian Carbon Credits Units annually.

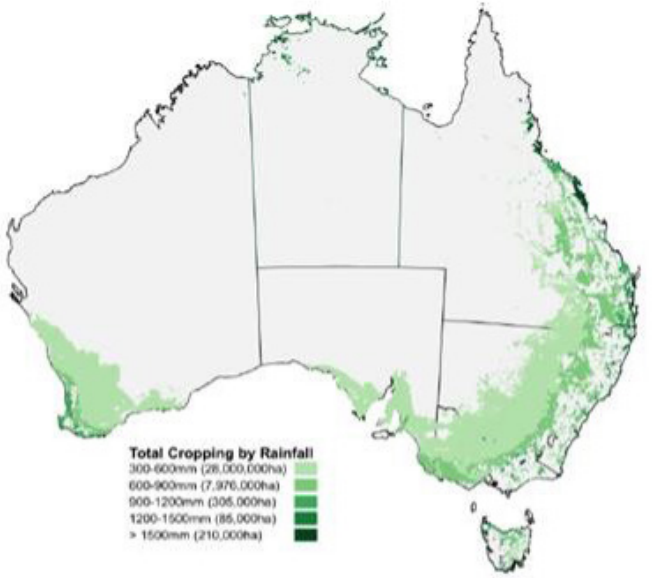
Source: Agriprove analysis, www.agriprove.io

Pasture and SOC Potential



Potential for soil organic carbon sequestration by pasture land use and rainfall zone in Australia			
Rainfall (mm)	ha	ACCUs/ha	ACCUs/yr
300 – 600	8,375,000	1.5	12,562,500
600 – 900	15,745,000	2.5	39,362,500
900 – 1200	3,510,000	3.3	11,583,000
1200 – 1500	705,000	4.3	3,031,500
>1500	615,000	4.5	2,767,500
Total	28,950,000		69,307,000

Cropping and SOC Potential



Potential for soil organic carbon sequestration by cropping land use and rainfall zone in Australia			
Rainfall (mm)	ha	ACCUs/ha	ACCUs/yr
300 – 600	28,000,000	0.8	22,400,000
600 – 900	7,976,000	1.25	9,970,000
900 – 1200	305,000	1.6	488,000
1200 – 1500	85,000	2.1	178,500
>1500	210,000	2.25	472,500
Total	36,576,000		33,509,000

2.4 Emerging technologies

There are a number of emerging technologies, in addition to the six priority technologies highlighted in the 2020 and the forthcoming LETS 2021, which are likely to play an important role in helping Australia meet its net zero by 2050 goal.

The roadmap process means that high potential emerging technologies can become priority low emissions technologies over time.

Australia is continuing to invest in these technologies and create the market conditions and environment to realise their full potential.

Livestock feed supplements

A major focus is identifying technological solutions for reducing methane emissions from livestock. This is Australia's largest source of agricultural emissions and represents around 10% of our total emissions.

Promising technologies include:

- feed supplements, including red algae, chemical inhibitors and tannins, as identified in the forthcoming LETS 2021
- alternative forage feeds
- genetic selection and breeding for low methane traits.[38]

Some technologies have the potential to reduce livestock methane emissions by over 80%.[39]

Controlled delivery of feed supplements is possible in feedlot environments. But 95% of Australia's livestock are grazing animals, so we are supporting the development of mechanisms to deliver feed supplements in grazing systems. Some feed supplements have also demonstrated good productivity benefits potential. If these benefits are realised when delivered in grazing systems, they will provide additional revenue to farmers and rural areas. They will also support the sector's ambition to reduce emissions, grow and create new jobs.

Australia is directing $30.7 million over six years towards these promising feed technologies:

- The $6 million Methane Emissions Reduction in Livestock program supports research into the abatement potential and productivity benefits of livestock feed technologies.
- The $23 million Low Emissions Supplements to Grazing Animals at Scale program will help develop technologies to deliver low emissions feed supplements to grazing animals.
- $1.7 million to scale-up production of the red seaweed, *Asparagopsis*, including:
  - a $1 million Accelerating Commercialisation grant under the Entrepreneurs' Program to scale-up production and support the commercialisation of *Asparagopsis*
  - a $675,000 grant from the $30 million Commercialisation Fund to establish a processing and manufacturing facility for this seaweed product.

The Government, industry and universities have also invested $270 million towards a new Marine Bioproducts CRC, which will aim to develop high-protein seaweed for use as a low emissions livestock feed.[40]

Low emissions cement

Australia is well placed to develop a low emissions cement industry, as highlighted in the forthcoming LETS 2021.

Cement is the key ingredient in concrete and is the most widely used construction material in the world. The Australian cement and concrete industry supports tens of thousands of Australian jobs.

The Australian cement industry has already reduced annual emissions by over 20% since 2010. The use of renewable electricity, improving energy efficiency and clinker substitution can help reduce emissions associated with the industry. CCUS will play a particularly important role in capturing the CO_2 released when converting limestone into clinker, the main ingredient in cement.

Noting the significant potential in this sector, the Government has invested $75 million for CRCs including the SmartCrete CRC, Building 4.0 CRC and Low Carbon Living CRC. The CEFC also finances commercial and industrial building projects that reduce embodied carbon by using lower emissions cement. The Government's investment in priority technologies like energy storage and CCUS also supports emissions reductions at various points along the value chain.

2.5 National agencies driving technology investment

The Technology Investment Roadmap will guide at least $20 billion of Australian Government investment over the next decade. The Government is aiming to drive at least $80 billion of new investment by 2030 by working with state and territory governments, research institutions and the private sector. This investment will create 160,000 jobs by 2030, more than half in regional areas.

Australia has dedicated agencies to deliver this investment, including ARENA, the CEFC and the Clean Energy Regulator. Other Australian science and research institutions and bodies also make important investments in low emissions technologies (Box 2.5 and Figure 2.7).

ARENA

ARENA's purpose is to support the global transition to net zero emissions by accelerating the pace of pre-commercial innovation, to the benefit of Australian consumers, businesses and workers.

ARENA has funded over $1.8 billion of early-stage research and development projects since 2012. It has supported advances in solar, wind and other renewable energy technologies, as well as enabling technologies like energy storage and grid integration.

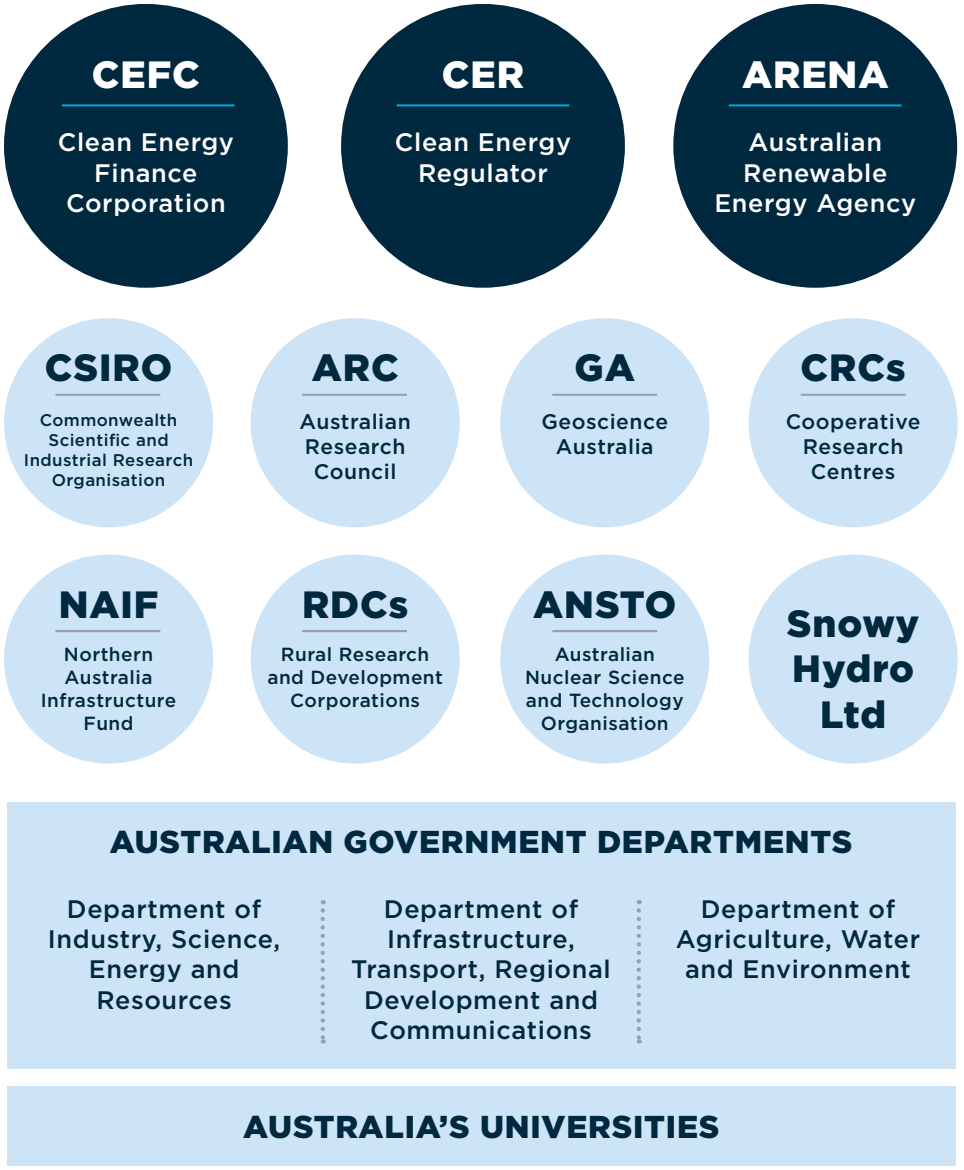
Recognising the need to unlock abatement across the economy, the government has given ARENA over $1.4 billion of funding for the period up to the 2031–32 financial year. This includes baseline funding and targeted programs for key technologies, including industrial energy efficiency and regional microgrids. The Government has also recently expanded ARENA's mandate to cover low emissions technologies in all sectors, including agriculture and transport.

CEFC

The purpose of the CEFC is to facilitate increased flows of finance into Australia's clean energy sector. It achieves this by investing directly and indirectly with co-investors. In doing so, it encourages and facilitates others to also invest in renewable energy, energy efficiency and low emissions technologies and projects.

The $10 billion CEFC is the world's largest government-owned 'green bank'. It has invested more than $9.5 billion in clean energy projects worth more than $32.8 billion. It supports the commercialisation of renewable energy and low emissions technology projects through loans and equity investments.

Figure 2.7 National agencies and bodies driving low emissions technology investment



By providing financial support, the CEFC has helped de-risk low emissions technologies across electricity generation, energy storage, industry and agriculture. It has also played an important role in developing an Australian sustainable finance sector.

Clean Energy Regulator

The purpose of the CER is to accelerate carbon abatement in Australia. It achieves this by administering a range of government schemes to measure, manage, reduce or offset Australia's carbon emissions. This includes Australia's ERF, which supports the creation, verification and purchase of Australian Carbon Credit Units (ACCUs) (see section 3.5).

To date, the CER has committed around $2.5 billion towards emissions reduction projects in the following sectors:

- agriculture and land (particularly revegetation projects)
- landfill and waste
- energy efficiency
- industry
- transport.

The CER also administers:

- Australia's National Greenhouse and Energy Reporting scheme
- the National Registry of Emissions Units
- the Large-scale and Small-scale Renewable Energy Targets

The CER is also helping voluntary carbon markets emerge and mature in Australia. It is developing an exchange trading platform for ACCUs and developing frameworks to give confidence to investors and consumers as new technologies and industries evolve. These include a Hydrogen Guarantee of Origin Certification scheme, in collaboration with DISER and the Australian Carbon Exchange.

Box 2.5 CSIRO National Missions

In 2020, the CSIRO announced a missions program with $100 million directed annually to the co-creation of large-scale scientific and collaborative research initiatives.

The program is aimed at solving some of Australia's greatest challenges, focused on outcomes leading to positive impact, new jobs and economic growth. They have ambitious goals, like:

- developing transition pathways to net zero emissions
- building Australia's clean hydrogen industry
- helping Australian businesses navigate the uncertainty of climate change.

They are being developed with broad coalitions of partners, working with governments, universities, industry and the community.

Key CSIRO missions are closely aligned with the Plan. Their goals include:

- finding profitable pathways to net zero by putting low emissions technologies into practice (systems of use) with industry and regional communities
- building Australia's clean hydrogen industry and reducing the cost of hydrogen to under $2 per kilogram, enabling hydrogen to be globally competitive
- addressing the complex problems and developing solutions for the private sector in response to the risks of a changing climate
- delivering cost competitive and sustainable battery materials to the world.

3. ENABLING DEPLOYMENT AT SCALE

Key points

- Achieving net zero by 2050 emissions will require low emissions technology to be deployed at scale across all sectors of the economy.
- As well as making these technologies cheaper, the Australian Government is tackling the challenges that may otherwise slow technology deployment across the economy.
- The Government is supporting business to lead technology deployment by putting in place the right measures and incentives. It is playing an enabling role to unlock investment and scale up technology deployment. This includes cross-cutting measures that apply across all sectors, and measures focused on overcoming barriers to technology deployment in individual sectors. These measures include:
  - investing in enabling infrastructure
  - providing consumers with transparent information
  - facilitating growth in voluntary carbon markets, and
  - incentivising voluntary action.

3.1 Enabling technology deployment across all economic sectors

A key principle of this Plan is that technology deployment will be led by the private sector. The Government will help by clearing the path, removing barriers and pulling policy and other levers that can enable technology adoption to occur at the necessary scale.

As well as making low emissions technology cheaper, the Australian Government is tackling the challenges that may otherwise slow technology deployment across each sector (Figure 3 1). Working with business and other levels of government, the Government is:

- planning and building the enabling infrastructure needed to catalyse technology deployment
- giving consumers and markets the information they need to de-risk technologies and make informed decisions
- providing the high integrity accounting systems and trading infrastructure necessary to grow voluntary carbon markets
- providing incentives and finance to encourage voluntary adoption of technology.

This chapter outlines the policies and investments the Government is implementing to address the challenges that could slow technology deployment in each sector.

In addition to these sector-based measures, Australia has introduced cross-cutting initiatives enabling voluntary emissions reductions across all sectors. For example, the CEFC is financing low emissions technologies across the economy, and ACCUs can be created for a wide spectrum of activities under the ERF. Climate Active – Australia's globally recognised carbon neutral certification scheme – provides transparency to consumers and motivates firms to become leaders in emissions reduction and technology (Box 3.1).

Figure 3.1 Enabling deployment at scale across all sectors

Electricity

Critical pathways – low emissions electricity

Priority technologies – ultra low-cost solar, energy storage

Achieving deployment at scale

- Investing in enabling infrastructure, like Snowy 2.0, transmission and interconnectors
- New regulations to support new technologies, like offshore renewable energy
- Planning for renewables growth through AEMO's ISP and post-2025 electricity market reform

Transport

Critical pathways – low emissions electricity, electrification, alternative fuels

Priority technologies – clean hydrogen, energy storage

Achieving deployment at scale

- Investing in enabling infrastructure, like EV recharging and hydrogen refuelling
- Improving heavy vehicle energy productivity and knowledge sharing

Buildings

Critical pathways – low emissions electricity, electrification, energy efficiency

Priority technologies – ultra low-cost solar, energy storage, clean hydrogen

Achieving deployment at scale

- Improving energy efficiency through standards, information, tools and disclosure.
- Lowering costs through incentives and finance
- Developing workforce skills and supply chains

Agriculture and the land sector

Critical pathways – land-based solutions, other emerging technologies

Priority technologies – soil carbon

Achieving deployment at scale

- Investing in offset projects through the Emissions Reduction Fund and Carbon + Biodiversity Pilot
- Building voluntary markets for carbon offset projects
- Developing livestock feed technologies for large-scale deployment
- Improving digital technologies and capabilities

Industry, mining and manufacturing

Critical pathways – electrification, clean hydrogen, CCUS

Priority technologies – clean hydrogen, CCUS

Achieving deployment at scale

- Incentivising uptake of low-emissions technology through the Safeguard Crediting Mechanism
- Supporting business cases and feasibility studies for energy efficiency upgrades and low emissions technologies
- Targeted regulations to improve equipment efficiency and phase down HFCs

CROSS-CUTTING

- Investing in R&D through ARENA, CSIRO, CRCs and other agencies
- Providing finance through the CEFC
- Investing in cross-cutting technologies including hydrogen and CCUS
- Incentivising offset projects through the Emissions Reduction Fund
- Certifying carbon neutral businesses through Climate Active
- Assessing cross-cutting infrastructure needs for priority technologies, including hydrogen, energy storage, and CCUS

The forthcoming LETS 2021 will underscore the central role of the Australian Government in building and planning enabling infrastructure. It introduces enabling infrastructure as a new technology category under the Technology Investment Roadmap, and identifies a digital grid and battery charging and hydrogen refuelling stations as initial investment priorities.

The Government will also committed through the forthcoming LETS 2021 to assess the cross-cutting infrastructure needs for priority technologies, building on the National Hydrogen Infrastructure Assessment already underway. This includes exploring ways to reduce costs by co-locating hydrogen, energy storage, and CCUS infrastructure with manufacturers of steel, aluminium and other commodities.

Box 3.1 Climate Active

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

Climate Active certifies businesses that reach net zero emissions by measuring, reducing and offsetting emissions against a best-practice carbon accounting standard. Certification is available for buildings, events, organisations, precincts, products and services.

Businesses with certifications through Climate Active include Telstra, Energy Australia, Qantas and ANZ, as well as many smaller businesses, schools, universities and councils.

Australia's rigorous carbon neutral certification is an effective way to encourage businesses to reduce their emissions. Climate Active certification sends a clear signal to clients, customers and stakeholders that businesses are committed to sustainability, innovation, and industry leadership.

