

Summary

Every sector of the economy must play its part in Australia's transition to net zero emissions by 2050. The pathways that best support this transition require Australia to accelerate the deployment of mature, low emissions technologies while rapidly developing emerging technologies. Governments – working together and with businesses, communities and households – need to plan and act to overcome the barriers, take the opportunities, and ensure Australia's rapid, orderly and just transition.

At the request of the Australian Parliament, the Climate Change Authority has identified the potential technology transition and emissions pathways in six sectors – electricity and energy, transport, industry and waste, agriculture and land, resources and the built environment – that best support Australia's transition to net zero emissions by 2050.

The authority has identified the range of emissions reductions that are achievable through the deployment of available and prospective technologies, and examined the relevant barriers, opportunities and enablers for each sector. In identifying possible technology and emissions pathways for each sector, the authority utilised whole-of-economy and sectoral modelling to provide a 'top-down' view and undertook 'ground-up' analysis to complement the modelling, drawing on a range of inputs from research, analysis and extensive consultation.

The modelling undertaken for the authority by the CSIRO, Australia's national science agency, examined several scenarios, two of which are featured in this report. The 'A50/G2' scenario is consistent with Australia achieving its current emissions reduction targets—a 43% reduction on the 2005 level by 2030 and net zero by 2050—in a world tracking to a global warming outcome of less than 2°C. The 'A40/G1.5' scenario is consistent with greater ambition and more rapid emissions reductions in a world on a trajectory to limiting global warming to 1.5°C with no or limited overshoot, in which Australia reaches net zero by 2040.

Working to reduce emissions now, using existing technologies, is far more efficient and effective than waiting and hoping that bigger breakthroughs will do all the work.

Waiting for new, better, cheaper technologies is tantamount to choosing to continue to emit. Waiting means greenhouse gases will continue to accumulate in the atmosphere, trapping more heat and causing more of the impacts already being felt. Accelerating action to reduce emissions can create virtuous cycles of learning and improvement, leading to rapidly falling costs, as has been experienced in relation to the deployment of renewable energy technologies (Way et al. 2022). The most sensible thing to do is to stop emitting greenhouse gases as much and as quickly as possible. It would be a mistake to wait.

The transition to net zero is not just about technologies themselves.

It involves the operational and behavioural choices governments, businesses, communities, households and individuals make about which technologies are used, when and how. It includes adopting new business models and circular economy principles, shifting transport modes, and making different choices about how much and what we consume.







For the purposes of this report the authority defined 'sectoral pathways' as: *The sets of potential technological and operational changes in each sector, that taken together could potentially deliver net zero emissions in Australia by 2050.* For simplicity, technologies, operational changes and other types of abatement and emissions reduction activities and opportunities are collectively referred to as 'technologies' in this report.

The pathways that best support Australia's transition to net zero emissions by 2050 involve accelerating deployment of mature zero and low emissions technologies, and the rapid development and commercialisation of emerging technologies.

Mature and proven technologies can substantially reduce Australia's emissions this decade and represent the lowest-cost way forward. Accelerating their deployment represents the 'low-hanging fruit' of the net zero transition. Decarbonising Australia's electricity supply as soon as possible will address Australia's largest source of emissions and is vital to unlocking emissions reductions in other sectors through electrification — replacing vehicles, appliances and industrial equipment powered by fossil fuels with new, efficient electric versions.

This will mean generating more electricity than ever before while transitioning to renewables connected by transmission and firmed with batteries, pumped hydro and gas generators, and potentially hydrogen over the longer term. Successfully managing the challenges of sequencing, integrating and optimising the deployment of these technologies, and the risks to reliability and security of supply, is crucial for ensuring an orderly transition.

Table S.1: Summary of key emissions reductions technologies by sector

 ELECTRICITY AND ENERGY	 TRANSPORT	 INDUSTRY AND WASTE	 AGRICULTURE AND LAND	 RESOURCES	 BUILT ENVIRONMENT
Mature technologies					
Wind, solar, pumped hydro, lithium batteries, gas-fired generation, synchronous condensers.	Battery electric light vehicles, mode shift, overhead electric rail.	Electrification (low/medium temperature process heat), energy efficiency, circular economy, diversion of organic waste from landfill.	Forest/vegetation protection, carbon farming, enhanced fertilisers, improved herd and pasture management, manure management, off-grid renewable energy.	Electrification, energy efficiency, carbon capture and storage, off-grid renewable energy and storage, fugitive abatement measures in oil and gas extraction, underground coal mine gas drainage and utilisation.	Electrification (hot water, cooking, air conditioning), rooftop solar and battery storage, energy/thermal efficiency.
Demonstrated and early-stage technologies					
Hydrogen production and turbines, new battery/long duration storage solutions.	For transport other than light vehicles: electrification, hydrogen, renewable fuels.	Electrification/hydrogen for high temperature process heat, hydrogen (in ammonia, alumina, iron), carbon capture and use, direct air capture/engineered removals.	Renewable fuels, battery electric farm vehicles, feed supplements, methane vaccines, early-life nutrition, new forms of protein.	Electrification (mining haulage), ventilation air methane abatement measures, renewable fuels, open-cut coal mine gas drainage.	Grid integration.

Note: Nuclear power generation is not included here as it is currently prohibited in Australia (see section EE.2.6).

A greater focus on boosting energy efficiency and incentives for energy demand to respond to supply signals in the electricity market will help. This includes bringing together consideration of 'demand-side' measures under the National Energy Productivity Strategy with planning for the supply of electricity through such processes as the Integrated System Plan for the National Electricity Market. Increased energy efficiency will produce benefits for energy consumers, contribute emissions reductions while the supply of electricity decarbonises, and lessen the overall amount of investment required in new clean energy infrastructure.

Demonstrated and early-stage technologies are within reach and will address more difficult to abate emissions over time, including from heavy transport, industrial processes and agriculture. Policy support and investment are needed to accelerate the deployment of these technologies, so they can have a meaningful impact in the 2030s and 2040s. These technologies include hydrogen and its derivatives, biofuels, solutions for livestock emissions (e.g. *Asparagopsis*), and carbon capture and use.

A range of sector pathways can combine to achieve net zero by 2050. All require significant effort.