Climate Active's membership has doubled in the last 12 months, with over 370 certifications across more than 240 Australian businesses. Thousands more businesses are expected join in coming years to align with investor, regulatory and consumer interests.

3.2 Electricity

Technology pathways, trends and barriers to deployment

Ultra low emissions electricity generation is central to Australia achieving net zero emissions by 2050. Electricity generation is Australia's largest source of emissions, responsible for 179 Mt CO_2-e, or 34% of emissions in 2019. Other sectors, like transport, buildings and industry, can decarbonise by switching to clean electricity. We can also use clean electricity to produce alternative fuels like clean hydrogen. It follows that low emissions electricity will enable much of Australia's economy to shift onto low emissions pathways.

Our modelling describes one scenario for how Australia's electricity sector could decarbonise. Under this scenario, declining technology costs enable the sector to achieve near zero emissions, with variable renewable energy providing more than 85% of total generation. Our modelling forecasts there will still be some coal and a significant proportion of gas in the electricity grid in 2050.

Australia's electricity sector has already begun down this pathway. Australia's latest emissions projections estimate the share of renewable generation will increase from 23% of total generation in 2020 to 61% by 2030.[42] Residential solar PV will continue to be popular [43] , and more than half of Australian homes could have solar PV systems by 2050.[44]

Over $35 billion has been invested in renewable energy in Australia since 2017.[45] World-leading deployment of renewables, including both large-scale and rooftop solar, has been driven by declining technology costs and financial support and knowledge sharing by ARENA and the CEFC. The RET and state government incentives have supported this by helping build a local industry and supply chains, and underpinning programs like Climate Active and Green Power. With renewable energy increasingly cost-effective in many parts of Australia even without subsidies, this investment looks set to continue.

However, the pace and scale of renewables deployment is also creating technical challenges for our electricity systems. If the integration of variable technologies is poorly managed, it could slow future deployment and make Australia's electricity supply less secure, reliable, and affordable. The key challenge for the sector will be to ensure the share of renewables can grow while maintaining system services and ensuring consumers can access affordable electricity when they need it.

Existing technologies can help manage these issues.[46] Batteries are already providing short-term firming and system services. Longer term firming technologies, alongside an expanded transmission grid, can provide seasonal storage and protection against weather variability. These could include pumped hydro, biomass, or new thermal generators combined with CCS.

Further in the future, other emerging technologies like new battery technologies, electric vehicle-to-grid and hydrogen will also help enable ongoing renewables deployment. There may also be the potential for Australia's domestic demand to be reliably met by very large, export-oriented electricity systems that produce 200% or more of Australia's needs [47] , or for modern third and fourth generation nuclear technologies to be deployed in Australia.

Addressing these barriers

The Australian Government is making major strategic infrastructure investments to enable ongoing renewables deployment. This includes our $1.38 billion investment in Snowy 2.0, which will add 2000 MW of dispatchable generation to the National Electricity Market.

Investments in transmission, interconnector and storage projects such as the MarinusLink interconnector, Project EnergyConnect interconnector and Tasmania's Battery of the Nation will provide vital support to the grid and connect new firm capacity. The Australian Government has supported or underwritten investment in more than $2.6 billion of new transmission. These projects will also create jobs, keep energy prices low and reduce emissions.

The Government is also making strategic investments in new dispatchable generation, including through the Underwriting New Generation Investment Program and its investment through Snowy Hydro Limited to construct a 660 MW open cycle gas turbine in NSW. The Government has committed $24.9 million in funding to support new gas generators to be hydrogen-ready.

The CEFC and ARENA are also making substantial investments in electricity generation, storage, transmission and other enabling technologies (see section 2.3).

The Australian, state and territory governments are working together and co-investing to enable the smooth integration of low emissions technologies into the electricity grid. The Australian Government has agreed 3 bilateral state deals – with NSW, Tasmania and South Australia – leveraging overall investment of more than $3 billion in energy and emissions reductions projects. These deals are:

- increasing gas supply
- supporting transmission, interconnectors and renewable energy zones
- reducing emissions through low emissions technology development.

Microgrid technology is becoming increasingly cost effective, creating the opportunity for a reliable, low-cost, low-emissions energy supply to regional communities and industries in off-grid and fringe-of-grid locations. In 2019–20, the government committed $50.4 million to the Regional and Remote Communities Reliability Fund to support feasibility studies into microgrid development and installation. A further $53.9 million was committed in 2020–21 through the Regional Australia Microgrids Pilots program to build on this fund through pilot studies.

Longer term challenges

Over the long term, the challenge will be to ensure Australia's electricity systems remain secure, reliable and affordable as variable renewable energy achieves an increasingly higher share of the energy market. Australia's governments and energy market bodies are preparing for this challenge.

A current priority for governments is delivering a long term, fit-for-purpose post-2025 market design for the National Electricity Market (Australia's largest electricity market and electricity grid). Advised by the Energy Security Board (ESB), governments are reforming systems, tools, and regulations so they can meet long-term consumer interests in this key market. Governments are also considering more immediate reforms to address the impacts that greater penetration of renewable energy generators are having on the National Electricity Market and to enable further renewables integration. The ESB's work is also seeking to deliver new market-based arrangements (where possible) to value the essential system services needed to support the changing mix of generation resources in the National Electricity Market.

Australia is also putting in place regulatory and institutional arrangements so new technologies can be deployed and integrated into our energy systems. For example, Australia is developing a regulatory framework for offshore energy technologies and infrastructure.

Governments, on the advice of the ESB, have adopted reforms such as Renewable Energy Zones planning rules. Renewable Energy Zones are areas where there is planned integration of renewable energy generators, storage and transmission into electricity grids. Victoria, NSW and Queensland are also developing state-based frameworks to stimulate investment in Renewable Energy Zones.

The transformation of Australia's electricity system is making the planning, investment and operation of the grid more complex. The Australian Energy Market Operator (AEMO) is world-leading in responding to these changing needs, and has responded by developing Integrated System Plans (Box 3.1) and an enhanced digital operating system. The forthcoming LETS 2021 will recognise that 'digital grid' technologies will be fundamental to a low emissions economy, and ARENA has contributed $2.23 million to support AEMO's work in this area.

Box 3.2 Australian Energy Market Operator's Integrated System Plan

The Integrated System Plan (ISP) is a whole-of-system plan to maximise market benefits and deliver low-cost, secure and reliable energy under a range of plausible energy futures to 2040 for the National Electricity Market.

The ISP is developed every 2 years. It identifies development opportunities and recommends priority transmission projects.

The ISP is informed by detailed consultation and sophisticated energy system modelling. Analysis for the 2020 ISP looked at a range of scenarios to 2040, including slow technology adoption and a step-change scenario characterised by rapid technology change and significant electrification of the transport and industrial sectors.

Based on the analysis performed, the ISP identified targeted transmission augmentations and transmission investments to support the change in generation mix. The aim is to ensure augmentation costs are kept to an efficient level, as well as strategically place interconnectors and Renewable Energy Zones coupled with energy storage. This is viewed as the most cost-effective way to allow for added capacity and to balance variable resources across the National Electricity Market.

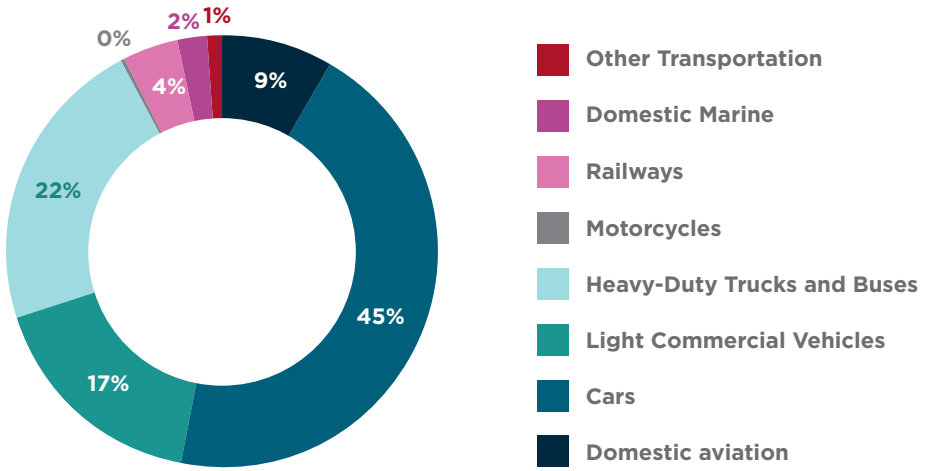
AEMO has begun work on its 2022 ISP, including updated scenarios for renewables deployment and a new scenario involving substantial growth in an Australian hydrogen industry.

3.3 Transport

Technology pathways, trends and barriers to deployment

Transport is Australia's largest end user of energy and in 2019 contributed around 19% of the nation's emissions. Substantial emissions reductions from transport are needed for Australia to achieve net zero emissions by 2050 – especially road transport, which is responsible for more than 80% of the sector's emissions (Figure 3.2). Global developments are unlocking new vehicle technologies, and our modelling shows that enabling the deployment of EVs and other low emissions transport technologies in Australia can help reduce transport emissions by 58% by 2050.

Figure 3.2 Transport emissions sources by source, 2019



Source: *National Greenhouse Gas Inventory*

McKinsey analysis found electric vehicles could reduce emissions by up to 80 Mt CO_2-e across the economy between 2019 and 2050, contributing around 15% of Australia's overall 2050 abatement task.

Electric vehicles are becoming more accessible and affordable, with global car manufacturers increasingly offering electric models across their ranges. Market take-up will likely accelerate once EVs reach price parity with conventional vehicles. Some experts forecast this could occur by around 2025 for shorter range electric vehicles as the affordability of batteries improve.[48]

In the short term, high international demand for EVs could constrain global supply chains, and this could slow deployment of these vehicles in Australia. Over the long term, public charging and refuelling infrastructure will need to be widely available and convenient for new transport technologies to be deployed at scale. This will be particularly important for consumers that routinely travel long distances or do not have access to off-street parking. Coordinated planning will also be needed to integrate both charging and refuelling infrastructure with existing transport and energy networks.

Reducing emissions in heavy transport applications, like long distance heavy road freight, aviation and shipping, may need to rely on use of hydrogen, ammonia, biofuels, and synthetic fuels, particularly where use of battery EVs may be impractical or unsuitable.

Addressing these barriers

Recent trends are promising. Fast charging networks have expanded and will soon cover highways from Adelaide to Brisbane. Charging points are becoming more common in urban and regional areas. According to industry estimates, the number of charging stations in Australia increased by almost 25% over the year to July 2021.[49]

However, public and private investment in battery electric charging infrastructure needs to increase to build consumer confidence and enable large-scale uptake. Investment is also needed in refuelling infrastructure for hydrogen and other alternative fuels. The Australian Government is tackling these issues through the forthcoming Future Fuels Strategy and a range of Government investments (Box 3.2). It will also develop a new ERF method to further incentivise the rollout of low emissions transport infrastructure. States and territories are also making substantial investments towards recharging networks.

Australia is also helping the heavy vehicle fleet to reduce emissions. The $24.5 million Freight Energy Productivity Program will increase the use of new truck technology and improve knowledge sharing for heavy vehicle freight operators. Both CEFC and ARENA have invested in projects demonstrating hydrogen use in heavy transport.

Box 3.3 Future Fuels Strategy and Government investment

Australia's forthcoming Future Fuels Strategy will be supported by measures that enable consumer choice, stimulate industry development and reduce emissions in the road transport sector. The Strategy will build on a range of existing work and investments, including:

- The Future Fuels Fund, which is:
  - helping businesses integrate new vehicle technologies into their fleets
  - reducing blackspots for public charging and refuelling infrastructure in both regions and cities
  - unlocking opportunities for heavy vehicle fleets to upgrade to utilise new transport technologies
- The Government is also investing in:
  - critical reforms to ensure the grid is 'EV-ready' and analysis to inform the roll out of charging and refuelling infrastructure
  - better information on EVs and charging infrastructure to support consumer choices.
  - $21 million of ARENA funding to roll out ultra-fast charging sites along 2 highway networks
  - up to $1.3 billion of CEFC finance made available to assist uptake of low and zero emissions vehicles
  - $25 million for the Future Battery Industries Cooperative Research Centre, which will develop Australia's battery industry, including batteries for transport

Longer term challenges

Cars in Australia typically remain on the road for 10 to 15 years. Encouraging fleets to adopt low emissions vehicles could rapidly increase demand and accelerate the uptake of new vehicle technologies, including EVs. Fleets buy almost half of the new cars[50] and many trucks in Australia, and seed much of the second-hand vehicle market. Some businesses are already leading in this area – in May 2021, Splend (a provider of vehicle subscriptions for Uber drivers) placed Australia's largest ever order for EVs.[51]

The Australian Government has prioritised an early focus on infrastructure and commercial fleets through the Future Fuels Fund. Investments made through the fund are complemented by work already underway through existing intergovernmental forums and energy market bodies on infrastructure planning, road-related revenue, and integration of electric vehicles into transport systems and energy networks. Global industry efforts to bring down the cost of EVs to price parity with conventional vehicles will enable wider scale adoption.

Bioenergy could also present pathways to reduce emissions in transport, as well as other sectors like electricity and industry. Through its forthcoming Bioenergy Roadmap, ARENA is exploring the potential economic opportunities for Australia, particularly regional areas, and the role that bioenergy could play. This will help assess where Australia has a competitive advantage and inform the Australian bioenergy sector's next investment and policy decisions. Bioenergy can create thousands of new jobs and attract billions in investment, particularly in agriculture and other regional industries.[52]

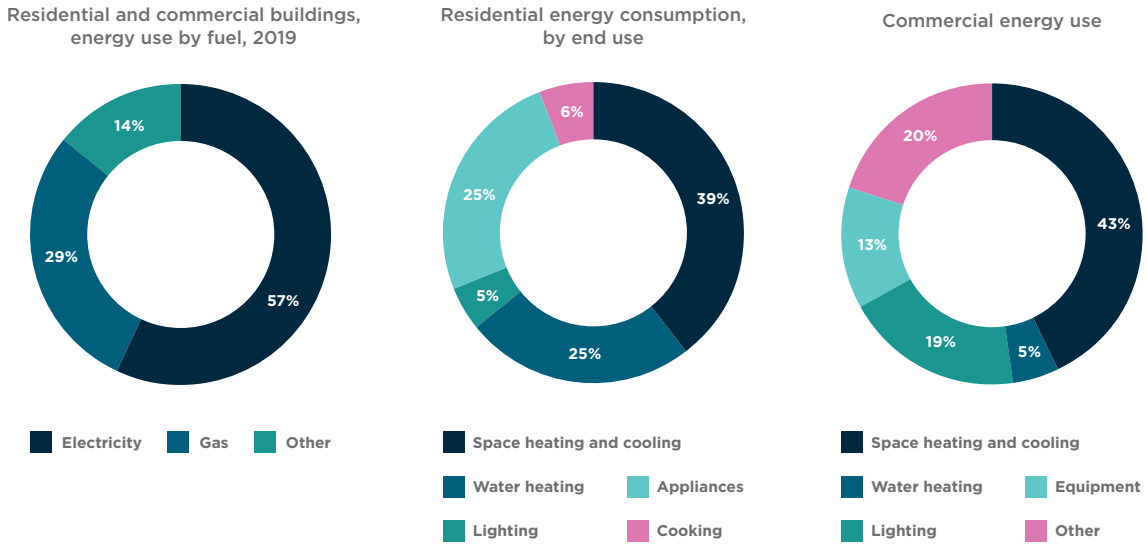
Decarbonising aviation and shipping will take longer to achieve, as it will require new technologies and global supply chains. Modelling for the Plan found global aviation and shipping emissions is expected to decline modestly, despite the value of these sectors more than doubling. Industry actions are promising. For example, Fortescue Metals Group is examining the use of clean ammonia in shipping, [53] and Qantas and Virgin are investing in sustainable aviation fuels.[54] As decarbonising these sectors will require global collaboration, Australia is working with industry and other nations through the International Maritime Organisation and International Civil Aviation Organisation. Australia has also committed to working through the Quad partnership, with India, Japan and the United States, on efforts to decarbonise shipping and port operations.

3.4 Buildings

Technology pathways, trends and barriers to deployment

Residential and commercial buildings contributed around a quarter of Australia's emissions in 2019 and account for just under half of Australia's electricity consumption. Our analysis shows the sector will need to nearly decarbonise by 2050 for Australia to meet its economy-wide net zero goal.

Figure 3.3 Indicative energy use in Australia's buildings: (a) residential and commercial buildings fuel consumption, (b) residential energy consumption by end use, and (c) commercial energy consumption by end use



Sources: *(a) Australian Energy Statistics[55] (b) Energy Consult[56], and (c) CSIRO[57]*

Box 3.4 – **Case study** – Low emissions technologies in Australian homes

A new 2-storey family home in Melbourne uses a mix of technologies to lower energy bills, improve comfort and health, and reduce emissions.

Even with minimal heating and cooling, the house enjoys comfortable temperatures all year round thanks to solar access, insulation, a heat recovery ventilation system and other technologies. A 5 kW solar system generates almost twice the energy the building consumes, while a high-efficiency water heat pump acts like a battery by capturing surplus solar electricity.[65]

Further North, a new one-storey home in Darwin uses a mix of technologies tailored to its tropical climate, including a split system air-conditioning unit rated as having good cooling performance in the Darwin climate according to the ZERL, and a solar hot water system to maximise energy efficiency.

Electricity makes up almost two-thirds of the energy buildings use, so a near-zero emissions electricity grid will allow buildings to significantly reduce emissions (Figure 3.3). Building owners, occupants and builders can accelerate these emissions reductions by deploying:

- high efficiency appliances, lighting, equipment and building envelopes
- on-site renewable energy (like solar PV) and battery storage.

Eliminating emissions from space heating, water heating and cooking is already technically possible through efficiency and electrification. Alternative fuels like hydrogen, biomethane and synthetic gas may provide additional options.

McKinsey analysis found that widespread adoption of low emissions technologies could enable nearly all emissions from Australia's buildings to be eliminated by 2050.

Cost-effective low emissions technologies are already being widely deployed in some building classes, like new top-tier commercial buildings.[58] Many new Australian homes are also adopting cutting edge technologies (Box 3.3). However deployment is slower for other building types due to:

- financial barriers, particularly upfront capital costs
- split incentives between landlords and tenants as well as builders and occupants
- the technical nature of renewable generation, batteries and energy efficiency, which makes decisions difficult for many households and businesses.

Addressing these barriers

Governments in Australia have implemented policies to address these barriers:

- The Nationwide House Energy Rating Scheme (NatHERS)[59] provides voluntary energy ratings for residential buildings, and the Your Home[60] guide provides information. These improve transparency for buyers and tenants and help motivate building owners to improve efficiency.
- The National Australian Built Environment Rating System (NABERS)[61] provides voluntary energy ratings for many commercial building sectors. The Commercial Building Disclosure program provides a mandatory energy performance disclosure framework for commercial office buildings. Together these schemes improve transparency for buyers and tenants and help motivate building owners to improve efficiency.
- The *Greenhouse and Energy Minimum Standards Act 2012* is improving the energy efficiency of appliances and equipment and making decisions easier for consumers.

- Consumer choice is being made easier through appliance labelling, including the Zoned Energy Rating Label (ZERL) used for air-conditioning units. This provides seasonal efficiency ratings for distinct climate zones, enabling stronger household engagement in energy efficiency decision-making.
- Financial barriers are being addressed by the CEFC, state energy efficiency schemes and Australian Government programs like the Hotel Energy Uplift and Powering Communities programs.

Longer term challenges

In 2019, the Australian, state and territory governments agreed the Trajectory for Low Energy Buildings. This national plan sets a trajectory towards zero energy (and zero carbon) ready commercial and residential buildings for Australia.[63] It includes 14 measures covering:

- better information, guidance and tools
- energy efficiency in the National Construction Code
- skills and supply chain development.

The trajectory will accelerate the deployment of low emissions technologies across both new and existing buildings. Changes to the National Construction Code can deliver increasing energy efficiency of new buildings. However, residential and commercial buildings have long lifetimes and slow turnover. This means that by 2050, around 7 million homes and a third of commercial buildings will not be subject to improved energy efficiency measures in the National Construction Code.[64]

For existing buildings, the trajectory is progressing initiatives to provide information for households and businesses, expand energy rating tools and improve energy efficiency in rental properties.[65]

To significantly reduce emissions from buildings, governments may need to consider additional measures that encourage large-scale refurbishments and technology adoption in existing buildings,[66] and thereby speed up the improvement of the existing stock.

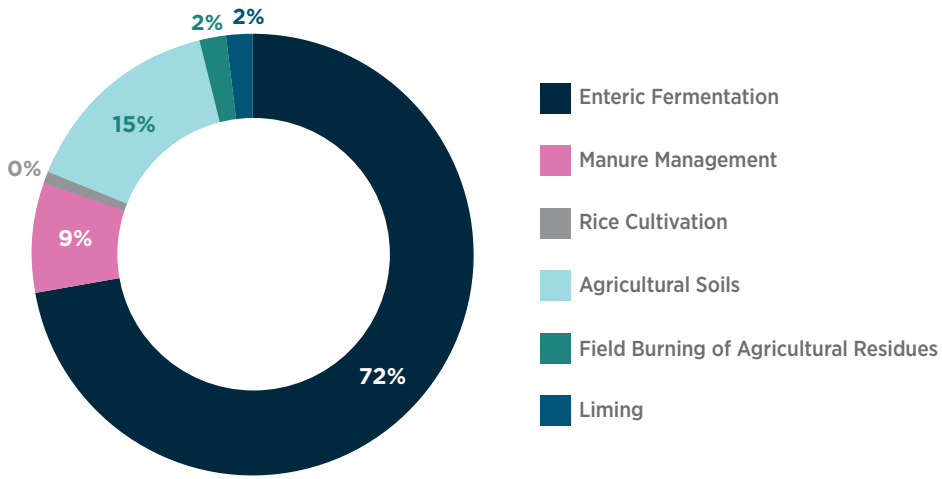
Non-financial barriers to deployment will persist across new and existing buildings, and further measures by governments may be needed. This could include measures to encourage the adoption of better performing appliances, equipment and buildings, such as expanded disclosure frameworks for additional building classes and precincts, which improve transparency and support consumer choice.

3.5 Agriculture and the land sector

Technology pathways, trends and barriers to deployment

In 2019, direct agricultural emissions contributed around 14% of Australia's total greenhouse gas emissions and around half of its methane emissions. Emissions from livestock dominate the sector and represent around 10% of the nation's emissions (Figure 3.4). The land sector is a net sink for greenhouse gas emissions, drawing 25 Mt CO_2-e out of the atmosphere in 2019 and helping reduce overall emissions from other sectors of the economy.

Figure 3.4 Agriculture, direct emissions sources, 2019



Source: *National Greenhouse Gas Inventory.*

Modelling for the Plan found Australian agricultural output could climb to $112 billion in 2030 (above the $100 billion industry goal) and $131 billion by 2050 while emissions fall to 36% below 2005 levels. Australian farmers and land managers can achieve this outcome by adopting low emissions technologies and abatement practices. These can include improving soil carbon, changing grazing practices, using livestock feed to reduce methane, and changing nitrogen application in cropping systems.

Many agricultural businesses in Australia are already adopting low emissions technologies and whole-farm management practices, and positioning to capture emerging markets for produce with low emissions footprints. For example, NAPCO, one of Australia's largest cattle companies, with 200,000 cattle over 6 million hectares, has certified Australia's first carbon-neutral beef through Climate Active. This has involved improving livestock management, converting to renewable energy, and purchasing land sector offsets through the ERF and international carbon markets.

However, the costs of establishing and maintaining projects remain a material barrier to reducing emissions in the sector. Many abatement activities provide benefits to farmers, including improved productivity, resilience and market competitiveness[67], but involve upfront costs. In other cases, abatement projects can result in foregone revenue if they cannot generate income in other ways.

Addressing these barriers

Incentives available through the ERF are helping to overcome these cost barriers. Around $2.5 billion has been committed to date through the ERF towards projects that reduce or avoid emissions or store carbon in the land. Regional areas have benefited strongly – since the program started, the Government has contracted more than 80% of the 209 Mt CO_2-e emission reductions from the agriculture and the land sector. ERF projects have also improved biodiversity and agricultural productivity and created employment opportunities for Indigenous Australians (Figure 3.5).

Carbon offsets can help farmers diversify their income and improve landscape resilience. Alternatively, farmers can use their offsets to market low emissions produce to premium markets. There are many opportunities to store carbon in ways that align with existing farm business objectives and improved productivity (Box 3.4).

The Government is continually looking for new ways the ERF can drive emissions reduction from agriculture and the land sector. The CER is developing an improved soil carbon method in 2021 and will develop will several new methods in 2022, including:

- an integrated farm method to enable farmers to combine separate activities like environmental plantings and soil carbon alongside traditional farming activities (see Section 4.3.2)
- new methods to further incentivise improved savanna fire management to store and avoid emissions

Box 3.5 Balancing competing demands on Australia's agricultural sector

Agricultural industries have long been at the forefront of efforts to reduce our emissions. Our agriculture and land sectors, and the communities built around them, can prosper while continuing to play a vital role in helping Australia achieve net zero emissions by 2050.

Scenarios explored for the Plan show significant carbon offsets can be voluntarily delivered by farmers without converting productive agricultural land. This includes abatement from increased storage of carbon in soils. Any plantings would occur mostly on marginal land, along property boundaries, streams and gullies.[68] They would be integrated into the farm business, increasing drought resilience and farm productivity, rather than displacing agricultural production.

Modelling for the Plan demonstrates that up to 63 Mt CO_2-e of accredited carbon offsets could be produced each year by 2050, involving 1.5 million hectares of on-farm plantings (equivalent to 2% of total agricultural land). Achieving this level of abatement from targeted environmental plantings is possible without any negative impact on farm output, such as through wind breaks and riparian buffer zones, and would occur voluntarily on the basis that it produces a more profitable business outcome for the farmer.

Figure 3.6 Activities incentivised by the ERF

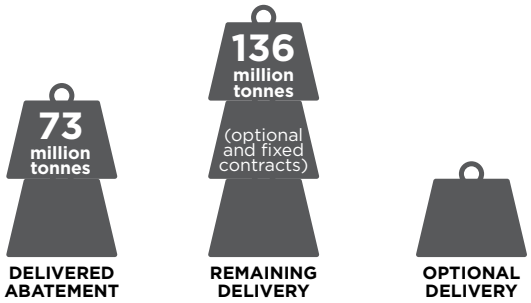
509

carbon abatement projects are currently under contract.

CONTRACTED ABATEMENT BY METHOD (MILLION TONNES)

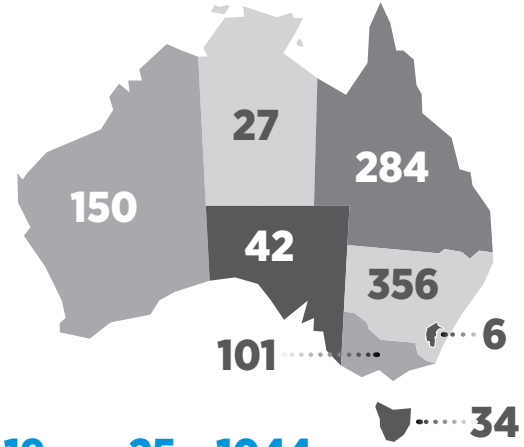
Vegetation	145.2
Waste	25.9
Savanna burning	13.6
Agriculture	15.1
Transport	1.2
Industrial fugitives	1.7
Energy efficiency	3.4
Facilities	3.4

During its existence, the ERF has contracted a total of **209 million tonnes** of CO_2 equivalent abatement*



*As of 22 October 2021 over the lifetime of the scheme. Figures exclude volume terminated/lapsed contracts (17.3 million tonnes)

ERF PROJECTS IN AUSTRALIA



19 MULTI-STATE PROJECTS

25 NATIONAL PROJECTS

1044 TOTAL PROJECTS

Source: Clean Energy Regulator.

Building on the ERF's success, the Government is introducing new incentives to reward farmers who improve biodiversity on their farms. The new Carbon + Biodiversity Pilot supports farmers and landholders to reduce emissions while building biodiversity on their properties. The pilot scheme is operating in conjunction with the ERF in six regions. Under the pilot, farmers and landholders who plant mixed tree species are paid a premium for both emissions reductions and biodiversity benefits (like providing habitat for threatened species).

Valuing the environmental benefits of trees can reward farmers as stewards of the land by creating new income streams. The pilot has shown that many farmers can get commercially viable returns through plantings and attract biodiversity premiums in addition to returns from carbon credits. Offset projects with environmental, social or cultural benefits attract a premium on the voluntary market. Energy companies including Woodside, Chevron and Shell are currently investing in projects with carbon and biodiversity benefits.

The Government's investment in a biodiversity trading platform will help farmers find potential buyers and kick-start this investment. The biodiversity certification scheme will help farmers demonstrate their credentials to their markets.

The ERF's crediting mechanism provides the foundation for state-based schemes like Queensland's Land Restoration Fund. The Australian Government has encouraged other states and territories to use the ERF as the basis for incentive schemes to improve transparency and accountability, and is pursuing opportunities to achieve this through bilateral state deals.[69] The ERF is also enabling many companies to voluntarily reduce their emissions. Over 60% of ASX50 firms have committed to net zero emissions.[70]

The ERF is also helping reduce emissions from other sectors of the economy. This includes the waste sector, which contributes almost 3% of Australia's total emissions, and from which the ERF has contracted 25.9 Mt of abatement. The Government is prioritising the development of new methods for the industrial and transport sectors, including CCUS, low emissions transport infrastructure, and the use of clean hydrogen in applications like gas networks, power generation and low emissions steel.

Longer term challenges

Livestock feed technologies could reduce methane emissions by over 80%[71] but are still at an early stage of development and the costs are unclear. More work is needed to understanding the implications and practicalities of these technologies. The Government is working with industry and researchers to develop ways to deliver this technology to grazing animals, which make up around 95% of Australia's livestock population (section 2.4). Even with significant technology progress, our modelling found livestock emissions contribute 51 Mt CO_2-e in 2050. This reinforces the significant technical and practical challenges in reducing livestock methane emissions.

Enabling technologies, such as digital technologies and remote sensing, will assist landholders to store carbon in soil and vegetation on farms. The Government is already acting to unlock the potential of the sector by investing in improving the data and technologies to make soil carbon measurement cheaper (section 2.3.6) and by enhancing the Full Carbon Accounting Model which underpins our measurements of carbon stored in vegetation and soil. The Government is also building digital skills and capabilities within the sector through the National Agricultural Innovation Agenda and Digital Foundations for Agriculture Strategy.

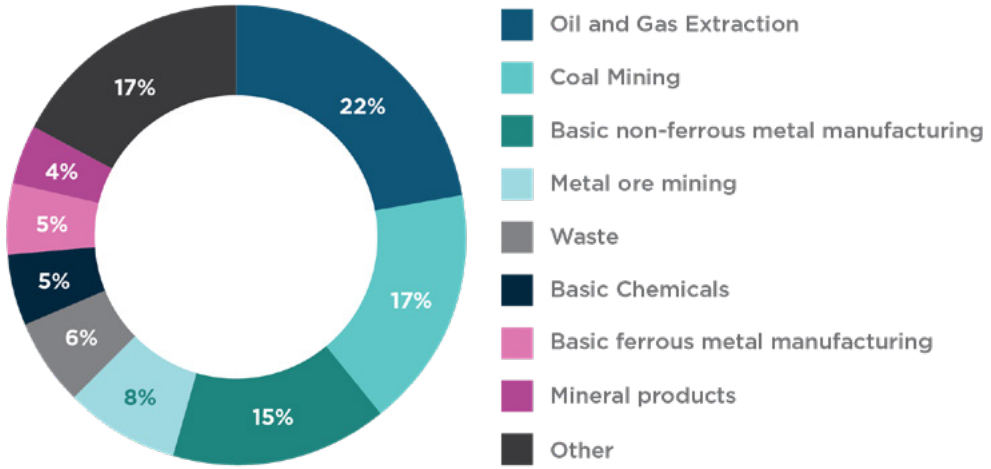
Achieving the long-term Paris goals will require that we protect and restore 'blue carbon' stocks in coastal ecosystems like mangroves, sea grasses and tidal marshes. Australia is already a world leader in blue carbon science, and a new $3.3 million research collaboration between CSIRO and BHP will improve our ability to measure and quantify the net emissions reduction potential in these ecosystems. The Government is also developing an ERF method to incentivise activities that support Australia's blue carbon stocks.

3.6 Industry, mining and manufacturing

Technology pathways, trends and barriers to deployment

Australia's industrial, mining and manufacturing sectors are major regional employers that will play a vital role in the nation achieving net zero emissions by 2050. Direct emissions from these sectors represent around a third of Australia's total emissions, and just under half when indirect emissions from electricity consumption are included (Figure 3.6).[72]

Figure 3.6 Emissions from industry, mining and manufacturing sectors



Source: *National Greenhouse Gas Inventory.*

Note: *Includes scope 1 and 2 emissions*

Reducing emissions across these sectors will require a range of new and bespoke technologies. Energy efficiency, resource efficiency and electrification will form the backbone of decarbonisation pathways for many industrial processes while increasing productivity, lowering costs and improving competitiveness. Niche technology solutions, such as low global warming potential refrigerants and carbon-free anodes for aluminium smelting[73], are emerging for some processes.

Analysis for the Plan by McKinsey found that widespread adoption of low emissions technologies could enable emissions from Australia's industry, mining and manufacturing sectors to fall by more than half between 2019 and 2050.

Australian industrial and manufacturing facilities are moving in this direction. For example, Sun Metals (operator of Queensland's biggest zinc refinery) has committed to power its entire operations with renewable electricity within 20 years. Sun Metals has developed a 151 MW solar farm co-located with the refinery and is working with the Queensland Government to establish a hydrogen production facility for export and use in industrial and transport applications.[74] Mining firms including BHP, Rio Tinto and Vale are collaborating to reduce emissions from surface mine operations through electrification.[75]

Many technologies are already available and cost-effective, like energy efficient heat pumps as an alternative to natural gas for low temperature heating (for example, food manufacturing).[76] However, adoption can be slow where technologies are unfamiliar to firms, involve high system costs (for example, the costs of integrating new technology into an old production line), or face competition for capital and other resources within the firm.

Addressing these barriers

To overcome these barriers, Australia is introducing a new Safeguard Crediting Mechanism (Box 3.5), which was a key recommendation of the 2020 King Review. The ERF and CEFC finance are also helping firms meet upfront technology costs and accelerate deployment across these sectors.

Other investments are helping to de-risk new technologies and promote knowledge sharing. For example, the Government's $43 million Industrial Energy Transformation Studies Program is providing financial support to firms to perform detailed engineering studies on energy efficiency improvements.

Through ARENA, the Government is also investing $2.3 million in the Australian Industry Energy Transition Initiative (ETI), a partnership between Australian non-government organisations, researchers and industry. This initiative is exploring solutions for reducing emissions and increasing long term competitiveness across five industrial supply chains – iron and steel, alumina and aluminium, LNG, other metals (such as lithium, copper and nickel) and chemicals including plastics, fertilisers and explosives.

Regulatory arrangements are in place to ensure Australian markets for industrial equipment keep pace with international technology developments:

- Through the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*, Australia regulates the manufacture, import, export, use and disposal of HFCs and other potent synthetic greenhouse gases. Australia has committed to an 85% phase-down of HFC imports by 2036, ahead of the international schedule agreed under the Montreal Protocol.
- The *Greenhouse and Energy Performance Standards Act 2012* ensures that industrial equipment, like electric motors, meets minimum energy performance standards, making it easier for Australian firms to adopt energy-efficient equipment.