The authority's ground-up analysis of each sector and the CSIRO's modelling of potential sector pathways are summarised in Figure S.1 below, with green bands illustrative of the range of potential pathways.

For some sectors, the authority's ground-up analysis and the two modelled scenarios closely align. In the electricity and energy sector, the technologies exist, the transition is well underway, and there is more certainty about what can be achieved with the right policies. This is also the case for the transport and built environment sectors, although their transitions are less well progressed.

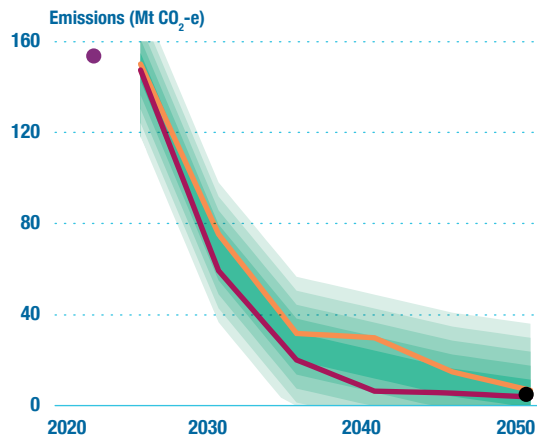
For other sectors there is more uncertainty, reflected by the range of outcomes across the modelling scenarios and ground-up analysis. In the resources, and agriculture and land sectors, the authority's ground-up analysis found that there are considerable real-world barriers that make the modelled outcomes difficult to achieve. Conversely, the authority's view is that there are opportunities in the industry and waste sector to achieve greater emissions reductions than the modelling suggests.

Technologies that are still experimental or generally unknown today could be 'game changers' in coming decades, completely redefining how countries think about achieving net zero. Cost breakthroughs in existing technologies could also pave the way for faster action to reduce emissions. The authority has not attempted in this report to examine how, where or when such future breakthroughs could occur. However, Australia has proven that it can both lead the world in scientific discoveries and quickly adopt game-changing technologies developed overseas, and it should seek to do both in the net zero transition.

Each sector is on a different emissions reduction pathway to Australia's net zero goal. For some, the pathway will be steep and rapid because technologies are mature and ready to scale (e.g. electricity and energy). Others face a slower and more gradual route because technologies are at an earlier stage of development or more barriers stand in the way (e.g. agriculture). Many sectors are dependent on the progress of others, particularly those reliant on the supply of renewable energy from the electricity and energy sector (e.g. transport, built environment).

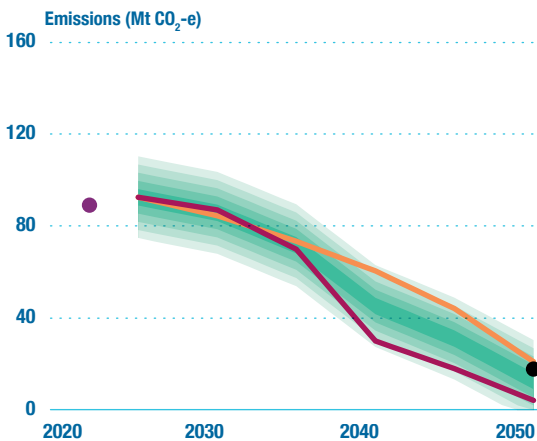
Figure S.1: Sector insights and potential pathways

Electricity and Energy



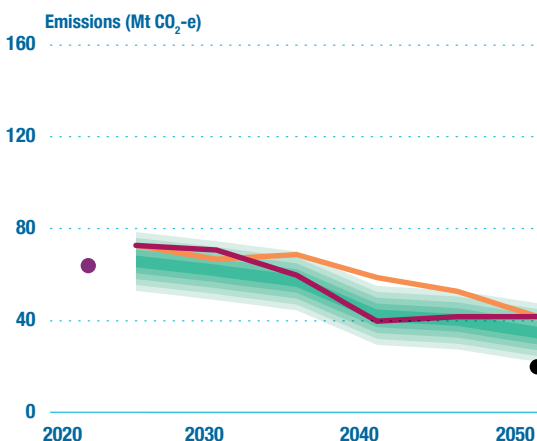
- Decarbonising electricity will address Australia's largest source of emissions and is vital to unlocking emissions reductions in other sectors.
- A massive construction effort is required to install renewable capacity, and poles and wires, to supply two-to-three times more electricity than generated today by 2050.
- Action is required to ensure there is enough storage in the system for system reliability.
- New sources of essential system services will be needed to maintain system security.

Transport



- Global manufacturers can supply the electric vehicles to decarbonise the passenger and light commercial vehicle fleet, which accounts for roughly half of Australia's transport emissions.
- Roll-out of charging infrastructure needs to lead the rapid uptake of electric vehicles.
- A mix of solutions will be required in other transport categories, including alternative liquid fuels and potentially hydrogen. Biofuels, such as biodiesel and Sustainable Aviation Fuel, will play an important but niche role—further planning and clarity are needed on the growth of this industry.

Industry and Waste

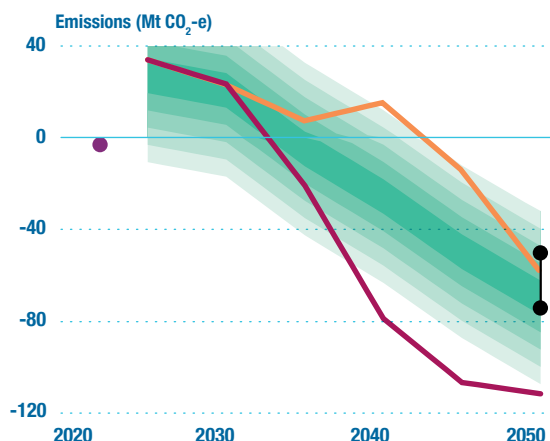


- Australia can secure a prime position as a manufacturer and exporter of low emissions alumina and aluminium by converting current high emitting processes to renewable electricity and hydrogen.
- Australia can achieve emissions reductions in the manufacture of steel with available lower emitting technologies, using natural gas in the short term. Low or zero emissions hydrogen will enable deep decarbonisation of domestic steel and ammonia production.
- The progress of hydrogen in achieving projected cost and production levels to displace fossil fuels in domestic markets needs to be closely monitored.

— A50/G2 — A40/G1.5 ● CCA GROUND-UP ANALYSIS
 ● POTENTIAL PATHWAYS ● 2022 ACTUAL SECTOR EMISSIONS

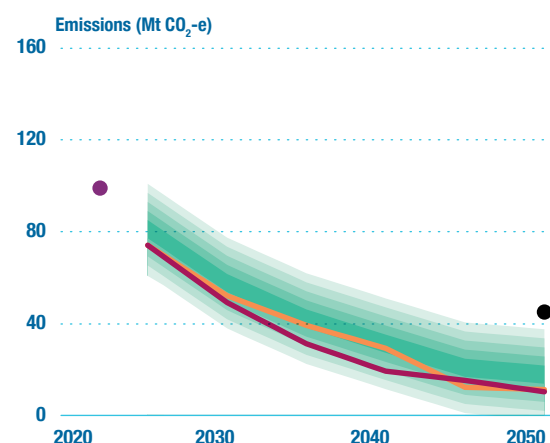
Figure S.1: Sector insights and potential pathways (continued)

Agriculture and Land



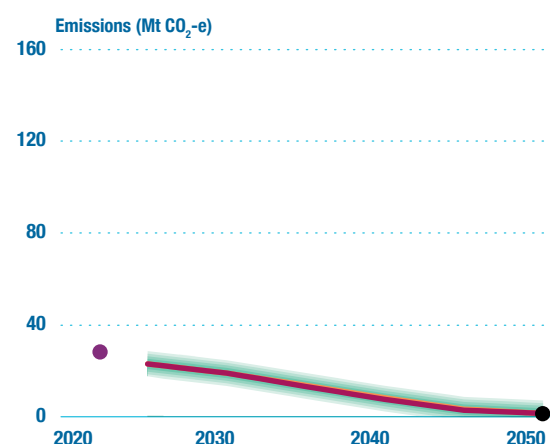
- Reducing livestock emissions, which account for more than half of agricultural emissions, requires changes in the way protein is grown.
- Major reductions in livestock emissions may not be realised until the late 2030s and in the 2040s. More investment in R&D is needed.
- Achieving Australia's net zero emissions reduction target may require the conversion of land to forest and this would require careful planning.
- The supply of suitable land for reforestation is limited, highlighting the need to focus on directly reducing emissions in all sectors.

Resources



- Australia can continue as a world leading resource producer. However, there will be a shift to increased iron and other metals and minerals production, and away from coal and eventually gas.
- The electrification of LNG processing with low or zero emissions electricity and deployment of carbon capture and storage to sequester reservoir CO₂ can lower the fuel combustion and fugitive carbon dioxide emissions footprint of Australia's gas industry.
- Electrification of mining haulage and ore processing are significant opportunities for Australia to build on its strengths as a resource exporter and position itself as an exporter of low emissions resources.

Built Environment



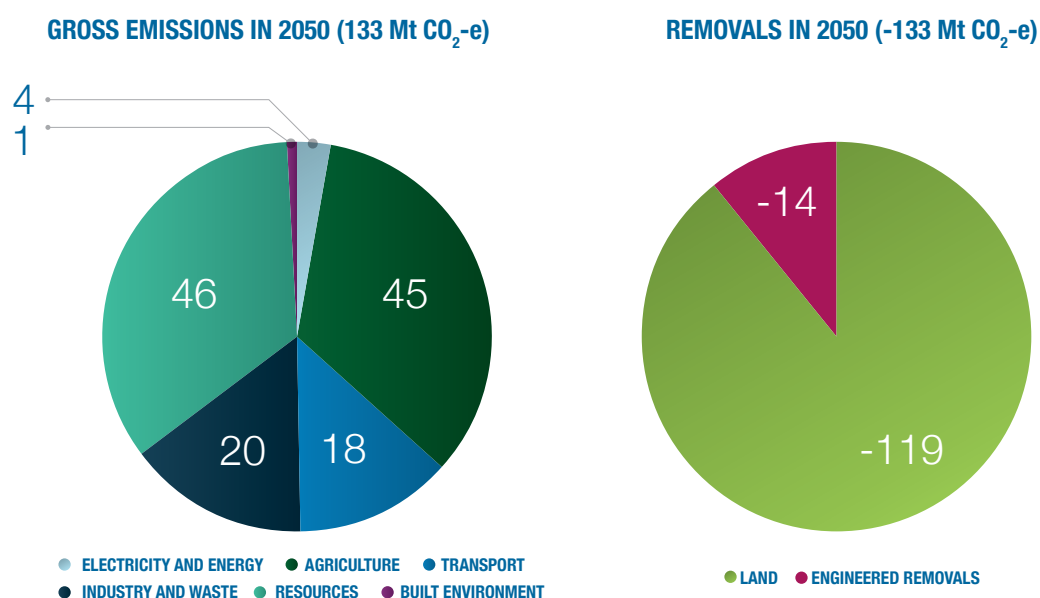
- Energy efficient, electrical appliances for hot water, heating and cooking can lower emissions and save money for households and businesses. Stronger regulation and targeted funding to address upfront costs can drive faster outcomes.
- The energy efficiency of the building stock can be improved by extending standards and reporting to a wider range of commercial buildings, and implementing a mandatory residential building efficiency scheme.
- Boosting energy efficiency and valuing demand response can reduce emissions while the supply of electricity decarbonises and can lessen the investment needed in new clean energy infrastructure.

— A50/G2 — A40/G1.5 ● CCA GROUND-UP ANALYSIS
● POTENTIAL PATHWAYS ● 2022 ACTUAL SECTOR EMISSIONS

Only the land sector is projected to achieve net negative emissions, and it does so by removing carbon from the atmosphere through the age-old technologies of managing soils and vegetation. New, engineered technologies to remove carbon from the atmosphere are under development but are likely to remain expensive, energy- and water-intensive, and require access to land.

The more emissions remain in the system by 2050, the more removals will be required to counteract (or offset) them if net zero is to be achieved. And the more removals are required, the greater the impacts on energy supply, water, and other land uses. The authority holds the view that it makes sense to minimise the need for removals by reducing emissions directly as much as possible and as soon as possible. Figure S.2 shows the possible sectoral composition of net zero in 2050 based on the authority's ground-up analysis.