Australia is also exploring technologies to reduce emissions from waste. ARENA and the CEFC are co-investing with business in technologies that can turn urban and industrial waste into energy and valuable products. This will create new revenue streams while also reducing landfill gas emissions. Technologies include energy-from-waste and biomethane production. The Australian Recycling Investment Fund (administered by the CEFC) is an important part of Australia's National Waste Policy and Action Plan. The plan is guiding national investment in recycling and other technologies that can reduce waste emissions.

Box 3.6 Safeguard Crediting Mechanism

The Government is introducing a Safeguard Crediting Mechanism to help incentivise deployment of new low emissions technologies in the industrial, manufacturing, mining, transport, oil and gas sectors.

The Government has allocated $279.9 million to 2030 towards the crediting mechanism. This will encourage projects that:

- significantly reduce the emissions intensity of facilities covered by the Safeguard Mechanism
- help develop and deploy emerging low emissions technologies.

The crediting mechanism will build on the existing architecture of the Safeguard Mechanism and National Greenhouse and Energy Reporting scheme. These schemes provide a framework for major emitters to measure, report and manage their emissions.

Longer term challenges

Low-cost abatement technologies do not yet exist for hard-to-abate sectors like steel, chemicals and cement. Deploying hydrogen and CCUS at scale will be essential to reduce emissions from these sectors.

Both technologies have been prioritised under the Technology Investment Roadmap. A major focus of the roadmap is to reduce the costs of these technologies through research, development and demonstration (Sections 2.4.2 and 2.4.4). Many Australian firms, such as Fortescue Metals Group [77], the Australian Gas Infrastructure Group [78] and Santos [79], are also working to unlock the full potential of these technologies.

In future, there may be a role for the Government to help build the industry's confidence to invest in these capital-intensive technologies. The Safeguard Crediting Mechanism and ERF could potentially provide that support – an ERF method for CCS has been developed and a CCUS method will be developed in 2022. However, the Government will monitor the need for additional measures.

3.7 Role of offsets in achieving Australia's net zero by 2050 goal

Offset projects will play a crucial role in Australia achieving net zero emissions by 2050. For key sectors of the economy, technical and practical challenges will make it very difficult to reduce emissions to zero. By investing in projects that draw carbon from the atmosphere and store it in vegetation, soil and geological structures, these sectors have credible and affordable alternative pathways for decarbonising.

In our modelling and analysis, a voluntary carbon incentive of up to $25 per tonne CO_2-e by 2050 unlocks a further 27 Mt CO_2-e of land sector offsets, and this enables Australia to get within range of net zero emissions by 2050. Analysis by McKinsey finds that achieving the same abatement without land sector offsets would require Australia to draw on more expensive abatement options in the industrial and transport sectors with a weighted average abatement cost of $62 per tonne CO_2-e.

LETS 2020 identified that scaling geological and biological sequestration to provide globally significant permanent sequestration of CO_2 is one of Australia's big technological challenges. It highlighted that the Government's strong focus 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. Farmers that choose to conduct offset projects can earn valuable additional revenue to supplement other income from their properties. Alternatively, farmers may choose to use offsets to support their own low emissions claims to build on Australia's reputation as a clean, green supplier of choice. The Government is helping build voluntary carbon markets so farmers can take advantage of these opportunities (Box 3.6).

Australia is prioritising the development of new opportunities for CCS and soil carbon offsets, and the ERF is one of the biggest offset markets in the world. The systems underpinning the ERF's crediting architecture, including its legislated offset integrity standards, ensure that ACCUs represent real, additional abatement and have not been double-counted. The higher prices that ACCUs attract through the ERF and in voluntary markets compared to international units reflects that buyers recognise ACCUs are of high quality and integrity. The CER is continuing to invest in improving its registry and other systems.

Box 3.7 Growing voluntary carbon markets

The CER administers accounting and registry services that underpin Australia's domestic carbon market. The voluntary market for carbon and carbon-related units is growing – voluntary demand for ACCUs and large-scale generation certificates in the June 2021 quarter was almost 40% higher than in the June 2020 quarter. Voluntary demand in Australia for international units over the same period also grew.[80] The market is expected to keep growing thanks to carbon reduction and neutrality commitments.

The CER will establish an exchange trading platform for ACCUs. The platform will reduce transaction costs, increase market depth and make it easier to purchase and surrender carbon units.

The CER is also enhancing the registry for ACCUs to make it easier to trace the origin of units. This will let the market differentiate and place a value premium on units with benefits, like increased Indigenous employment from savanna burning projects.

4. SEIZING OPPORTUNITIES IN NEW AND TRADITIONAL MARKETS

Key points

- Australia's regions have always powered the growth of our nation and provided energy, resources and food to the world. The Government's ongoing investments in infrastructure, people, and local communities will ensure Australia's regions continue to be a base for our industries into the future.
- The Government recognises that changes in global demand for our energy exports will have implications for our regional communities. These changes will be driven by the actions of our trading partners and not our own efforts to reduce emissions. These changes will occur over several decades.
- Most of our major sectors will grow strongly to 2050, even as the world decarbonises, but some sectors will face global headwinds. By building new industries like clean hydrogen, renewable energy and critical minerals, Australia will create new export markets and jobs. These will help offset long-term impacts in sectors, like thermal coal and natural gas, affected by falling global demand and the shifting choices of international consumers.
- The Australian economy has specialised in the production of emissions-intensive exports and we are the world's 4th largest energy exporter. We will continue to export our traditional energy exports for as long as our customers demand them. If we were to withdraw supply and reduce our exports, other countries would fill the gap in supply. Australia's coal and gas export industries will continue through to 2050 and beyond, supporting jobs and regional communities.
- Global changes in demand will also create many opportunities for Australia. Analysis for the Plan highlights that Australian policy settings will be crucial to realising these opportunities. By focusing on technology and enabling the private sector, our plan will support regions to maintain attractive job opportunities and economic prosperity.
- Our regions can supply low emissions products to the world, including critical minerals, other essential metals, clean hydrogen, LNG, uranium, low emissions manufactured materials, clean energy equipment and services, and agricultural products. Analysis for the Plan finds that hydrogen, renewable energy and minerals like lithium could create more than 100,000 new direct jobs by 2050, many in Australia's regions. These industries could also create many more indirect jobs, including in up- and downstream manufacturing.
- Our farmers will benefit from delivering carbon sequestration and biodiversity through soil management, revegetation and plantings that are part of the farm business. Agricultural industries have long been at the forefront of Australia's efforts to reduce emissions. They will continue to supply clean, green and safe agricultural products to domestic consumers and the world.
- Australia is supporting our regional industries to succeed in new and traditional markets through the Critical Minerals Strategy, National Hydrogen Strategy, Global Resources Strategy, Modern Manufacturing Strategy and Ag2030 Strategy. The Government will play an enabling and coordinating role so that economic benefits are shared fairly across the country.

4.1 Opportunities for Australia and its regions from the global transformation

Regional industries have helped Australia's economy to specialise in the production of emissions-intensive exports and become the world's fourth largest energy exporter. Australia has built some of the world's largest and most significant energy and resources supply chains into strong, fast-growing export markets across the Indo-Pacific region.

Australia is a global top three (or higher) exporter across a range of commodities, and is uniquely blessed with natural resources across:

- Traditional energy sources (e.g. coal and LNG),
- Emerging low emissions fuels (e.g. clean LNG, blue hydrogen and CCS), and
- The new energy economy (e.g. world-leading solar resource, available land, productive agriculture, critical minerals, green hydrogen potential).

Modelling from international bodies such as the IEA and IPCC illustrate the scale of change required to achieve the global goals of the Paris Agreement. To achieve the 2°C goal, global emissions must fall by over 75% between 2017 and 2050 and reach global net zero by around 2070.[81] Global electricity emissions will need to fall by more than 70%, even as electricity generation increases.[82] More rapid change will be needed to achieve a 1.5°C goal. Under all scenarios, low emissions technologies like solar, wind and nuclear power will need to contribute an increasing share of global electricity production.

Despite the scale of this transformation, multiple studies (including modelling undertaken for this Plan) show the global economy will continue to grow and incomes continue to rise. The world's demand for energy, minerals, agricultural products, and manufactured products like steel, are all projected to grow strongly to 2050 as the global population grows and living standards improve.

With our natural endowments, experienced regional industries and skilled workforce, Australia is uniquely placed to benefit as this global shift unfolds. We can prosper in a world in transition and capitalise on the global shift to a new energy economy:

- We have world-leading reserves of the minerals and base metals, such as lithium, nickel and copper, needed to produce batteries, renewables and electric vehicles.
- We are one of the world's biggest producers and exporters of liquefied natural gas (LNG), a critical transition fuel, and have built some of the world's largest and most significant energy and resources supply chains into fast-growing export markets across the Indo-Pacific region.
- Our unmatched renewable energy resources and high quality CO_2 storage reservoirs can be the foundation for hydrogen production and low emissions manufacturing.
- Australian researchers and entrepreneurs are at the leading edge of low emissions technology innovation and have driven the development of globally significant technologies like solar photovoltaics (PV).

Modelling undertaken for this Plan shows that most of Australia's export sectors across manufacturing, mining and agriculture stand to benefit from this shift. The value of Australia's exports is projected to more than triple from 2020 and 2050. Building on the modelling, McKinsey estimates that net regional employment in mining and heavy industry alone could grow by 62,000 by 2050.

The long-term prospects for Australia's coal and gas sectors will depend on the preferences of our customers and the pace of international action. Australian natural gas production is expected to remain robust, and will be higher in 2030 than it is today. Coal production will remain flat or decline slightly, by around 6% over the same period. There will be ongoing demand for both commodities, especially in emerging markets in the Asia-Pacific and Indo Pacific. Given our proximity to these markets, our strong reputation as a supplier of energy exports and the high quality of our fossil fuel commodities, Australia is well-placed to meet this demand.

Figure 4.1 Australian Global Export Rankings and Reserve Rankings

	COAL (METALLURGICAL)	COAL (THERMAL)	LNG	IRON ORE	URANIUM	BAUXITE	LITHIUM	ZINC	COPPER
Australian global export rankings	1	2	2	1	1	–	1	2	3
Australian global reserve rankings	3	3	15	1	1	2	2	1	2

Source: *DISER, Resources and Energy Quarterly September 2021, Geoscience Australia 2021. Australia's Identified Mineral Resources 2020. Geoscience Australia, Canberra. Source: Geoscience Australia and US Geological Survey*[84]

However, our modelling indicates that, in a 2°C global economy, the global demand for these commodities will decline over the long term as our customers shift towards low emissions technologies, fuels and commodities. As a result of these global trends, Australian fossil fuels production is projected to fall over the period to 2050, and will be 35% lower than 2020. International demand for coal is projected to taper more rapidly than for natural gas. Our modelling finds that changing customer demand for these commodities, and not a domestic emissions goal, drives the economic impacts on these sectors.

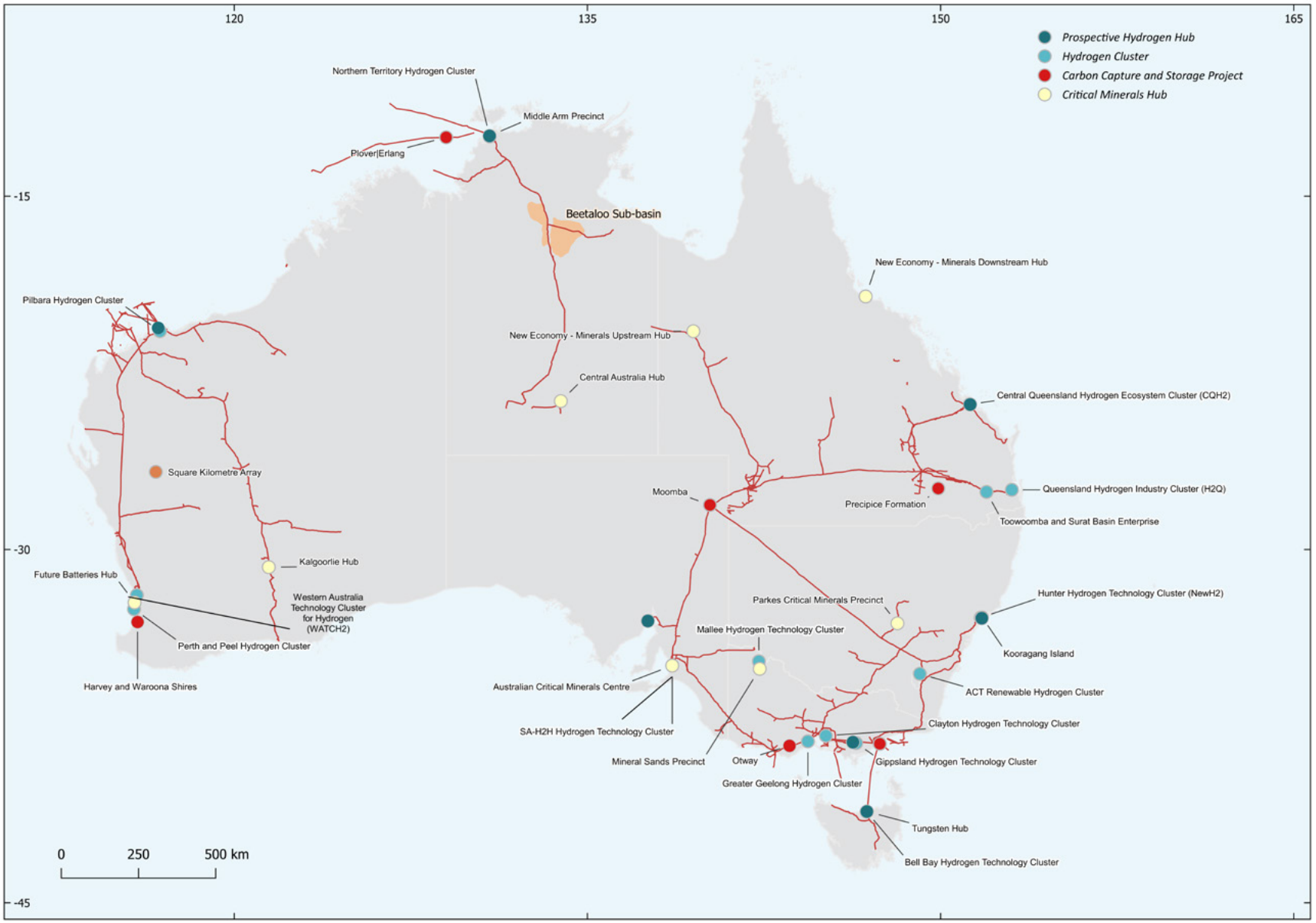
The Australian Government will support industries and communities affected by these global shifts. This will be a long term transition and not a sudden shock, and we are putting the right settings in place now to ensure regional communities can thrive throughout this process. These sectors will continue to underpin jobs in these communities for many decades.

Our plan is to partner and co-invest to ensure communities realise the broader opportunities through the global transition and in the new energy economy (Box 4.1). In addition, our plan includes a focus on CCUS opportunities to reduce the emissions intensity of fossil fuels and enable the ongoing use of fossil fuels in producing clean hydrogen.

Australia is already a top global exporter of traditional energy sources and other resources, and can build on this expertise in capturing economic opportunities both through the global transition and in the new economy (Figure 4.1).

Our economic modelling underscored the potential for very strong growth over the coming decades in regional industries like mining and heavy industry. Opportunities are already beginning to emerge for regional Australia. Consistent with the findings of the IEA [85] and World Bank,[86] our modelling indicates low emissions fuels, technologies and commodities will be a major source of global growth. Australia's existing industrial regions like the Hunter, Central Queensland, the Pilbara, Portland and Whyalla are well suited to host low emissions industries that can meet this demand, such as hydrogen and energy-intensive manufacturing powered by renewable energy. This is because of existing skilled workforces and proximity to high quality renewable resources, ports and transmission infrastructure.[87]

Figure 4.2 Map of new energy export opportunities



Box 4.1 Employment opportunities from building new regional industries

Many relevant skills and infrastructure assets already exist in regional areas. The question is how to enable these workforces to take advantage of emerging job opportunities.

For example, Victoria's Latrobe Valley has a long history as an energy producing region. It is geologically suitable for producing hydrogen and storing carbon underground, and is located in close proximity to electricity and shipping infrastructure. These advantages underpin the Hydrogen Energy Supply Chain (HESC) project, a world-first pilot project supported by the Australian, Japanese and Victorian governments. The project will safely and efficiently produce and transport clean hydrogen from the region.

This is just one example of the opportunities available to regional Australia in the new energy economy.

The Technology Investment Roadmap identified that investing in Australia's priority technologies could support up to 160,000 direct and indirect jobs by 2030, many in regional areas. Further analysis undertaken by DISER and McKinsey has identified substantial low emissions technology job opportunities for regional communities:

- Producing and exporting the minerals needed for clean energy technologies like cobalt, copper, lithium, nickel, uranium and rare earth elements could support up to 52,000 jobs in regions like southern Western Australia, the Pilbara and South Australia by 2050.
- Hydrogen production could support up to 16,000 jobs by 2050 in regions like central Queensland, southern Western Australia and the Pilbara.
- The construction boom associated with new renewable energy generation to support hydrogen production could support up to 13,000 new, permanent jobs by 2050 across Australia, especially in regional NSW and Queensland. This is in addition to potential jobs growth of up to 35,000 between now and 2050 across the energy sector, many in regional areas, to support a broader expansion of electricity production for domestic use as sectors like transport and industry switch to electricity.
- Low emissions steel and alumina could support up to 18,000 jobs in regions like South Australia and Queensland.

In total, this analysis by DISER and McKinsey projects more than 100,000 new direct jobs could be created by 2050.

McKinsey has also identified further indirect job opportunities, both upstream and downstream, including:

- expanded manufacturing powered by low-cost renewable energy in regions like Geelong, the Hunter Valley and the Pilbara
- new upstream energy generation manufacturing like wind turbines and hydrogen electrolysers, which could support jobs in existing industrial areas like Geelong, the Hunter Valley and the Illawarra
- new downstream value-adding manufacturing like the production and export of green ammonia and hot briquette iron, which could support jobs in Central Queensland, Gladstone, the Hunter Valley and the Pilbara.