Figure S.2: Sectoral composition of net zero in 2050 (Mt CO₂-e) – ground-up analysis



Source: CCA analysis.

Notes: The authority's ground-up estimate of gross emissions in 2050, totalling 133 Mt CO₂-e (left). Estimated sink from the land sector and potential role for engineered removals to offset gross emissions in 2050 (right). The authority's upper estimate for the net sink from the land sector was 119 Mt CO₂-e and the remaining 14 Mt CO₂-e is consistent with the authority's analysis of the potential role engineered removal technologies, such as direct air capture and storage, could play in achieving net zero. See Box IW.2 in the Industry section of this report and the authority's examination of carbon dioxide removals in its 2023 insights paper, Reduce, remove and store: The role of carbon sequestration in accelerating Australia's decarbonisation.

Ultimately, there are many sets of sector pathways that can combine to achieve net zero by 2050. Like nations under the Paris Agreement, sectors can be thought of as having 'common but differentiated responsibilities and respective capabilities' when it comes to meeting Australia's national targets. This report does not recommend specific emissions reduction targets for each sector. Instead, it sets out the abatement potential of each sector on Australia's pathway to net zero emissions by 2050.

A clear conclusion from the authority's analysis is that none of the potential sets of pathways will be easy and every sector will need to play a unique but important role. Across all sectors, a significant and urgent ramp up in effort, investment and coordination is required and there are barriers that will need to be overcome if Australia is to achieve its target.

The transition to net zero involves much more than each sector moving along technology-based decarbonisation pathways. A zero-carbon mindset must become the new normal so that it permeates operational, policy and investment and purchasing decisions across governments, businesses and households.

It requires actively managing a major reorganisation of public and private finance, supply chains, production systems, industrial zones, energy sources, infrastructure and workforces within Australia.

It means close collaboration between governments, businesses, First Nations people, landholders, communities and households, and between Australia and its Pacific neighbours and international trading partners.

It means making trade-offs between alternative uses of limited resources including energy, water and land, and working towards a circular economy to reduce the need for virgin resource extraction.

It means actively ensuring an equitable transition so that the burdens and benefits are fairly shared between governments, sectors, businesses, regions and communities.

And it means judiciously deploying every tool in the policy toolkit, including information, markets, regulations, planning, investment, and international engagement, towards achieving Australia's net zero goal.

The federal government is in the driver's seat for Australia's transition to net zero emissions by 2050. The Net Zero Plan will need to bring together sectoral plans and a whole of economy strategy to reach net zero, and set out how the Australian Government will work with the states and territories given the crucial role they play.

The government has stated that its Net Zero Plan will articulate Australia's transition to net zero, including the government's priorities, policies and measures for driving down emissions and supporting ongoing and new investment in low emissions and renewable activities.

The opportunity for the government is to prepare a Net Zero Plan that provides clear, long-term signals to businesses, investors and households on the transition of the Australian economy in a world moving to net zero emissions. It can set out the roles to be played by the different parts of the economy and provide foundations for supporting regions and the disadvantaged with the transition.

All levels of government must work together in planning for and coordinating the transition to net zero emissions, to ensure policy architecture, investment horizons and regulatory environments are aligned. The states and territories have a significant role to play given their authority over many energy, infrastructure and transport projects. Close cooperation between the Australian Government and states and territories will therefore be necessary to ensure policy and legislative alignment. Similarly, responsibility for skills, education and training is shared between the federal and state and territory governments. Local governments play a significant role in land use planning and development within their jurisdiction, and are often best-placed to engage with the community to provide education and gather input and feedback on planning and development matters.

Australians can achieve net zero by 2050 only by working together to overcome the barriers that stand in the way.

There are barriers that stand in the way of the timely deployment of technologies needed to secure Australia's transition to net zero emissions by 2050. The key barriers identified by the authority are:

- lack of willingness to pay the 'green premium' – the higher cost of low and zero emissions technologies relative to the high emissions technologies they must replace, which often face no penalty for the harm caused by the greenhouse gas emissions they generate
- slow and complicated development approval processes for renewable energy and enabling infrastructure projects
- a lack of community support (referred to as 'social licence') for changes such as deployment of key clean energy infrastructure like wind farms and transmission lines
- constraints in supply chains for important low emissions technologies including renewable energy generation, electric mining and haulage equipment and low emissions liquid fuels
- workforce shortages, particularly in regional areas and highly skilled new industries
- information and data gaps that impede planning for decarbonisation, the workforce it will require, and the investment decisions that could finance it.

Below the authority sets out the strategies and actions that can be incorporated in the Net Zero Plan for overcoming the barriers to Australia's transition to a prosperous, net zero economy. In addition to the (mainly) cross-sectoral strategies and actions listed below, sector-specific enablers and opportunities are described throughout the report.

The future is inherently uncertain. Plans need to facilitate bold and urgent action while being sufficiently flexible to accommodate new technologies and knowledge as they emerge. By adopting an adaptive approach, Australia's plan to reach net zero can offer a reliable way forward, empowering businesses, investors and communities to navigate uncertainties with confidence.

Strategies and actions for the net zero plan

1. Overcome the ‘green premium’ through fit-for-purpose policy interventions, including regulation, market-based mechanisms and government finance to leverage private investment

The Australian Government has in place a suite of mechanisms that mandate or put a value on reducing greenhouse gas emissions and channel finance to low and zero emissions activities. These include market-based mechanisms (e.g. the Safeguard Mechanism and ACCU Scheme), and institutions and programs such as CEFC and ARENA, the National Reconstruction Fund, and the Capacity Investment Scheme that support achievement of net zero objectives. States and territories have programs of their own.

There are also standards that regulate emissions or energy use, including the New Vehicle Efficiency Standard for light vehicles and the Greenhouse and Energy Minimum Standards for consumer appliances. Some states encourage energy efficiency through ‘white certificate schemes’ and grant programs.

However, these foundations must be built upon if Australia is to get on and stay on the pathway to net zero. Some sources of emissions are not covered by policy interventions, or where policies are in place they need strengthening or complementary measures to ensure barriers are overcome. The government should plan for the scope, scale, pace and sequencing of technology deployment that could achieve net zero at least cost and risk, and implement policies accordingly. Plans should be adaptive and implemented effectively and efficiently through judicious use of every tool in the policy toolkit, including information, markets, regulations, planning, investment, and international engagements.

Actions

- Expand the scope of key existing policy frameworks such as the Safeguard Mechanism, ACCU scheme and National Greenhouse and Energy Reporting Scheme.
- For the electricity and energy sector—to provide greater certainty and stronger signals for investors—strengthen the Capacity Investment Scheme (which could be legislated, administered by a standalone statutory agency and increased in size and pace) and establish policy settings and market design arrangements that will continue to drive the clean energy transition beyond 2030.
- Further promote efficient decision-making and resource allocation by harmonising signalling across the economy on the cost of carbon (value of emissions reductions), through standardised guidance developed by the Treasury for use in government and regulatory decision-making.
- Set interim goals and guiderails within each sector that strive for ambition while promoting an orderly transition, based on the principle of common but differentiated responsibilities and respective capabilities.
- Tighten and broaden mandatory emissions and energy efficiency standards for consumer and commercial products.
- Establish a ‘one stop shop’, which could be within the Net Zero Economy Authority, to help people find and access the federal, state and territory emissions reduction financial support programs that best suit their circumstances and needs.
- Pursue an orderly phase-out of government policies and programs that support emissions-intensive activities while redirecting resources—including skills and capital—to support clean energy and low emissions alternatives.
- Develop a National Carbon Market Strategy that includes setting out how carbon offsetting will be used to channel finance towards deployment of removals technologies without substituting or delaying direct emissions reductions.



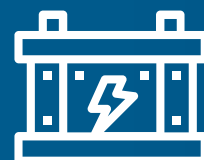


2. Accelerate the deployment of net zero infrastructure by reforming planning and approvals processes, coordinating business engagement within and across jurisdictions, and identifying and fast-tracking the development of renewable energy zones and clean industrial hubs.

Planning and approvals processes are slowing the necessary expansion of renewable energy generation and related and essential infrastructure such as energy storage projects and transmission lines. Taking an integrated, place-based approach to the challenges and opportunities of the net zero transition will enhance Australia's prospects for success. For example, identifying 'zones' or 'hubs' where facilitating combinations of projects in renewable generation, hydrogen production and carbon capture and storage can bring together the ingredients for decarbonising existing activities and facilitating new green industries. Coordinating across levels of government to address these challenges and leverage these opportunities will be essential.

Actions

- Prioritise net zero transition projects in a principled, planned approach with input from the Net Zero Economy Authority and in collaboration with state, territory and local governments.
- Simplify, coordinate and expedite approval processes for priority projects within and between jurisdictions.
- Use sector plans and National Energy Transformation Partnerships as the basis for building a set of government-industry agreements, with principles, time limits on decision making and agreements under which governments and businesses navigate approvals together.
- Develop low emissions industrial precincts, including pre-evaluation of regions for suitability for priority activities and new net zero industries, and of the renewable electricity generation and other infrastructure needed to power them, based on principles including environmental and community impacts.
- Accelerate access to firmed, off-grid renewable electricity, including by developing common user infrastructure.
- Ensure sufficient energy storage and synchronous generation is deployed in the electricity system for system reliability and security to be preserved, without slowing the closure of coal-fired power stations and deployment of renewables and storage.





3. Strengthen the foundations for social licence and a just transition to net zero

through enhancing climate literacy, building capacity in business and communities to negotiate benefit and burden-sharing arrangements, and working with communities to support the net zero transition.

The impacts of climate change and climate-related policies affect the wellbeing of Australians in different ways. Climate-related wellbeing in turn affects the social licence granted by communities and the people who live in them for the changes required for decarbonisation to proceed, such as support for new renewable electricity projects and installation of transmission lines. The Net Zero Plan should promote a just transition – whereby the means and ends of the net zero transition entail an equitable sharing of the burdens and benefits as Australia accelerates emissions reductions and adopts new ways of doing things.

Actions

- Develop a dedicated, independent information and engagement campaign to combat mis- and dis-information and to build climate literacy and understanding of the Net Zero Plan.
- For priority transition projects, work with state, territory and local governments to adopt a best-practice benefit and burden sharing framework.

- Make available a toolkit to help governments, project developers and communities (including remote, rural, regional and First Nations communities) negotiate agreements with free, prior and informed consent.
- Adopt a strategic, place-based approach to urban planning and regional development so, where viable, the benefits of new industries can be co-located with burdens of declining industries and infrastructure.





4. Think global, act local for Australia to prosper in a net zero world.

Australia is a small, open trading economy. Global decarbonisation presents both challenges and opportunities for Australia, and Australia's net zero transition has consequences for how we interact with the rest of the world, including via the international competitiveness of our businesses and industries. International cooperation can yield substantial benefits for Australia while supporting our trading partners' emissions reduction efforts.

Actions

- Negotiate bilateral decarbonisation agreements with key trading partners to help secure supply chains for essential net zero technologies and inputs and support an orderly transition away from fossil fuels for mutual benefit.
- Plan for and signal early investment in the infrastructure necessary for the transformation of the energy system, to retain Australia's spot in the global supply chain queues.
- Develop and implement plans for the decarbonisation of Australia's exports and to support more rapid emissions reductions overseas, leveraging our comparative advantages (e.g. renewable energy, critical minerals and sequestration potential) and preparing for the inevitable decline in demand for fossil fuel exports.
- Implement a carbon border adjustment measure to maintain the competitiveness of Australian businesses as decarbonisation accelerates.



5. Rapidly address workforce shortages by diversifying and deploying a rapid skills program and enhancing workforce mobility.

The rapid transformation to a net zero economy necessitates a rapid capability build. Workforce and skills shortages are already emerging as a barrier to decarbonising almost every sector of the economy.

Jobs and Skills Australia has found that if workforce pipelines are not adjusted, skills shortages could prevent Australia reaching net zero by 2050, and from realising opportunities to broaden its industrial base.

Actions

- Reinstate and expand the ABS Employment in Renewable Energy Activities statistics to enable better workforce planning in clean energy and low carbon activities, particularly in regional areas. Data collection should include renewable energy construction, energy efficiency construction, energy generation and low and zero carbon transport workforces. See more on information and data gaps below.
- Embed workforce planning in sector plans, with governments working together with businesses to prioritise workforce diversification and ensure a fit-for-purpose education system.