The Government's $464 million investment towards establishing up to seven regional hydrogen hubs, and over $300 million in funding for CCUS technologies and hubs projects, are two examples of how it is helping enable regional communities to capture new opportunities. Around half of the funds invested by ARENA and almost a third of CEFC finance have been directed to regional areas.[88]

4.2 Leveraging Australia's competitive advantages

4.2.1 Minerals and metals used to manufacture clean energy technologies

Modelling for the Plan projects global demand for metals like copper, lithium, and nickel will increase steadily between 2020 and 2050. Global demand for these metals will be driven in part by their use in lithium-ion batteries, EVs, solar panels and wind turbines.

Australia is moving to capture economic opportunities from this growth and play an important role in securing domestic and global strategic supply chains.[89] Analysis by DISER suggests that in a 2°C global economy, Australian lithium exports could grow from $1 billion in 2020 to $10 billion in 2050. They could reach as high as $34 billion per year if further refined all the lithium we mined. Battery demand could also grow Australia's nickel exports from $4 billion in 2020 to over $31 billion in 2050. Increased demand across a range of low emissions technologies could see Australian mined copper exports grow from $7 billion to as much as $19 billion in 2050, despite substantial increases in copper reuse and recycling. Australia's total exports of these three resources could grow from $12 billion in 2020 to as much as $84 billion in 2050.

Other studies have highlighted the opportunities for Australia in expanding further up the battery mineral value chains. For example, 34,700 jobs could be supported by 2030 if Australia builds its capabilities in downstream refining, manufacturing, and battery integration and services.[95]

Australia's resources sector is already a world-leading global supplier of base metals and energy commodities. We have globally significant reserves across a range of mining commodities (Figure 4 1). South Australia, southern Western Australia and the Pilbara are rich in the minerals used in low emissions technologies.

The Government will continue to support the growth of the sector so it can deepen supply chains for the raw materials the new energy economy demands. A strong focus is on unlocking Australia's reserves of lithium, rare earths and other minerals through the Critical Minerals Strategy (Box 4.2). To support this strategy, a new $2 billion Critical Minerals Facility, to be managed by Export Finance Australia, will fill finance gaps in critical minerals resources developments. Australia's Global Resources Strategy will also identify new markets for our resources commodities and critical minerals and facilitate opportunities for expanding trade.

4.2.2 Clean hydrogen production

Studies by organisations such as the IEA and Bloomberg New Energy Finance project that, although currently very small, the global demand for clean hydrogen could increase rapidly as various industrial and transport applications switch to this fuel. The IEA has said that the international hydrogen trade alone could be worth up to US$300 billion by 2050 under a global net zero scenario.[91]

The IEA[92] and the World Energy Council[93] have both identified Australia as a potential hydrogen production powerhouse. Australia could be a major supplier of clean hydrogen to key trading partners like Japan, Korea, Germany and Singapore. Analysis by McKinsey has highlighted that international emissions reductions from Australian hydrogen exports could grow to almost 100 Mt CO_2-e per year by 2050.

The potential economic opportunities for regional Australia from hydrogen are substantial. Modelling for the Plan found that hydrogen production in Australia could be worth more than $50 billion (US$35 billion) by 2050 in a world with ambitious climate action. An Australian hydrogen industry could supply low emissions manufacturing (e.g. of steel), exports of clean hydrogen or ammonia, or domestic demands for electricity generation, transport and heating. This is a conservative estimate, and other analysts have suggested much higher economic opportunities – by one estimate, Australia could generate export revenue from hydrogen and its derivatives valued at $70–$130 billion (US$50–$90 billion) by 2050.[94]

As with earlier waves of resource development, regional Australians are likely to be major beneficiaries from hydrogen's growth. DISER's modelling and analysis by McKinsey find clean hydrogen production could support up to 16,000 jobs in 2050, in regions like the central coast of Queensland, the Pilbara and southern Western Australia. Renewable energy construction to support hydrogen exports could support a further 13,000 jobs in 2050. Analysis for the National Hydrogen Strategy suggests there are many areas of Australia suitable for low cost hydrogen production, with opportunities in every state and territory.

Box 4.2 Australia's Critical Minerals Strategy

Australia has some of the most abundant natural endowments of critical minerals globally. We have the world's second-largest lithium reserves, the sixth-largest rare earths reserves, and substantial resources of cobalt, manganese, tantalum, tungsten and zirconium.

Australia's Critical Minerals Strategy outlines the government's policy framework to:

- position Australia as a world leader in the exploration, extraction, production and processing of these resources
- help deepen global supply chains for the technologies they underpin

The Australian Government's policies will help grow the critical minerals sector and contribute to the Whole-of-Economy Long Term Emissions Reduction Plan on the following 3 fronts..

Bolster geopolitical stability

We will directly support the strategic energy, defence and economic needs of key partners (like the US, Japan, India, the Republic of Korea, the UK, and EU member states) by supplying:

- rare earths (used in magnets for EV motors and wind turbines)
- minerals for lithium ion and vanadium batteries
- titanium alloys.

Build sovereign capability

We will move into downstream processing and grow Australia's capability in specialist skills such as hydrometallurgy, chemical separation and smelting.

Grow our regions

We will create stable, sustainable and high-paying jobs in regional Australian communities, and integrate these into fast-growing sectors of the global economy.

We achieve this by:

- de-risking and accelerating projects, including with targeted financial support under the Modern Manufacturing Initiative or through investment from government financing agencies
- creating an enabling environment through:
  - working with the states and territories to help the sector scale up and attract international investment
  - trade facilitation
  - better leveraging our world-leading research and development capabilities.
- securing strategic partnerships and commercial arrangements with key countries like the US, Japan, India, the Republic of Korea, India, Germany and France.

4.2.3 Low emissions fuels, including LNG and uranium

Australia is one of the biggest exporters of LNG in the world, and our exports will continue to play a significant role in the global energy mix over the coming decades. Our exports have the potential to reduce global emissions by up to 166 Mt CO_2-e annually by displacing more emissions-intensive fuels.[95] With access to high-quality storage reservoirs, Australia can meet the emerging demand for lower emissions LNG. The Gorgon CCS project, one of the world's biggest CCS facilities, is expected to capture around 100 Mt CO_2-e from LNG production over its lifetime,[96] and further projects, like the proposed Moomba CCS Hub, could commence operations as soon as the middle of this decade.

The global shift towards low emissions electricity is also expected to expand the world's nuclear generation capacity. Australia can help supply the uranium needed to power these generators. We have the world's largest uranium reserves and we are currently the third biggest producer. By helping to meet this demand, Australia's annual uranium exports could grow from $762 million today to up to $1.3 billion in 2050 (Appendix C).

The Government's Global Resources Strategy will support the Australian resources sector to remain the world's supplier of choice for major commodities like LNG and uranium, as well as our critical minerals and new energy resources like hydrogen. It will support Australian resources companies and mining equipment, technology and services (METS) companies to strengthen their global competitiveness, scale up and expand their market export opportunities.

4.2.4 Low emissions manufacturing, including steel and aluminium

Global demand for aluminium, steel and other metals will remain high in a net zero global economy. New energy technologies, including solar and wind, will be major sources of demand for these manufactured metals.

Australia's mineral and renewable resource endowments, alongside falling technology costs and our proximity to growing markets, could see Australia realise an industrial advantage in energy-intensive manufacturing.[97] We can strengthen our position as an exporter of aluminium, steel, processed iron ore (as hot briquetted iron) and other energy-intensive manufactured commodities. We can do this by fuelling industry on low-cost, zero emissions electricity and hydrogen, or by harnessing CCUS. Geelong, the Hunter and the Pilbara are some of the regions that could benefit.

The potential economic opportunities of low emissions manufacturing are substantial. By one estimate, turning one-fifth of our current iron ore extraction and half of our current bauxite and manganese extraction into zero emissions metals could be worth $100 billion in export revenue and create over 65,000 jobs.[98]

By prioritising low emissions materials through the Technology Investment Roadmap and Modern Manufacturing Strategy (Box 4.3), Australia will sustain its existing industries and enable regional Australia to be a base for new and expanded heavy manufacturing.

4.2.5 Clean energy equipment and services

Australian industry can produce and export much more than commodities. We can also offer high-value manufactured products, expertise and innovation. Australia has outstanding research capabilities, innovative people and a track record of contributing globally significant technologies. For example, solar PV technology developed by the University of New South Wales (UNSW) is now used in around 90% of today's global solar PV manufacturing.[99] The Australian business Tritium is one of the world's most popular manufacturers of EV direct current fast charging equipment.[100]

At a per capita rate, Australia is deploying renewable energy 8 times faster than the world average and nearly three times faster than the next fastest country, Germany.[101] This is positioning us at the leading edge of the development of enabling technologies for decentralised, low emissions energy systems. With our market and geographical characteristics, we are also emerging as leaders in niche technologies like hot climate batteries, off-grid systems, and rapidly deployable modular renewable systems.

Australia's Modern Manufacturing Strategy is supporting its innovators to commercialise and scale-up these products. It is also connecting them with export opportunities created by global markets that are demanding solutions to changing energy systems (Box 4.3).

Box 4.3 Modern Manufacturing Strategy: Recycling and Clean Energy National Manufacturing Priority

The Recycling and Clean Energy National Manufacturing Priority road map is part of the Government's Modern Manufacturing Strategy. It sets a vision to develop world-leading advanced manufacturers that seize opportunities from sustainability, clean energy, and waste reduction demands. This is done by leveraging Australia's advantages in innovation, technology, renewable and mineral resources, as well as our onshore industrial base.

Manufacturing opportunities that play to Australian strengths include:

- hydrogen technologies
- modularised renewables
- specialised batteries
- recycled and remanufactured products
- low emissions metals.

The Government is backing promising projects through the $1.3 billion Modern Manufacturing Initiative (MMI). This funding is supporting domestic manufacturers to:

- leverage opportunities from large energy projects
- meet changing consumer demands
- mobilise large-scale investments in new ways of using energy and materials.

MMI co-investments aim to link collaborations across supply chains, including through hubs, so manufacturers can overcome barriers to scale and competitiveness.

This is just one of six priority areas under the Modern Manufacturing Strategy. The Resources Technology and Critical Minerals Processing road map is also helping manufacturers capture opportunities in the new energy economy.

4.3 Helping Australia's agriculture sectors and farming communities grow

Australia's agriculture sector is a major part of our export economy, producing enough food to feed 80 million people. The sector exports 70% of everything raised and grown in Australia. It underpins many communities and is a source of jobs and prosperity for regional Australia.

Modelling for the Plan underscores the positive outlook for Australian agriculture in a net zero global economy. We are the 3rd largest agricultural landmass in the world. We are the 2nd largest cattle exporter, and the 7th largest wheat exporter. Building on these strengths, Australia's agriculture sector will grow and supply produce to global markets that increasingly prioritise low emissions commodities.

Australian farmers can build on our existing reputation for clean, green and safe produce, and become a supplier of choice for trading partners seeking food and fibre with a low emissions footprint. Emissions intensities of key existing Australian agricultural products like wheat and grass-fed beef are below the global median,[102] and ambitious industry-led targets will further reduce emissions intensities.[103] As a result, expanding our market share and meeting a greater proportion of international demand will reduce emissions globally. CSIRO analysis estimates exports of premium Australian food products, including premium sustainable beef and lamb, could potentially grow by 55% to 2030.[104]

Placing all major commodities on a trajectory trending towards carbon neutrality by 2030 is part of the sector's roadmap to exceed $100 billion in farm gate[110] output. The Government is supporting industry to achieve this goal by bringing down the costs of technologies like soil carbon measurement and livestock feed technologies (sections 2.3.5 and 2.4).

4.4 Supporting regional economies and communities

Australia's regions have powered the growth of our nation and continue to provide energy, resources and food to the world. The Government is supporting our regions so they remain attractive and vibrant places to live, work and invest, and can remain the base for our industries into the future.

4.4.1 Building a skilled workforce

Developing a workforce with the right skills and expertise is critical in capturing opportunities from low emissions technologies and emerging markets.

Australia will need highly skilled workers to develop and deploy new technologies domestically and enable Australia to realise its comparative advantages in emerging global markets. We will need a workforce with general capabilities (like communication, problem solving and digital literacy), as well as discipline-specific skills in fields like construction, physical sciences, engineering, project management and data analytics.

The Australian Government is supporting the national skills architecture, state training systems and apprenticeships, including a record $6.4 billion investment in 2021–22. This investment is helping train highly skilled and qualified workers, including in regional areas, and is supporting existing workers to acquire new skills and expertise. In 2020, the Government established the National Skills Commission to provide trusted and independent intelligence on Australia's current and future skills, education and jobs.

This is complemented by the Modern Manufacturing Strategy, National Hydrogen Strategy and other initiatives. Collectively, these measures are helping build the skilled workforce Australia will need to capture the opportunities new technologies present in domestic and global markets. For example, the Australian and Tasmanian governments are working together on the $16.14 million Energising Tasmania Program. The program is developing a skilled workforce equipped with the electrical and engineering expertise needed for the Battery of the Nation initiative, MarinusLink interconnector and ongoing growth of Tasmania's renewable energy sector.

4.4.2 Infrastructure to connect communities and unlock supply chains

Infrastructure is the key to vibrant regional communities, reducing the costs of getting materials and products to markets, and building the job-creating industries of the future. The Government is investing heavily in transport, water and telecommunications infrastructure. We are directing around a third of our rolling $110 billion pipeline of infrastructure projects towards regional projects.

Better infrastructure enables industries to grow by unlocking supply chains and connecting farmers, miners and manufacturers to domestic and international markets. Australia's $4.9 billion Roads of Strategic Importance initiative is ensuring key freight roads are efficiently connected. The Northern Australia Infrastructure Facility is helping finance economic infrastructure like ports and airports. Australia's investments in rail infrastructure are connecting communities and regions, as well as enabling low emissions commuting and freight.

World-class communications infrastructure and ultra-fast digital connectivity are increasingly central to regional communities and will underpin both new and traditional industries. Australia's investments in regional telecommunications infrastructure, including through the National Broadband Network and the Government's Regional Connectivity Program, are helping connect farms, mines and factories with their customers and suppliers. It will also enable emerging digital technologies, like smart grid technologies, to be integrated into their operations.

4.4.3 Ongoing investments in local regional communities

Regional Australia is already home to one in three Australians. More and more people will move to the regions as new low emissions industries grow and as existing industries become stronger. The Government is supporting our regions so they remain attractive and vibrant places to live, work and invest.

This includes ensuring local communities have access to high quality healthcare, educational opportunities and other services. The Government will continue to invest in services like primary health, hospitals, aged care, disabilities, Aboriginal and Torres Strait Islander peoples' health and mental health. Scholarships and new Industry Training Hubs will improve opportunities for young people, and higher education reforms and investments will increase regional Australians' access to higher education.

The Government is making substantial investments in local regional communities. Nearly 1,300 local projects have been funded through five rounds of the Building Better Regions Fund. Projects range from water recycling facilities to refreshed streetscapes, as well as community infrastructure and capacity building projects that build local resilience to economic shocks.

Through the Future Drought Fund and the National Resilience and Recovery Agency, the Government is supporting local communities to respond to and rebuild following natural disasters and droughts.

All levels of government will continue to work together to develop and revitalise our regions. The Australian Government has allocated $100 million to the new Regional Recovery Partnerships initiative. We are coordinating investments with state and local governments to deliver jobs, economic recovery and economic diversification across 10 regions. This includes a $5 million investment in a pilot project relating to hydrogen technology in the Gladstone region.

5. FOSTERING GLOBAL COLLABORATION

Key points

- Australia is partnering and co-investing with trading and strategic partners to foster a globally collaborative approach to low emissions technologies. We are establishing new bilateral partnerships and playing a leading role in multilateral initiatives and institutions.
- Our aim is to accelerate the technology transformations needed to decarbonise the world's economy, not just our own. Scaling up global production and supply chains will lower the costs of deploying the technologies all countries – including Australia – need.
- Australia is also working with other countries, especially in our region, to access and adopt new technologies and build resilience to climate impacts.
- Australia is working with our neighbours to establish a high-integrity carbon offset scheme in the Indo-Pacific. This will boost our region's ability to attract private sector investment in low emissions technologies and provide access to an established market for offset credits.

5.1 Building international partnerships

Australia is working closely with the international community on low emissions technology innovation to reduce emissions and create jobs. These partnerships are:

- building strategic relationships with partners that share our ambitions
- sharing knowledge across global supply chains
- accelerating the development and deployment of low emissions technologies.

The Government has appointed Dr Alan Finkel, Australia's former Chief Scientist, as Special Adviser to the Australian Government on Low Emissions Technologies. Dr Finkel is:

- supporting and expanding technology collaboration by brokering partnerships with Australia's priority trade and strategic partners
- intensifying international engagement to drive investment in shared research and development, including Australian-based projects.

The Government has allocated $565.8 million to support international partnerships that help accelerate development of low emissions technologies and advance and support the goals of Australia's Technology Investment Roadmap. The Government aims to attract at least $3 of funding from partners and other private sources for every $1 it invests. The Government has already announced partnerships with Germany, Japan, Singapore and the United Kingdom (Figure 5.1).

Each of these partnerships will further Australia's technology-led approach to reducing emissions by strengthening global cooperation on low emissions technology development and deployment. 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.

Figure 5.1 International partnerships

Germany

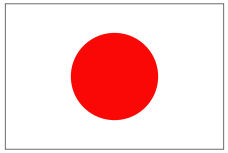
Australia-Germany Hydrogen Accord

- 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

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.



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.

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.