6. Address information and data gaps by expanding, simplifying and automating data collection and dissemination.

Information is crucial for effective planning and for well-functioning markets. There is already a range of schemes in place to ensure policymakers, consumers, businesses and investors can be well-informed of the consequences of their decisions in terms of emissions outcomes and energy use. However, there is much more that could be done.

Actions

- Expand the suite of government resources that enable individuals and businesses to make better informed purchasing decisions (like the Green Vehicle Guide, the National Australian Built Environment Rating System, GEMS, and Guarantee of Origin) and put them in one place as a one stop shop to provide tailored information, including on:
 - the benefits and risks of investments in electrification, energy efficiency, and fleet electrification
 - the value proposition for farmers and businesses of adopting low emissions practices and technologies
 - the cost-of-living benefits to households of adopting energy efficiency and electrification.
- Following the implementation of mandatory climate-related financial disclosures, prioritise establishing mandatory digital reporting as a next step to give investors, financial institutions, businesses, developers, governments and end-users ready access to data about emissions in their supply chains.
- Incorporate a net zero data strategy in the Net Zero Plan, which expands the collection of, and enhances the availability of, the data that consumers, businesses and investors require to make informed decisions in keeping with Australia's net zero goals.



Introduction

Australia's transition to a net zero economy is necessary, inevitable and urgent. Among developed countries, Australia is one of the most vulnerable to the impacts of climate change. The impacts of nearly 1.5 degrees of warming can already be seen in trends of declining rainfall in the south-east and south-west, an increase in extreme fire weather and longer fire seasons, higher sea surface temperatures, rising sea levels and increasing ocean acidification.

A temperature rise of 2.9°C¹ – the future we can expect by the end of the century based on countries' current Paris Agreement pledges, according to the United Nations Environment Programme (2023) – would present severe risks to Australia's economic, social and environmental life (Australian Academy of Science, 2021; Lawrence et al., 2023).

Australia can prosper in a world with lower emissions, and not only because it would deliver a more hospitable climate. With its plentiful solar and wind resources, Australia can generate large amounts of renewable energy relative to the size of its population. An abundance of clean energy and

critical minerals, combined with a skilled, highly educated workforce, innovative companies and strong institutions, will give Australia advantages in the global low emissions economy.

With these advantages, Australia can become a hub for low and zero emissions manufacturing and processing, and there may be long-term potential for Australia to offer sequestration of carbon emissions captured overseas, further supporting global decarbonisation efforts (CCA, 2023). The emergence of new, low and zero carbon industries can counterbalance the loss of jobs, income and international competitiveness associated with declining demand for Australia's fossil fuel exports.

1 The uncertainty range around the 2.9°C figure is 2.0 – 3.7°C, with a 66% chance of remaining within this range. The data underpinning the range include all 'unconditional' Nationally Determined Contributions (those that are not contingent on international support such as finance, technology transfer or capacity building) announced up to 25 September 2023 (UNEP 2023, pp. 23-31).



Australia in 2050



The future is inherently uncertain, but a net zero world in 2050 will undoubtedly be different from the one we live in today.

In a net zero 2050 world, Australians would be living and working in more efficient and comfortable buildings, with improved health and greater resilience to climate-related hazards. Transport would continue to be affordable, accessible, reliable, safe while also being zero emissions. People would easily and quickly charge their electric vehicles at home, work, along highways and at many other destinations. A large increase in public and active transport infrastructure would give people greater access to transport and better health, reducing congestion, traffic noise, and reliance on private vehicles.

Australia's economy would be powered by the secure and reliable supply of renewable electricity, and the export of products manufactured using that energy. Fossil fuel industries would have largely phased out, replaced by rising critical minerals and 'green' metals industries, like green iron, that harness Australia's natural endowments and a circular economy. In doing so, Australia would have created new jobs and opportunities in rural and regional communities. Australia's agricultural lands and biodiversity would be strong, vibrant, productive and integrated. First Nations people would benefit as leaders and partners in the transition on the First Nations estate, and by undertaking traditional and cultural land management practices on Country.

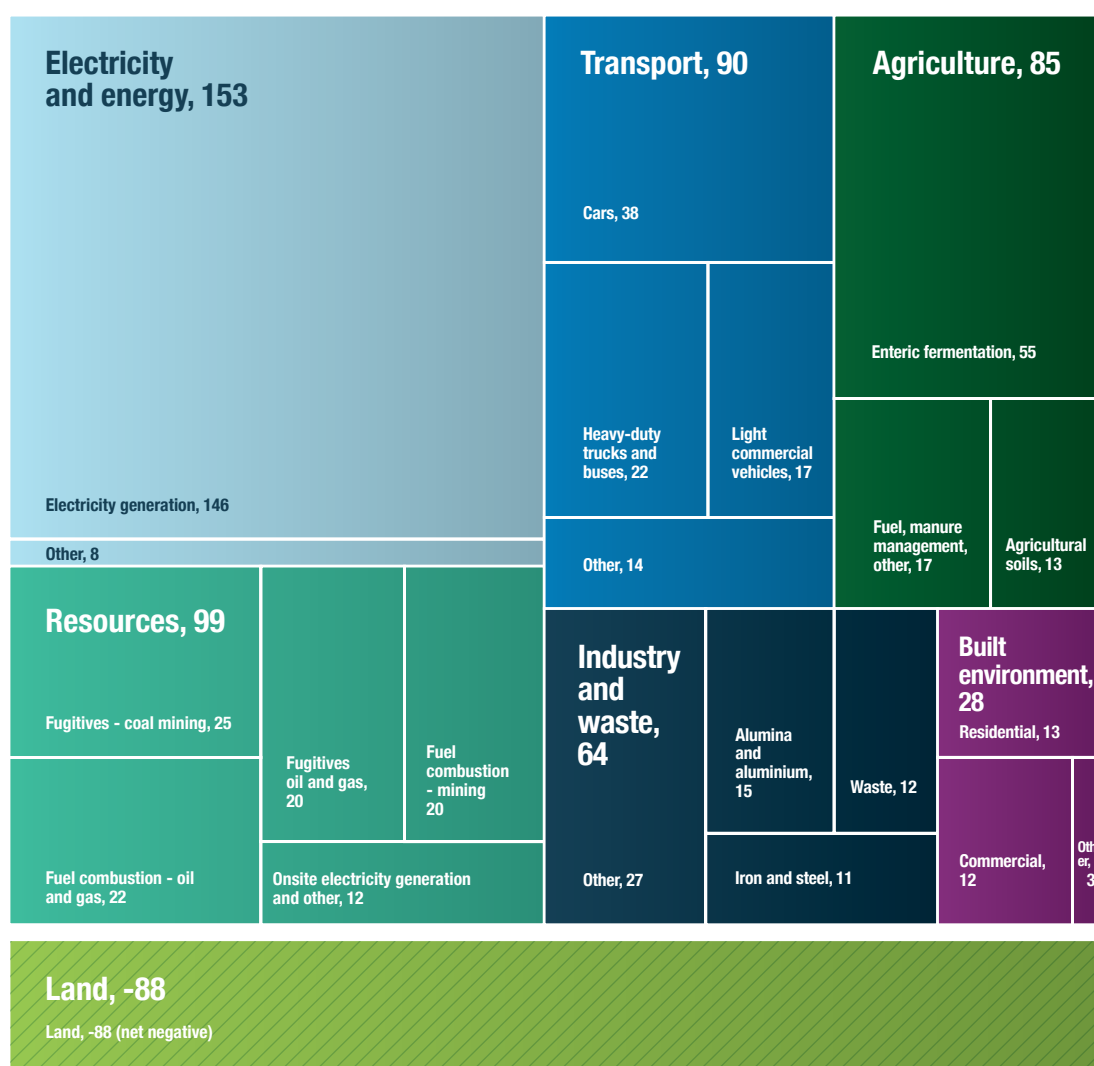
Australia stands to benefit by following a planned, orderly pathway to net zero. The Australian Government, as well as state, territory and local governments, are already setting emissions reduction targets and rolling out policies to achieve them. Australian businesses and households are adopting low emissions technologies such as rooftop solar, heat pumps and electric vehicles. Australia's peer countries and trading partners, including those who currently rely on Australia's fossil fuels for their energy security, have also announced emissions reduction targets and are ratcheting up action towards meeting them.

Australia risks being left behind if it acts too slowly or fails to successfully navigate the global transition. As the rest of the world continues to decarbonise, global demand for the significant fossil fuel component of Australia's exports can be expected to decline and the demand for green products will increase. Australia will face a world that, increasingly, no longer wants its coal, gas and oil, and that is seeking zero emissions versions of other key exports like iron ore, bauxite and alumina. Without alternative green metals, minerals and energy exports, Australia will be left with a hole in its economy.

The emissions reduction task and the authority's approach to this review

Australia is committed to achieving net zero greenhouse gas emissions by 2050, a 433 Mt CO₂-e decline from 2021-22 levels². Figure I.1 shows how Australia's emissions were distributed across sectors of the economy in 2021-22. The challenge for Australia is to reduce emissions in each sector as much as possible, as soon as possible, and to remove as much carbon dioxide from the atmosphere as fast as possible.

Figure I.1: Sectoral share of Australia's emissions (Mt CO₂-e), 2021-22



Source: Sector totals from authority national sectoral pathways emissions mapping based on Australia's National Greenhouse Accounts and emissions reported under the National Greenhouse and Energy Reporting Scheme.

Notes: See Appendix B for more information about the authority's mapping of emissions to sectors, and the sector chapters in Part 1 for more information about the breakdown of emissions within sectors. This figure separates the agriculture and land sector into agriculture and land subsectors. Subsector emissions may not sum to sector totals due to rounding.

2 2021-22 is the most recent year with final data. Sources: CCA analysis based on Australia's National Greenhouse Accounts.

The authority focused its modelling analysis for this report on two emissions reduction scenarios representing potential Australian and global ambition, summarised in Table I.1.

Table I.1: Emissions reduction scenarios modelled by the CSIRO to frame the analysis for this report

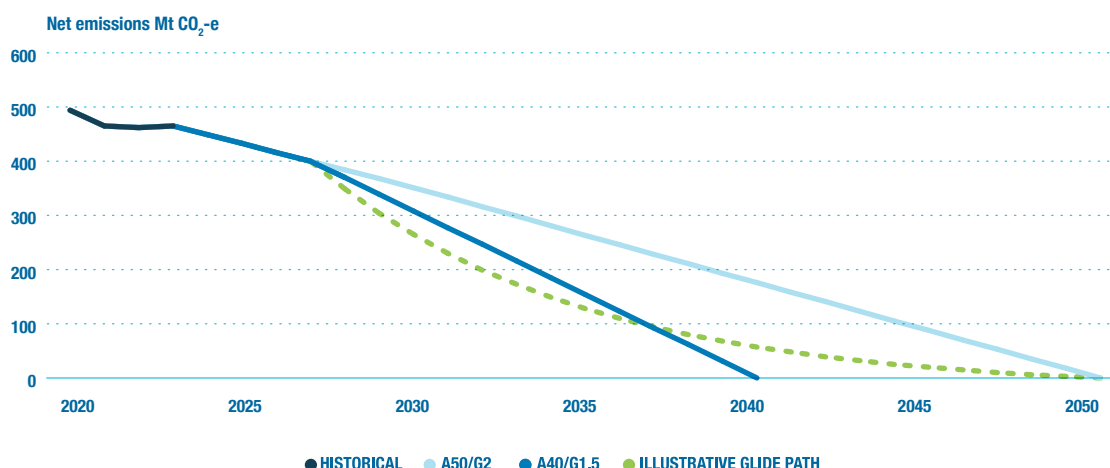
A50/G2	A40/G1.5
<ul style="list-style-type: none"> Australia achieves its current 2030 target and reaches net zero in 2050 Global emissions are consistent with limiting the average temperature increase to under 2°C 	<ul style="list-style-type: none"> Australia overachieves on its 2030 target and reaches net zero in 2040 Global emissions are consistent with limiting the average temperature increase to 1.5°C
<p>This scenario is consistent with Australia achieving its current 2030 and 2050 emissions reduction targets in a less than 2°C world. Although these targets are challenging, Australia is not a leader in decarbonisation in this world and reaches net zero in 2050, while many other developed nations reach net zero in 2040 or 2045. The global energy mix retains more fossil fuel demand than the 1.5°C world, and Australia's fossil fuel production declines gradually. There is a strong global investment in negative emissions (land-based and technology-based emissions removals) to support the achievement of this goal.</p>	<p>This scenario is consistent with the world cooperating to limit warming to 1.5°C. Australian targets are consistent with greater ambition from other developed nations. Australia achieves a 75% reduction on 2005 levels in 2035 and net zero by 2040, reflecting greater ambition and more rapid emissions reductions. Fossil fuel demand falls more rapidly globally and in Australia, and there is even stronger investment in negative emissions technologies.</p>