5.2 Multilateral initiatives and institutions

These bilateral international partnerships will sit alongside our ongoing engagement with multilateral technology initiatives. For example:

- Australia is an active member of Mission Innovation. This initiative of 22 countries (and the European Commission) is accelerating clean energy technology innovation through performance breakthroughs and cost reductions. Through Mission Innovation, Australia is contributing to global collaboration on clean energy innovation and building practical bilateral cooperation. Australia co-leads Mission Innovation's new Clean Hydrogen Mission, whose aims include increasing the cost-competitiveness of clean hydrogen to the end user by reducing end-to-end costs to a tipping point of US$2/kg by 2030.
- Australia is a long standing member of the Clean Energy Ministerial, which has 19 member countries. The CEM brings together a community of the world's largest and leading countries, companies and international experts to achieve acceleration of clean energy transitions. Australia leads on the Clean Energy Solutions Centre, and participates across a range of initiatives including on smart grids, hydrogen, energy efficiency, and CCUS.
- Australia is also a member of the Leadership Group for Industry Transition. Launched by India and Sweden in 2019, this group brings together 16 nations and 19 industry leaders to develop sectoral roadmaps and promote public–private collaboration on critical challenges in hard-to-abate sectors. Australia's membership lets us influence the global agenda for emissions reductions in key economic sectors including steel, chemicals and cement. This helps create business opportunities for Australian industries.

Australia is also continuing to work through multilateral institutions, including the World Trade Organisation and APEC, to tackle trade barriers and reduce trade-related costs. Removing trade barriers can reduce the cost of new and emerging technologies, making them more accessible and cost-competitive. It can take emerging low emissions technology industries to a much larger scale, increase the rewards for innovation, and improve access, helping make net zero by 2050 achievable for both developed and developing countries.

5.3 Supporting our regional neighbours to adopt technologies and build resilience

Australia has for many years supported our regional neighbours, particularly Pacific and Southeast Asian countries, to access and adopt low emissions technologies and build resilience to the impacts of climate change (Box 5.1). More than 70 % of Australia's bilateral and regional climate financing supports adaptation and ensuring communities are better prepared and more resilient to climate impacts.

Australia has committed $1.5 billion towards climate finance over the 2020-25 period. This will be implemented through Australia's development assistance program. This builds on the $1.4 billion in climate finance Australia provided over 2015-2020 (which exceeded the $1 billion commitment we had made at the Paris conference).

Climate change is being integrated into every aspect of Australia's international development program. Australia's assistance is supporting Pacific and Southeast Asian countries to build more climate-resilient infrastructure, including roads, schools and bridges. Our commitment is also support local communities to better prepare for and recover from disasters, and address climate-related water and food security challenges. Australia is sharing its scientific expertise, providing regional partners with better information and forecasts to plan their development. We will increasingly support investments in nature-based solutions that protect the oceans and environment in ways that capture carbon and support local livelihoods.

Reliable and secure energy is vital for South-East Asia's ongoing development and prosperity. Supporting the region's transition to a low emissions energy future will require significant financial and technological support. Australia's climate finance will have a growing focus on partnering with the private sector to help other countries, especially in our region, access and adopt new technologies. Following the September 2021 Quad leaders meeting, Australia has announced it will host a Clean Energy Supply Chain Summit in 2022. The summit will bring together expertise across industry, science and academia with the aims of improving the transfer of clean energy technologies and building better international supply chains.

Our ongoing climate finance will build on the strong foundations established through our past investments. In particular, Australia has for many years supported developing countries to build capacity in emissions measurement, reporting and verification, blue carbon, national inventory systems, and emissions accounting. We will continue to share our expertise in these areas. Robust and transparent measurement and reporting systems will enable countries to track progress towards their goals. These systems are crucial for translating ambition to achievement.

Box 5.1 Projects supported through Australian climate finance

- The $2 billion Australian Infrastructure Financing Facility for the Pacific is financing renewable energy for the Solomon Islands through the Tina River Transmission Line, which will strengthen energy security, reduce the country's exposure to volatile global fuel prices and enable Solomon Islands to meet 100% of its Paris emissions reduction target.
- Through the Indonesia-Australia Partnership for Infrastructure we have supported a new Waste-to-Energy project in Semarang City that will divert and use waste in electric power generation, expected to reduce landfill by around 80% and generate 17MW of electricity, enough to power 17,000 homes.
- Our $140m Australian Climate Finance Partnership will mobilise private finance to reduce emissions and build resilience through investments across Southeast Asia and the Pacific.
- Australia is helping to build the skills of ni-Vanuatu to adapt to climate change and move towards clean, affordable low carbon growth in tourism, agribusiness, handicraft and construction sectors through the $21 million Vanuatu Skills Partnership.
- Our agriculture programs in Cambodia have introduced new drought- and flood-resilient rice varieties, better irrigation and farming technologies, including direct seeders and drones, helping more than 750,000 people improve their resilience to climate change.
- Through the $23 million Climate and Oceans Support Program in the Pacific, Australia's Bureau of Meteorology supports 14 Pacific country counterparts to prepare and communicate seasonal forecasts, and provide information on sea level rise, tide and wave data for shipping and fishing.

5.4 Indo-Pacific cooperation on high-integrity carbon markets

In April 2021 Australia committed $59.9 million to work with our neighbours to establish a high-integrity carbon offsets scheme in the Indo-Pacific. This support will help these countries adopt new low emissions technologies and provide access to an established market for offset credits. The Australian Government wants to ensure that, like carbon credits created in Australia, these offsets are credible and robust.

The scheme will establish the Indo-Pacific region as a strong voice in global standard setting, and increase market confidence that emissions reductions being achieved are real, and not being double counted.

Key elements of the scheme include:

- helping partners establish robust national policy frameworks and inventory systems that meet the requirements of the Paris Agreement and increase investor confidence
- demand-driven support designed to leverage Australia's recognised collaborative advantages in knowledge transfer and reporting capability
- improved reporting coverage of emissions sources across sectors and mutual confidence in claimed outcomes
- demonstration projects that help to establish a pipeline of projects funded by the private sector
- a sustainable financing approach to attract and aggregate co-investment by Australian business in a pipeline of future abatement projects
- a digital data analysis and mapping tool that can be used to calculate potential carbon emissions and sequestration in the land sector at the national and regional level quickly, easily and transparently.

Many Australian and international corporations have made voluntary commitments to reduce their greenhouse gas emissions. Their business strategies increasingly reflect a transition towards net zero by 2050. This shift is creating a growing demand for carbon offsets, and global carbon markets are expected to expand rapidly in the next five years. They offer an opportunity for governments and businesses to meet their climate targets cost effectively and direct finance towards countries that need support for urgent climate change action.

Australia's high-integrity carbon offsets scheme in the Indo-Pacific will boost our region's ability to attract this private sector investment in low-emissions renewables and nature-based solutions. It will help countries meet and report against their NDCs and offer many other important environmental, adaptation and livelihoods benefits. The scheme will have robust social and environmental safeguards, and ensure that real benefits are reaching communities on the ground.

PART C LOOKING AHEAD

6. AN ADAPTIVE PLAN FOR THE FUTURE

Key points

- Australia's Plan will be flexible and adaptive so we can refine and evolve our policies as technology and market developments occur, and as prospective pathways for different sectors and applications become clearer.
- The Australian Government will maintain a five yearly 'review and refine' cycle for the Plan in alignment with the delivery of Australia's successive National Determined Contributions under the Paris Agreement. This will ensure Australia's policies are calibrated to reflect the latest technology advances, international developments and other factors relevant to our national circumstances.
- Australia will not reach net zero emissions by 2050 at the expense of our regions. The Government will conduct five yearly assessments of the impact of Commonwealth and state emissions reduction actions on regions and communities. These reviews will report against a range of key economic indicators such as energy prices, employment (particularly regional employment), export volumes and trends, investment trends and growth in national income.
- Australia will maintain its commitment to transparency and accountability. This includes our annual and quarterly emissions reporting and annual projections, and our commitment to continually improve our systems and methods

6.1 'Review and refine' cycles to guide our path to net zero emissions by 2050

Our pathway to net zero emissions by 2050 will depend on our success in developing and deploying affordable low emissions technologies across all sectors. We are improving our understanding of the key technologies needed to achieve net zero emissions, yet the 'lived experience' reinforces that the future is uncertain (Box 6.1). Costs may fall faster than anticipated for some technologies, and new and disruptive technologies may emerge. This uncertainty reinforces that Australia must continuously refine and adapt its Plan as technology and market developments occur and prospective net zero pathways for different sectors and applications become clearer.

Box 6.1 The 'lived experience

Reducing emissions does not need to damage our economy. This has been the 'lived experience' over recent decades, both in Australia and internationally. Australia has reduced emissions by 20% between 2005 and 2020, with our emissions per capita falling by 36%.[106] However, our economy (real GDP, chain volume measures) has grown by 45% over the same period, with GDP per capita increasing by 14%.[107]

Technology advances are an important factor behind this outcome. Many experts, including the IEA, have been consistently surprised by the pace and scale at which technology adoption can happen. Historical estimates for solar PV deployment underscore this. In 2015, the IEA forecast a global installed solar PV capacity of 429.5 GW in 2020[108], which was well short of the actual installed capacity of at least 627 GW at the end of 2019.[109] Similarly, the IEA's 2015 forecast of 9 GW of Australian solar PV capacity in 2020 was well short of the 16.3 GW installed by the end of 2019.[110]

These forecasts did not anticipate dramatic reductions in technology costs. Innovation and manufacturing efficiency drove down the global cost of utility-scale crystalline silicon modules by around 90% between 2010 and 2019.[111] These advances have translated as lower costs in Australia, where the average cost has fallen from $8.50 per watt to 52 cents per watt between 2006 and 2019.[112] Similarly, unanticipated cost reductions have been observed across other emerging low emissions technologies, like wind, batteries and electric vehicles.

Australia will monitor and evaluate our progress towards net zero emissions through our reporting on national emissions. Australia's emissions reporting and accounting system is the most comprehensive and transparent in the world. Australia goes beyond its annual emissions reporting obligation under the UNFCCC and Paris Agreement. Each quarter it publicly reports emissions for all sectors and all greenhouse gases across Australia's economy, providing a comprehensive snapshot of Australia's emission reduction progress throughout the year. We will continue to refine our inventory methods as new information emerges and international practice evolves.

The global efforts of other nations should match Australia's resolve to ensure transparency and accountability for their targets. To this end, Australia encourages the wide adoption of our world-leading approach to emissions measurement and inventory management. We will also continue to share our technical expertise with countries in our region to enable them to increase their capabilities and meet new Paris Agreement emissions measurement and reporting obligations.

We will refine our Plan through five yearly 'review and refine' cycles. As outlined in the 2017 Review of Climate Change policies[113], the five yearly review process associated with the delivery of NDCs under the Paris Agreement sets a logical timing for reviewing and updating Australia's Plan.

Australia will conduct its next five yearly review process in 2024. This will inform the development of our next NDC, due to be submitted in 2025. The Government will consult widely through this process, especially with industry and regional communities.

These reviews will leverage Australia's world-class emissions measurement and reporting systems so we can monitor and evaluate the progress by each sector in reducing emissions. It will also draw on the evaluation frameworks embedded in other initiatives. In particular, the forthcoming LETS 2021 will outline a comprehensive impact evaluation framework for annually evaluating our progress in achieving the economic stretch goals for priority technologies and driving technology deployment.

The Government is has made it clear that we will not reach net zero emissions at the expense of our communities, particularly our regions. Accordingly, Australia will conduct five yearly assessments of the impact of Commonwealth and state emissions reduction actions on regions and communities. These reviews will report against a range of key economic indicators such as energy prices, employment (particularly regional employment), export volumes and trends, investment trends and growth in national income. The first of these reviews will be undertaken in 2023.

Table 6.1: Australia's Climate Change and Technology Reviews

REVIEW	SCOPE OF REVIEW	TIMING
Paris Agreement – Review and refine cycle	Comprehensive reviews of domestic emissions reduction policies, emissions trends and progress in reducing emissions, to inform the setting of upcoming Nationally Determined Contributions and any policy adjustments needed to maintain a pathway towards net zero emissions by 2050.	Every five years, to coincide with Australia setting its five yearly Nationally Determined Contributions under the Paris Agreement
Low Emissions Technology Statements	Reports on progress towards achieving Australia's technology stretch goals and the investments made by the Government to meet them May identify additional technology goals	Annual
Emissions Reduction Policy Impact assessments	Domestic reviews to report on the impacts on households and regions of Commonwealth, State and Territory emissions reduction policies. These reviews will report against a range of key economic indicators such as energy prices, employment (particularly regional employment), export volumes and trends, investment trends and growth in national income	Every five years, with the first to be undertaken in 2023

Australia will set out its net zero by 2050 commitment through its updated NDC under the Paris Agreement. As with the 2030 target already enshrined in our NDC, Australia will not legislate its long-term net zero by 2050 target.

6.2 Choices for bridging the gap to net zero by 2050 emissions

Australia has choices for how it bridges any gap to net zero emissions by 2050. These include:

- land sector offset credits
- units generated through international emissions trading
- securing further technology breakthroughs through additional technology investments.

As outlined in section 5.2, maintaining the right balance between these choices will be a core focus of Australia's flexible and adaptive Plan into the future.

6.2.1 Domestic land sector offset credits

Modelling for the Plan has underscored the substantial opportunities for Australian farmers to voluntarily invest in carbon sequestration projects on their land. These projects can generate valuable new revenue streams while offsetting hard-to-abate emissions from elsewhere in the economy.

Australia welcomes the economic opportunity this presents for the Australian land sector, and recognises the potential to expand carbon forestry projects. The opportunities include voluntary investment in offset projects on marginal lands or on-farm activities that co-exist with traditional farming enterprise. However, Australia is committed to maintaining a vibrant agriculture industry and exporting food to the world, so will ensure any offset approach carefully balances the competing demands on our agriculture and land sectors.

6.2.2 International carbon markets

Australia has for many years supported our regional neighbours' efforts to strengthen their capacity by sharing our expertise in:

- emissions measurement, reporting and verification
- blue carbon and forests
- national inventory systems
- emissions accounting.

In 2021, Australia committed to work with our neighbours to establish a high-integrity carbon offset scheme in the Indo-Pacific that will build on support provided to date. The scheme will boost partner countries' abilities to attract private sector investment in emissions reduction projects in the renewables and nature-based solutions sectors. It will help these countries adopt new low emissions technologies and provide access to an established market for offset credits.

Indo-Pacific countries interested in participating in this market will need strengthened capacity to demonstrate the environmental integrity and social benefits of their carbon offsets.

Encouraging development of quality offsets through this scheme provides an additional option for Australia to bridge the gap to net zero emissions by 2050. It will also create a revenue stream for our neighbours and offer important environmental, adaptation and livelihoods benefits.

The benefit to the climate of an avoided tonne of emissions is the same wherever it occurs. By helping our neighbours deploy new low emissions technologies, Australia can help the Indo-Pacific region position itself to be competitive in a low emissions future.

6.2.3 Achieving further technology advances

Additional direct emissions reductions could be enabled through a more aggressive approach to technology. Informed by the Technology Investment Roadmap and annual LETS, Australia could focus on bringing down the costs of currently very expensive abatement opportunities in hard-to-abate sectors like industry and agriculture.

Australia could also capitalise on high potential technologies, like bioenergy with CCS or direct air capture with CCS, if global developments see those technologies emerge faster than anticipated.

6.3 Institutions to provide expert advice

Australia's pathway to net zero emissions by 2050 will have enduring effects across the economy, with impacts on markets, fiscal settings, government decisions and consumer preferences. Existing institutions, including the Climate Change Authority and the Technology Investment Advisory Council, will play important roles in monitoring and providing expert advice to the government.

The Climate Change Authority is an independent statutory agency established to provide expert advice to the Government on climate change policy. The Technology Investment Advisory Council (Section 2.2) provides advice on low emissions technology investment priorities, as well as economic stretch goals and pathways that will drive economic prosperity and lower emissions. In addition to advising the Minister for Industry, Energy and Emissions Reduction on annual LETS, the council will continue to advise the Government on technological opportunities that will help Australia realise its net zero emissions goal.

GLOSSARY – ABBREVIATIONS AND ACRONYMS

ABARES - Australian Bureau of Agricultural and Resource Economics and Sciences

ACCUs – Australian Carbon Credit Units

AEMO – Australian Energy Market Operator

ARENA – Australian Renewable Energy Agency

CCS – Carbon capture and storage

CCUS – Carbon capture use and storage

CEFC – Clean Energy Finance Corporation

CGE – Computable General Equilibrium

CO_2 – Carbon dioxide

CO_2-e – Carbon dioxide equivalent

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DISER – Department of Industry, Science, Energy and Resources

ERF – Emissions Reduction Fund

EV – Electric Vehicle

GTEM - Global Trade and Environment Model

GDP – Gross Domestic Product

GW – Gigawatts

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Change

ISP – Integrated System Plan

LETS – Low Emissions Technology Statement

LNG – Liquefied natural gas

LULUCF - Land Use, Land Use Change and Forestry

MWh – Megawatt hour

Mt – Million tonnes

NEM – National Electricity Market

PV – photovoltaics

Quad – country grouping referring to Australia, United States, Japan and India

UNFCCC - United Nations Framework Convention on Climate Change

APPENDICES

APPENDIX A – SUMMARY OF AUSTRALIA'S EMISSIONS REDUCTION POLICIES, MEASURES, INSTITUTIONS AND MAJOR INVESTMENTS

TABLE A.1: KEY INSTITUTIONS	
Australian Renewable Energy Agency (ARENA)	ARENA provides grant funding to **early-stage low emissions technologies** to accelerate the pace of pre-commercial innovation. It has funded over $1.8 billion of early-stage research and development projects since 2012, with a focus on solar, wind and other renewable energy technologies, as well as enabling technologies such as energy storage and grid integration. ARENA has been provided with an additional $1.62 billion of funding for the period up to the 2031–32 financial year. As well as the ongoing **Advancing Renewables Program** and Innovation Program, ARENA also administers targeted funding programs including the **Regional Australia Microgrids Pilot Program** and the I**ndustrial Energy Transformation Studies Program**. ARENA's mandate was recently expanded to cover low emissions technologies in all sectors, including agriculture and transport.
Clean Energy Finance Corporation (CEFC)	The CEFC supports the **commercialisation of renewable energy, energy efficiency and low emissions technology projects** through loans and equity investments. By providing financial support, CEFC helps de-risk technologies across electricity generation, energy storage, industry and agriculture. It has also played an important role in developing an Australian sustainable finance sector. The $10 billion CEFC is the world's largest government-owned 'green bank'. Since 2013, it has invested more than $9.5 billion in clean energy projects worth more than $32.8 billion. The CEFC administers several targeted funds, including: • Clean Energy Innovation Fund • Advancing Hydrogen Fund • Australian Recycling Investment Fund • Sustainable Cities Fund • Reef Fund. The Government has introduced legislation to establish a new Grid Reliability Fund, also to be administered by the CEFC.

TABLE A.1: KEY INSTITUTIONS	
Clean Energy Regulator (CER)	The CER administers the **Emissions Reduction Fund** (ERF), which supports the creation, verification and purchase of Australian Carbon Credit Units (ACCUs). The Government allocated $2.55 billion to the ERF in 2014–15, and in 2018–19 allocated a further $2 billion through the **Climate Solutions Fund** to build on the ERF's success and support additional low-cost abatement. To date, the CER has committed around $2.5 billion through the ERF towards emissions reduction projects across: • agriculture and the land sector (particularly revegetation projects) • landfill and waste • energy efficiency • industry • transport. The CER also administers the following: • Australia's National Greenhouse and Energy Reporting (NGER) scheme. This is a single national framework for reporting and disseminating company information about greenhouse gas emissions, energy production, energy consumption and other information specified under the *National Greenhouse and Energy Reporting Act 2007*. • the Large-scale Renewable Energy Target (RET) and Small-scale Renewable Energy Scheme (SRES). The Large-scale RET encourages investment in renewable power stations while the SRES supports small-scale installations like household solar panels and solar hot water systems. • the Australian National Registry of Emissions Units, which is a secure electronic registry system that tracks the location and ownership of units issued under the Kyoto Protocol and the Emissions Reduction Fund. • the Safeguard Mechanism, which places mandatory emissions limits on around 200 of Australia's largest emitters. The CER is also leading work to build the systems and registries needed to underpin Australia's voluntary carbon markets. This includes establishing an exchange trading platform for ACCUs and enhancing the registry for ACCUs to make it easier to trace the origin of units.

TABLE A.2: ACTIONS FOCUSED ON PRIORITY AND KEY EMERGING TECHNOLOGIES	
Ultralow cost solar	**Investments** – ARENA and the CEFC have directed $4.33 billion towards solar technologies since their inception. The **Reliable Affordable Clean Energy ('RACE for 2030') Cooperative Research Centre** is focused on opportunities arising from low-cost renewable energy, network integration and smart energy management. The Australian Government has committed $68.5 million over 10 years, with industry and research partners committing $279 million. **Renewable Energy Target:** • The Large-Scale Renewable Energy Target (LRET) encourages investments in renewable energy power stations, including hydro power stations, wind farms and large-scale solar. • The Small-scale Renewable Energy Scheme (SRES) supports small-scale installations like household solar panels and solar hot water systems.
Energy storage for firming	**Investments** – The Australian Government has committed around $300 million in battery-related research and development since 2015, including $90 million from **ARENA** and more than $208 million from the CEFC. The **Future Battery Industries Cooperative Research Centre** (FBICRC) drives collaboration on research and development across all segments of the battery value chain. The Australian Government has committed $25 million over 6 years to the FBICRC, while industry and research partners have committed $110.9 million.
Clean hydrogen	**Investments** – The Australian Government has announced over $1.2 billion in support specifically for the hydrogen industry, including support through ARENA, the CEFC and other institutions. This includes $464 million to develop up to seven **Clean Hydrogen Industrial Hubs** in regional areas across Australia. These will co-locate users, producers and potential exporters, helping develop supply chains and providing focal points for innovation and skills development. The CEFC has made up to $300 million available to support the growth of the Australian hydrogen industry through its advancing hydrogen fund. Over $100 million is being provided to three 10 MW hydrogen electrolyser projects through ARENA. $24.9 million has been allocated towards helping new gas generators to be hydrogen-ready. $9.7m has been provided to the Clean Energy Regulator to complete trials of a hydrogen Guarantee of Origin Scheme. More than $300 million has been committed for other research, development and demonstration activities or for delivery of National Hydrogen Strategy actions, including $50 million for the HyGate technology incubator under the Australia-Germany Hydrogen Accord

TABLE A.2:	ACTIONS FOCUSED ON PRIORITY AND KEY EMERGING TECHNOLOGIES
Clean hydrogen	**National Hydrogen Strategy** – Agreed by the Australian, state and territory governments in 2019, the strategy has 57 actions to build Australia's hydrogen industry. These actions set the foundations for industry growth, ahead of supporting industry scale-up to service international and domestic markets as they emerge. As well as investments, Australian Government focus areas have included: • building international relationships, including with Germany, Singapore, Japan and the UK. • developing a domestic Hydrogen Guarantee of Origin scheme and helping shape the design of an international methodology • mapping prospective hydrogen production regions • a review of legal and regulatory frameworks • conducting the National Hydrogen Infrastructure Assessment These actions are complemented by measures implemented by states and territories. A new **ERF method for hydrogen** will be developed in 2022. This will include injection of clean hydrogen into the gas network and the use of hydrogen in electricity generation or other uses, such as low carbon steel.
Low emissions materials – steel and aluminium	The **Heavy Industry Low-carbon Transition Cooperative Research Centre** (HILT CRC) will help develop materials such as 'green' iron, alumina, cement and other processed minerals for the Australian heavy industry sector. The Australian Government has committed $39 million over 10 years, with a further $175.7 million from industry, research and other government partners. Recycling and clean energy is a National Manufacturing Priority identified in the 2021 **Modern Manufacturing Strategy**. Investments in low emissions domestic manufacturing have been invited under the $1.3 billion Modern Manufacturing Initiative, launched with the strategy.

TABLE A.2:	ACTIONS FOCUSED ON PRIORITY AND KEY EMERGING TECHNOLOGIES
Carbon capture and storage (CCS) and carbon capture, use and storage (CCUS)	The Australian Government has committed $250 million over 10 years to the **CCUS Technologies and Hubs Program**, which will • fund CCUS projects • establish CCUS hubs • support research, development and commercialisation of CCUS technologies. The $50 million **CCUS Development Fund** is supporting technologies such as direct air capture, CCS from power stations, and carbon-negative construction materials. These investments build on $790 million invested in CCUS and related low emissions technologies since 2008. Australia is developing a **National Carbon Capture Use and Storage (CCUS) Technology Emissions Abatement Strategy** which will guide the Australian Government's approach to deploying CCUS, signal government priorities and support the development of potential hubs. **Bilateral partnerships** with Japan and Singapore include a focus on CCUS. An **ERF method has been introduced to incentivise CCS**. A new **ERF method for CCUS**, including in the production of industrial and building materials like insulation or concrete, will be developed in 2022. The Government has introduced reforms to **ARENA** and the **CEFC** to enable funding and investment in CCS.
Soil carbon	Incentives for landholders to improve soil carbon are available using two existing **ERF** methods, with a third method under development. Advance payments of up to $5,000 are available to assist landholders with upfront measurement costs The $8 million **Soil Carbon Data Program** is gathering data to help develop and validate measurement approaches. This data will also be used to improve models of soil carbon change. The **National Soil Carbon Innovation Challenge** will identify and fast-track low-cost, accurate technological solutions for measuring soil organic carbon, with $36 million available for grants. The $20 million **National Soil Science Challenge** grants will address fundamental gaps in soil science and improve our understanding of how to better manage soil. The **National Soil Strategy** will help farmers monitor, understand and make better decisions about their soil health, productivity and sequestration potential. This includes the $54.4 million **National Soil Monitoring and Incentives Pilot**, which is trialling new measures to incentivise soil testing and data sharing. The **Cooperative Research Centre for High Performance Soils** is focused on developing soil science, agricultural technologies and improving soil productivity. The Australian Government has committed $39.5 million over 10 years, with industry and research partners committing $126.8 million. Further work on agricultural innovations, including soil carbon measurement, is being supported by the **CEFC, ARENA, CSIRO and Rural Research and Development Corporations (RDCs)**.

TABLE A.2: ACTIONS FOCUSED ON PRIORITY AND KEY EMERGING TECHNOLOGIES	
KEY EMERGING TECHNOLOGIES	
Methane-reducing feed for livestock	The Australian Government has allocated $30.7 million over six years to support the development and deployment of **innovative livestock feed technologies**: • The $6 million **Methane Emissions Reduction in Livestock** program supports research into the abatement potential and productivity benefits of livestock feed technologies. • The $23 million **Low Emissions Supplements to Grazing Animals at Scale** program will help develop technologies to deliver low emissions feed to grazing animals. • $1.7 million will help scale up production of the red seaweed, *Asparagopsis*. This includes: – a $1 million Accelerating Commercialisation grant under the Entrepreneurs' Program to scale up production and support the commercialisation of *Asparagopsis* – a $675,000 grant from the $30 million Commercialisation Fund to establish a processing and manufacturing facility for this seaweed product. The **Marine Bioproducts Cooperative Research Centre** is helping accelerate the growth of Australia's emerging export-focused marine bioproducts industry, with a focus on the production of new sources of marine biomass and high-value bioproducts. This could include the development of high-protein seaweed for use as a livestock feed. The Australian Government has committed $59 million over 10 years, with $209.6 million committed by industry and universities.
Low emissions cement	The Government has invested $75 million for Cooperative Research Centres which have examined low emissions cement: • The **SmartCrete Cooperative Research Centre** is supporting collaboration on issues across the concrete supply chain. The Australian Government has committed $21 million over seven years, with industry and researchers committing $69 million. • The **Building 4.0 Cooperative Research Centre** aims to develop an internationally competitive, dynamic and thriving Australian advanced manufacturing sector to deliver better buildings at lower cost. The Australian Government has committed $28 million over 7 years, with industry and researchers committing $102 million. • The **Low Carbon Living Cooperative Research Centre** led research and innovation aimed at driving the nation's built environment sector towards a globally competitive low carbon future. The Australian Government committed $28 million between 2012–2019, with industry and researchers committing $102 million. The **CEFC** also finances commercial and industrial building projects that reduce embodied carbon by using lower emissions cement.

TABLE A.3:	POLICIES, MEASURES AND MAJOR INVESTMENTS TO DEPLOY TECHNOLOGIES AT SCALE IN KEY SECTORS
Electricity	**Investments** Strategic infrastructure investments in storage and dispatchable generation: • Up to $1.38 billion towards Snowy 2.0, which will add 2000 MW of renewable dispatchable generation to the National Electricity Market and be the largest storage project in the southern hemisphere. • $150 million towards the Battery of the Nation initiative, with a further $30 million invested by the Tasmanian Government, which will develop a pathway of future opportunities in Tasmania's hydropower system expansion including pumped hydro. • The 660 MW Hunter Power Project, an open-cycle gas turbine to provide firm capacity in NSW, to be delivered through a commitment of up to $600 million equity to Snowy Hydro Ltd. Funding, underwriting or other financial support to get major **transmission and interconnector projects** off the ground, including all priority projects identified by AEMO's 2020 Integrated Systems Plan: • The **Marinus Link Interconnector** project will potentially provide up to 1500 MW of additional transfer capacity between Tasmania and Victoria and unlock a pipeline of renewable energy investment in Tasmania. • The **Victoria to New South Wales Interconnector** (VNI) West project, which is expected to provide 1800 MW of additional electricity transfer capacity between Victoria and NSW, unlocking electricity from Snowy 2.0 to the Victorian market and unlocking two renewable energy zones. • **Project EnergyConnect**, an 800 MW interconnector enabling electricity to flow between South Australia and NSW that will unlock renewable energy projects in Victoria, South Australia and NSW. • **HumeLink**, which will strengthen the network in southern NSW and transport renewable energy to consumers from new projects, including Snowy 2.0. • The **Queensland to NSW Interconnector** (QNI) Upgrade of power transmission between Queensland and NSW, which also supports the development of renewable energy zones. The Australian Government is pursuing strategic infrastructure investments through **bilateral state deals**. Three deals have been agreed to date – with NSW, Tasmania and South Australia – leveraging overall investment of more than $3 billion in energy and emissions reductions projects. Bilateral deals with other jurisdictions are expected in due course. Infrastructure investments will be supported through the **Underwriting New Generation Investment** (UNGI) program. Key UNGI investments will be delivered through the $1 billion **Grid Reliability Fund** that will be administered by the CEFC. The $50 million **Regional Australia Microgrid Pilots Program** (RAMPP) aims to improve the resilience and reliability of power supply for regional and remote communities. RAMPP builds upon the $50.4 million **Regional and Remote Communities Reliability Fund** (RRCRF), which funded feasibility studies for regional and remote communities to investigate deployment of local microgrid technologies.

TABLE A.3:	POLICIES, MEASURES AND MAJOR INVESTMENTS TO DEPLOY TECHNOLOGIES AT SCALE IN KEY SECTORS
Electricity	**Markets, regulatory arrangements and institutions** The Australian Government, working with the states and territories, is progressing reforms to deliver a long-term, fit-for-purpose **post-2025 market design** for the National Electricity Market (NEM). National Cabinet has endorsed a final package of reforms, acting on the recommendations of the ESB, which set out immediate, initial and long-term changes. This includes reforms to systems, tools and regulations to meet long-term consumer interests. This work will address the impact that greater penetration of renewable energy generators is having on the NEM and facilitate further renewables integration. The Australian Government has introduced legislation to establish a **regulatory framework for offshore electricity infrastructure.** The **Australian Energy Infrastructure Commissioner** 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. The **Australian Energy Market Operator's Integrated System Plan** (ISP), delivered every two years, is a whole-of-system plan that identifies development opportunities and recommends priority transmission projects to maximise market benefits and deliver low-cost, secure and reliable energy. The 2022 ISP is scheduled to be published on 30 June 2022, with the draft scheduled to be released on 10 December 2021. *See also: measures to develop priority and emerging technologies, including ultra low-cost solar, energy storage and hydrogen.*
Transport	Australia's **Future Fuels Strategy** is focused on increasing consumer choice, stimulating industry development and reducing emissions in the road transport sector. To support the strategy, the government is investing $74.5 million in: • help businesses integrate new vehicle technologies • reduce blackspots for public charging and refuelling infrastructure • unlock new transport technologies for use in heavy vehicle fleets • support households to use smart charging technology • progress reforms to ensure the grid is EV ready • ensure consumers can make informed choices about new vehicle technologies. The $24.5 million **Freight Energy Productivity Program** will aim to increase the use of new truck technology in the road freight sector to improve fuel efficiency, increase productivity and reduce emissions. Through its forthcoming **Bioenergy Roadmap**, ARENA is exploring the potential economic opportunities for Australia, particularly regional areas, and the role that bioenergy could play in decarbonising the industrial and transport sectors. A new ERF method for transport, including to credit emissions reductions created by electric vehicle (EV) charging and hydrogen refuelling infrastructure, will be developed in 2022. *See also: measures to develop priority and emerging technologies, including hydrogen, energy storage and bioenergy.*

TABLE A.3:	POLICIES, MEASURES AND MAJOR INVESTMENTS TO DEPLOY TECHNOLOGIES AT SCALE IN KEY SECTORS
Buildings	The **Nationwide House Energy Rating Scheme** (NatHERS) provides voluntary energy ratings for residential buildings. By providing a 'measuring tape' for energy efficiency, NatHERS helps to make Australian homes more comfortable to live in and helps residents save on energy bills through smarter design choices. The **Your Home** guide is an independent resource for homeowners to assist them in designing, building or renovating homes to ensure they are energy efficient, comfortable, affordable and adaptable for the future. The **National Australian Built Environment Rating System** (NABERS) is a national rating system that measures the environmental performance of Australian non-residential buildings and tenancies, providing a national standard and instrument to improve the quality of our built environment. The **Commercial Building Disclosure** program is a regulatory program that requires energy efficiency information to be provided in most cases when commercial office space of 1000 square metres or more is offered for sale or lease. Its aim is to improve the energy efficiency of large office buildings and to ensure prospective buyers and tenants are informed. The ***Greenhouse and Energy Minimum Standards (GEMS) Act 2012*** establishes minimum energy performance standards or labelling requirements for a range of appliances, products and equipment used by households and businesses. Building on existing and past measures, the Australian Government and all state and territory governments have agreed to a **Trajectory for Low Energy Buildings**. This is a national plan that sets a trajectory towards zero energy (and zero carbon) ready buildings for Australia. It includes 14 measures covering: • energy efficiency in the National Construction Code • better information, guidance and tools • skills and supply chain development. The Australian Government provides grants, incentives and support to enable businesses and community organisations to make energy efficiency improvements: • The **Hotel Energy Uplift Program** has provided grants totalling $9.9 million to over 400 small and medium hotels across Australia to help these businesses reduce their energy use, improve energy productivity and deliver carbon abatement. • The $10.2 million **Powering Communities Program** will support not-for-profit community organisations improve energy productivity and reduce emissions by investing in energy efficient equipment, energy monitoring and management, and on-site renewable energy and batteries. • The $40 million **Energy Efficient Communities** program has helped businesses and community groups lower their energy bills and reduce emissions. Over 1,200 grants totalling $19.7 million have been awarded to community organisations, dairy farming businesses, small businesses and businesses with high energy use. • Since August 2019, the $12 million **Business Energy Advice Program** has helped over 12,000 small businesses better understand their energy use, receive tailored advice on energy efficiency opportunities best suited to their industry, and make significant savings on their energy bills. *See also: measures to develop priority and emerging technologies, including ultra low-cost solar, energy storage and hydrogen.*