These two modelling scenarios assume Australia's emissions decline in a straight line to net zero in either 2040 or 2050. The straight-line trajectories are simplified, indicative representations of different average levels of ambition across the entire Australian economy. These two trajectories are shown in Figure I.2. More information about the modelling is at Appendix C and in the accompanying CSIRO modelling report.

Australia's emissions will not follow a straight line, and nor should they. The curved line in Figure I.2 is an example trajectory that contributes similar total cumulative emissions reductions by the time it reaches net zero in 2050 as the straight line trajectory to net zero in 2040. The cumulative emissions over time are represented by the areas under the three lines. Greater, early effort will mean less total emissions (a smaller emissions budget) over the period to 2050. Delaying efforts increases the risk of several adverse outcomes for Australia:

- a later, more expensive and less orderly transition
- missed or delayed opportunities for cost-of-living relief through energy efficiency and electrification
- missing new green export opportunities
- attracting carbon tariffs to Australia's exports
- impacts on Australia's reputation, particularly in the region
- slower global momentum towards reducing emissions and hence heightened risks of dangerous climate change impacts.

Figure I.2: Stylised trajectories to net zero – modelled straight line trajectories and an illustrative curved trajectory



Source: Authority analysis of DCCEEW (2023).

Note: Historical emissions are from DCCEEW's Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2023 as this was the most recent when the modelling was undertaken.

The modelling does not provide forecasts of the future, but it does provide insights about possible developments in each sector and across the economy under different emissions pathways. It has limitations in that results depend on input assumptions, including about technology costs, and it is a simplified representation of the economy that cannot take all relevant factors into account. It is one line of evidence that sits alongside detailed analysis and consultation the authority undertook in each sector to inform this review.

In its ground-up analysis of each sector, the authority considered the range of real-world factors not well captured by economic modelling that enhance understanding of the unique emissions trajectories available to each sector and their respective roles in the economy as a whole achieving net zero. Potential impacts on jobs, communities, rural and regional areas, businesses and Australia's economy, as well as ways to mitigate and manage them, are considered throughout the report. See Appendices B and C for more information about the authority's analysis and modelling approaches.

When combined, the sector trajectories will result in a real-world pathway to net zero that is unlikely to be linear. Greater or faster emissions reductions could be achieved if barriers to technology adoption are more quickly overcome, new 'game changing' technologies emerge, or technology costs decline faster than incorporated in the modelling – as evidence suggests could well be the case (Way et al., 2022).

An economy-wide 'net zero' target does not mean that all emissions from a sector, facility, business or household are necessarily eliminated by 2050. The authority's analysis is not unique in finding that, based on our knowledge of technologies today, there will very likely be residual emissions across the economy that will need to be counterbalanced with carbon dioxide removals to achieve net zero emissions (see Part 2).

In the electricity and industry sectors, emissions reductions can be lumpy as a relatively small number of high emitting pieces of capital equipment, such as coal-fired generators, are replaced. The land sector has already achieved net negative emissions, and there are opportunities in the electricity (renewables), transport (light electric vehicles) and built environment (heat pumps for space and water heating) sectors to make relatively fast and steady progress.

Technologies to address some emissions sources in the agriculture (methane emissions from enteric fermentation), mining (fugitive methane emissions) and industry (high heat) sectors will take longer to implement. More emissions may remain in 2050 in those sectors. The extent to which barriers to the adoption of new technologies can be overcome will also impact how steep and smooth the trajectory of emissions reductions in each sector is. These factors are discussed further in the sector chapters in Part 1 and in Appendix C.

For simplicity, individual technologies (such as solar photovoltaics), clusters of technologies (such as renewable energy), and operational changes (such as using appliances more in the middle of the day), as well as other types of abatement and emissions reduction activities and opportunities are collectively referred to as 'technologies' in this report. Technologies referred to throughout this report can be categorised into three broad categories of readiness:

Mature technologies are ready and available to be deployed now. Mature technologies are already being widely adopted, but barriers may prevent their full, rapid deployment in some circumstances.

Demonstrated technologies are available but not yet widely adopted. Barriers need to be overcome for these technologies to become widely available and deployed to their full potential.

Early-stage technologies are still in the research, development and demonstration stage or are not yet ready to be deployed due to significant barriers that will take some time to overcome.

Under both scenarios and both analytical approaches, sector pathways are heavily reliant on the electricity sector decarbonising quickly, and more than doubling its output to support increased electricity demand from electrification across the economy. Energy efficiency in every sector, including the built environment, can help smooth the transition by reducing costs for consumers and pressure on the electricity system.

In the transport, resources, industry and waste, and electricity sectors, hydrogen can play a key role to reduce emissions beyond what is possible with renewables and electrification alone. It will also be an enabler of new export opportunities such as green metals and critical minerals.

The resources sector remains an important and significant part of the Australian economy, with an increasing role for the critical minerals and metals required to produce batteries, solar panels, wind turbines, electric vehicles and green manufactured products.

Australia's agricultural businesses, including exporters of Australian livestock and crops, continue to be an integral part of the economic landscape. Agriculture is likely to be the largest source of remaining emissions in 2050.

The remainder of this report outlines sector pathways to net zero, the barriers that stand in the way, and the means to overcome them.

- Part 1 sets out the potential technology and emissions pathways in each sector and the barriers and opportunities they entail.
- Part 2 provides an economy-wide view of Australia's pathways to net zero emissions by 2050, the barriers that affect all sectors, and Australia's pathway to prosperity.

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