TABLE A.3:	POLICIES, MEASURES AND MAJOR INVESTMENTS TO DEPLOY TECHNOLOGIES AT SCALE IN KEY SECTORS
Agriculture	Around $1.9 billion has been committed to date through the Emissions Reduction Fund towards projects that reduce or avoid agricultural emissions or store carbon in the land. ERF projects have also provided co-benefits including improved soil health, biodiversity and agricultural productivity. Savanna fire management projects in northern Australia are providing employment and income for Indigenous communities. A new **Carbon + Biodiversity Pilot** supports farmers and landholders to reduce emissions while building biodiversity on their properties. The pilot scheme is operating in conjunction with the ERF in six regions. Under the pilot, farmers and landholders who plant mixed tree species are paid a premium for both emissions reductions and biodiversity benefits (like providing habitat for threatened species). A priority of the $95.4 million **King Review Technology Co-Investment Fund** is to improve knowledge sharing with natural resource management groups and Indigenous land managers to boost participation in the ERF. *See also: measures to develop priority and emerging technologies, including soil carbon and livestock feed technologies.*

TABLE A.3: POLICIES, MEASURES AND MAJOR INVESTMENTS TO DEPLOY TECHNOLOGIES AT SCALE IN KEY SECTORS	
Industry, mining and manufacturing	A new **Safeguard Crediting Mechanism** will help deploy new low emissions technologies. The Government has allocated $279.9 million to 2030 to the crediting mechanism, which will encourage projects that: • significantly reduce the emissions intensity of facilities covered by the Safeguard Mechanism • help develop and deploy emerging low emissions technologies. The crediting mechanism will build on the existing architecture of the **Safeguard Mechanism** and **National Greenhouse and Energy Reporting scheme**. These schemes provide a framework for major emitters to measure, report and manage their emissions. The Government's $43 million **Industrial Energy Transformation Studies Program** will provide financial support to firms to perform detailed engineering studies to inform investment decisions on energy efficiency improvements. A priority of the $95.4 million **King Review Technology Co-Investment Fund** is to develop industrial energy tools to help businesses identify energy productivity improvements and inform clean energy decisions. The **GEMS Act 2012** establishes minimum energy performance standards for industrial equipment, including motors. Through the ***Ozone Protection and Synthetic Greenhouse Gas Management Act 1989***, Australia regulates the manufacture, import, export, use and disposal of hydrofluorocarbons (HFCs) and other potent synthetic greenhouse gases. Australia has committed to an 85% phase-down of HFC imports by 2036, ahead of the international schedule agreed under the Montreal Protocol. The $100 million **Australian Recycling Investment Fund** (administered by the CEFC) is guiding national investment in recycling and other technologies that can reduce waste emissions. A new **ERF method** to credit the capture of biogas from organic waste and its refinement into biomethane as a natural gas substitute will be finalised in late 2021. *See also: measures to develop priority and emerging technologies, including hydrogen and CCS.*

TABLE A.4: OTHER CROSS-CUTTING MEASURES AND INSTITUTIONS	
International technology partnerships and the Special Advisor on Low Emissions Technologies	The Government appointed Dr Alan Finkel, Australia's former Chief Scientist, as S**pecial Adviser to the Australian Government on Low Emissions Technologies**. Dr Finkel is leading work to broker international partnerships with priority trade and strategic partners. The Government has allocated $565.8 million to support **international technology partnership**s that help commercialise low emissions technologies, particularly the priorities identified through the Technology Investment Roadmap and Low Emissions Technology Statements. The Government announced four new low emissions technology partnerships in 2021: • the Australia–Germany Hydrogen Accord • the Japan–Australia Partnership on Decarbonisation through Technology • the Australia-Singapore partnership on low emissions technology in the maritime sector • the Australia–UK partnership to drive low emissions solutions.
CSIRO missions program	In 2020, CSIRO announced a **missions program** with $100 million directed to Australia's greatest research challenges each year. Key CSIRO missions closely aligned with Australia's Whole-of-Economy Long-Term Emissions Reduction Plan include: • finding profitable pathways to net zero by putting low emissions technologies into practice • building Australia's clean hydrogen industry and reducing the cost of hydrogen to under $2 a kilo • developing solutions for the private sector to respond to climate risk • delivering cost competitive and sustainable battery materials to the world. CSIRO is Australia's national science agency and has been at the leading edge in developing low emissions technologies over many years. The missions program will build on past and current investments by CSIRO across all sectors of the economy. This includes renewable and low emissions energy technologies and breakthrough technologies in agriculture (such as the Future Feed livestock feed supplement).
Climate Active	Climate Active is Australia's globally recognised **carbon neutral certification** initiative. Climate Active certifies businesses that reach net zero emissions by measuring, reducing and offsetting emissions against a best-practice carbon accounting standard. Certification is available for buildings, events, organisations, precincts, products and services. It provides transparency to consumers and motivates firms to become leaders in emissions reduction and technology. Climate Active's membership has more than doubled in the last 12 months, with over 370 certifications across more than 240 Australian businesses
Safeguard Mechanism	The Safeguard Mechanism provides a framework for Australia's largest emitters to measure, report and manage their emissions. It places emissions limits, called baselines, on large emitters, giving covered businesses a legislated obligation to keep net emissions below their baseline.

TABLE A.4: OTHER CROSS-CUTTING MEASURES AND INSTITUTIONS	
Indo-Pacific regional crediting scheme	The Australian Government will invest $59.9 million to **establish a high-integrity carbon offset scheme in our Indo-Pacific region.** The scheme will boost partner countries' abilities to attract private sector investment in emissions reduction projects in the renewables and nature-based solutions sectors. It will help these countries adopt new low emissions technologies and provide access to an established market for offset credits. This commitment will: • boost public and private investment in climate action and practical projects in the region • deliver real social, economic and environmental benefits for local communities • generate a scalable supply of high-quality offsets that help Australian companies meet emissions reduction targets.
Climate Change Authority	The Climate Change Authority plays an important role in the governance of Australia's mitigation policies, undertaking **reviews and making recommendations on the Australian Government's climate change policies**. Reviews are also undertaken on other matters as requested by the Minister responsible for climate change or the Australian Parliament. The authority also conducts and commissions its own independent research and analysis.
Technology Investment Advisory Council	The Council advises the Minister for Industry, Energy and Emissions Reduction in preparing annual **low emissions technology statements**. The council is comprises leaders from science, business, technology and government. It includes the chairs of ARENA, the Climate Change Authority, the CEFC and the CER.

APPENDIX B – ANALYSIS OF MINERAL OPPORTUNITIES IN THE CLEAN ENERGY TRANSITION (OFFICE OF THE CHIEF ECONOMIST, DISER)

Australia's comparative advantage in mining is a source of both economic prosperity and employment. In 2020–21, the sector contributed to around 10% of Australia's GDP, and employed more than a quarter of a million people. Resources and energy exports reached a record $310 billion in 2020–21, accounting for more than 65% of Australia's total exports.

Export earnings from energy commodities (coal, LNG, uranium and liquid fuels) made up just over a quarter of Australia's total resources and energy exports in 2020–21. This is expected to grow to around 40% in 2022–23, returning to typical pre-COVID-19 levels. Energy commodities are expected to continue to be demanded in the Asia-Pacific, as populous nations develop rapidly. Australia is well placed to maintain its position as a leading supplier within the region.

Australia also has a significant opportunity to capture mineral demand from low emission technologies. Many of these technologies are reaching important economic tipping points, with take-up likely to accelerate over the coming years.

The rapid pace of change in this sector can make forecasting particularly challenging. Prices are highly volatile and difficult to predict over the long-term. Supply chains and technologies are evolving quickly and the role Australia may play in terms of market-share and value-adding downstream is fluid. Another source of uncertainty is the role recycling may play in dampening mining demand and prices.

Yet the size of the prize for Australia is expected to be large. By 2050, combined earnings from lithium, copper, nickel and uranium production has the potential to reach anywhere between $28 billion per annum (p.a.) under a gradual transition scenario and $42 billion under a rapid transition scenario in 2020 dollar terms. This could grow to as high as $85 billion, if current commodity spot prices are maintained and Australia further refines all the lithium it produces.

These estimates are intended to be purely illustrative to help frame the key drivers, issues, uncertainties and potential opportunities for Australia, rather than as definitive forecasts of future outcomes. This analysis is not exhaustive, and only a subset of low emissions technologies have been examined for the purpose of illustrating the potential size of the economic opportunity. There is significant potential for opportunities for exports using low emissions technologies not included in this analysis, including hydrogen and carbon capture, use and storage.

Approach

To inform Australia's Long Term Emissions Reduction Plan, the Office of the Chief Economist within DISER has examined the economic opportunities for Australian producers of lithium, copper, nickel and uranium arising from low emissions technology demand. The opportunities have been investigated under two scenarios:

- A **gradual transition** scenario, under which low technology change is moderate and steady, and is linked to current policy settings. This scenario is consistent with the International Energy Agency's (IEA) 2020 Current Policies Scenario, under which global warming exceeds 2°C and may reach 3°C or more.
- A **rapid transition** scenario, supported by faster technological progress and changes in policies. This reflects the IEA's 2020 Sustainable Development Scenario, and is consistent with the Paris Agreement's long-term goal of limiting average temperature increases to 1.5–2°C.

These scenarios were used to develop projections of low emissions technologies to estimate the potential size of the global market. The two scenarios have differing implications for:

- **Battery demand**, which is expected to significantly affect the demand for lithium and nickel. Batteries are deeply linked to growth in electric vehicle (EV) markets, stationary storage, and consumer electronics. In 2020, passenger EVs made up 27% of lithium-ion battery demand. EVs are expected to account for the majority of lithium-ion battery demand by 2025 under the 'rapid' scenario, and by 2030 under the 'gradual' scenario.
- **EV demand** beyond battery demand (notably for engines and charging infrastructure), which is linked primarily to copper.
- **Wind and solar power generation** (notably generators, gears, wiring, cables and tubing), which is expected to primarily affect copper demand.
- **Nuclear power generation**, which is expected to affect uranium demand.

Demand for these technologies was translated to potential global demand for commodities used as inputs. Information about global supply curves, planned projects and market share informed forecasts of Australia's potential output. Estimated long-term prices were based on production costs faced by the highest cost producer on global supply curves at output levels that met forecast demand.

Findings

The demand for **lithium** is likely to be driven by rising demand for rechargeable electric transport and energy storage equipment, as the world shifts towards low emissions technologies.

- Strong growth in demand for lithium used in lithium-ion batteries is projected under both the gradual and rapid scenarios. This demand is also expected to incentivise increased recycling rates, partly offsetting growth in mining output.
- Net of recycling, global lithium production is expected to increase 3-fold from 2020 to 2050 under the gradual scenario, and 4-fold under the rapid scenario. There is potential upside, as this projection assumes rapid improvements in recycling rates.[iii]
- With a 55% share of production, Australia is currently the world's biggest lithium producer. If this share is maintained, Australia could increase production from 233 kilo-tonnes (kt) of Lithium Carbonate Equivalent (LCE) p.a. in 2020 to 698 kt LCE by 2050 in the gradual scenario, and 959 kt LCE under the rapid scenario.
- Australian exports of lithium were worth around $1 billion p.a. in 2020. If Australia can convert 20% of its spodumene into lithium hydroxide and maintain current market share, earnings in 2050 may grow:
  - By more than six-fold to $8 billion p.a. under a gradual transition scenario, or
  - by more than nine-fold to $10 billion under a rapid transition scenario.
- If Australia could expand its capacity to process 100% of its spodumene production into lithium hydroxide and maintain current market share, earnings in 2050 may grow by:
  - more than 12-fold to $14 billion p.a. under a gradual transition scenario, or
  - more than 17-fold to $19 billion under a rapid transition scenario – or more than 30-fold to $34 billion if the current spot price of US$22,165 a tonne for lithium hydroxide is maintained.

Growth in **nickel** demand is expected to move closely in line with the rising demand for batteries and renewable energy. Recycling is also expected to become more material over time.

- Net of recycling, world nickel mine production is projected to double from 2020 to 2050 under the gradual scenario and to increase 3-fold under the rapid scenario.
- Australia's nickel exports were worth around $3.8 billion in 2020–21. Australia is projected to grow its share of global nickel production under both the gradual scenario and rapid scenarios. Australia has significant reserves of both sulphide and laterite nickel resources that can produce the high quality Class 1 nickel used in batteries.
- Australia's nickel production is also expected to grow in absolute terms by more than 3-fold from 170 kt in 2020 to 638 kt in 2050 under the gradual scenario and 7-fold to 1,207 kt under the rapid scenario.
- Australia's nickel earnings in 2050 are projected to grow:
  - 3-fold to $12 billion p.a. under the gradual transition scenario, or
  - by more than 5-fold to $22 billion under the rapid transition scenario – or more than 8-fold to $31 billion if the current spot price of US$19,930 a tonne is maintained.

Growth in **copper** demand is the least variable of the commodities studied in this project, with the bulk of copper demand linked to broader infrastructure and urban development. However, the emergence of electric vehicles and batteries offers a significant upside.

- Growth in copper demand is expected to be more than offset by increasing recycling rates out to 2050. Net of recycling, global mined copper output is projected to decrease 24% from 2020 to 2050 under the gradual scenario and 17% under the rapid scenario. There is upside to these forecasts if recycling rates improve more slowly than predicted.
- Nevertheless, Australia's mined copper production is projected to grow as a share of global production and in absolute terms – with production projected to increase by 36% from 884 kt of copper in 2020 to 1,201 kt in 2050 under both scenarios.
- Australian exports of mined copper were worth around $7 billion p.a. in 2020. This is expected to increase to $8 billion by 2050 under both a gradual and rapid transition scenario – or if current spot prices of US$9,550 a tonne are maintained, reach $19 billion.

iii. Leading forecasts for lithium global production vary substantially due to differences in forecasted ramp up of lithium recycling. This analysis assumed a ramp up of recycling consistent with the World Bank's 2020 Minerals for Climate Action report which projects recycling rates to increase from around 0% in 2020, to between 40% and 80% from 2020 to 2050.

Uranium exports are determined by growth in nuclear power generation. The International Energy Agency estimates that this form of generation will need to double over the next 30 years in order to hold global temperature warming below 2°C.

- 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.
- Development of small modular reactors using Generation IV technology offers a potential means to enable production at scale, with easy shipment and grid connection on site providing an alternative to constructing reactors singly at different locations. However, such technology is not expected to be commercialised until the 2030s.
- Nuclear generation under the rapid scenario is assumed to double by 2050, in line with IEA projections that such an increase would be necessary for the world to meet the 2°C warming target. Efficiency gains of around 6% by 2050 are also assumed, which results in a reduction in uranium requirements relative to growth in nuclear power generation.
- Uranium exports are currently declining from the 2020 level (of around $762 million per year) due to the closure of the Ranger mine. However, growth in uranium export earnings are expected to resume in the long term, and reach:
  - just under $900 million (by 2050) under the gradual transition scenario, or
  - $1.3 billion (by 2050) under the rapid transition scenario.

Methodology notes

- Projections used in this analysis for the global deployment of electric vehicles, stationary storage and wind and solar generation are described in Table C.1. These projections are primarily drawn from the IEA's Stated Policies and Sustainable Development Scenarios, and are complemented by analysis from other sources – including the IEA's 'Future is Electric Scenario' and BloombergNEF's New Energy Outlook (NEO). Where necessary, to extend the projection beyond the IEA World Energy Outlook period (2040) to 2050, average growth rates for the period 2035–2040 were applied.
- Further analysis then enabled these projections to be translated to demand for individual metals. Changes in battery chemistry used in stationary energy and EVs was based on BloombergNEF projections to 2030, and then held constant. The metal use ratio of copper in EVs was based on estimates by the International Copper Association. The metal intensity ratio for wind and solar power generation was also based on BloombergNEF. The gradual scenario for uranium demand was built on baseline projections for nuclear energy growth under 'business as usual conditions', as produced by UxC, a leading market forecaster.
- In this analysis, global supply – being the sum of both primary (mined) and secondary (recycled) sources – is assumed to increase such that demand is met. The share of minerals demand able to be met by secondary sources is taken into account in this analysis, and is based on published estimates for future trends in metal recycling.
- The value chain for minerals is complex: minerals go through several layers of processing and conversion between the mine site and end use. Supply of the mined product is assumed to meet demand for, and supply of, finished products, after adjustments for yield losses (between different stages of processing) and stockpiling.
- Mineral demand not associated with clean energy (for example, lithium associated with consumer electronics) was considered for the purpose of balancing supply and demand, but not included in the estimates of economic opportunities arising from the global shift to clean energy.

Table C.1: Projected cumulative global deployment of electric vehicles, batteries, wind, solar and nuclear

	2018	2030	2040	2050
Rapid				
Electric vehicles (millions)	2	44	96	120
Stationary storage (gigawatts)	4	137	554	1505
Solar (gigawatts)	495	2537	4815	7238
Wind (gigawatts)	566	1721	2930	3410
Nuclear (terawatt hours)	2563	3038	3767	5209
Gradual				
Electric vehicles (millions)	2	15	33	42
Stationary storage (gigawatts)	4	84	332	898
Solar (gigawatts)	495	1866	3142	5060
Wind (gigawatts)	566	1288	1856	2516
Nuclear (terrawatt hours)	2563	2685	2917	3556
TOTAL Vehicle Sales [b]	**81**	**90**	**100**	**120**

Note: *Electric vehicles include passenger EVs, commercial EVs and electric buses; b: total vehicle sales – whether ICE or EV. Electric vehicle numbers adapted from Bloomberg NEF – where data available to 2040 only. Historical sales 2018 source from Bloomberg. Historic vehicle sales over 2007-2019 show CAGR 2.1%, 2007-2018 – 2.7%, i.e. average 2.4%. Sales growth for EV's over 2040 – 2050 based on CAGR 2.4%.*

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APPENDIX C – REFERENCES

Note: Most analysis conducted for the Plan uses emissions estimates up to 2019 consistent with Australia's most recent official inventory submission under the United Nations Framework Convention on Climate Change. Where statistics are available for 2020 or 2021, these are reported where relevant.

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