Australia's National
Science Agency

Key findings from "Pathways to Net Zero Emissions – An Australian Perspective on Rapid Decarbonisation"

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Limiting global average warming to 1.5-degrees Celsius (1.5°C) by 2100 necessitates a rapid transformation of global economic and social systems that will leave no country unaffected

For Australia, the need to become more resilient to the physical impacts of climate change is accompanied by the opportunity to grow new and existing industries to provide essential goods and services for decarbonising economies.

This modelling work by CSIRO, Australia's national science agency, illustrates how Australia's economy will need to transform to reach net zero emissions by 2050. The results translate the International Energy Agency's (IEA) widely referenced global scenarios to an Australian context:

- CSIRO Rapid Decarbonisation (**CRD**), based on a rapid but plausible decarbonisation pathway to net zero for Australia aligned with the IEA's NZE global 1.5°C carbon budget.
- CSIRO Stated Policies (**CSP**), based on stated policies internationally and within Australia, which projects a 2.6°C temperature increase by 2100.

This summary presents the key highlights from the CSIRO Rapid Decarbonisation (CRD) scenario.

Existing technologies can be deployed faster to reduce emissions by 52% from 2020 levels by 2030

To be in line with the CRD trajectory, Australia will need to reduce emissions by 52%, from 512 Mt CO_2-eq in 2020 to less than 246 Mt CO_2-eq in 2030 (Figure 1). This is a faster reduction than the current federal government target of 43% below 2005 levels by 2030 (or a 32% reduction on 2020 emissions).

Emissions fall most rapidly in the electricity sector, declining by 83% from 174 Mt CO_2-eq in 2020 to 29 Mt CO_2-eq in 2030, followed by the mining and transport sectors (Figure 1). Transition of the electricity sector to low emissions drives wider decarbonisation through electrification in the mining sector, and later across all sectors, enabling emission reductions even as production activity grows overall.

The land and agriculture sector and new technologies will need to produce net negative emissions to support Australia's decarbonisation path. By 2030 the Agriculture, Forestry and Other Land Use (AFOLU) sector moves from being a net emissions source to a net emissions sink, sequestering 76 Mt CO_2-eq per year by 2030.

By contrast manufacturing (including heavy industry) and agricultural emissions only decline gradually, with agricultural emissions intensity reductions of 54% complicated by 80% growth in output by 2050.

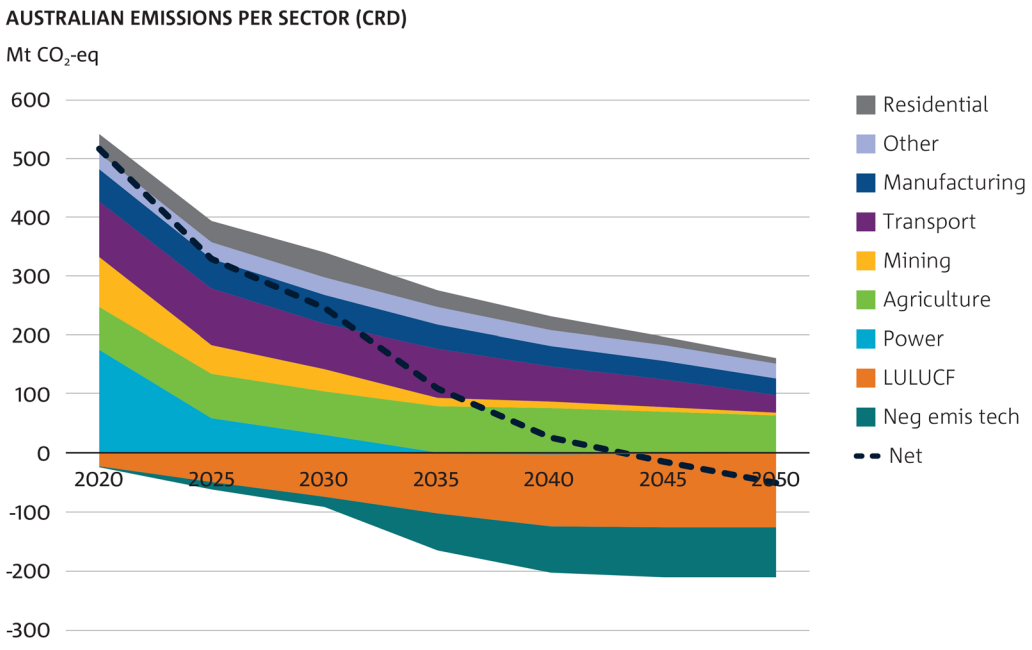

Figure 1 Australian gross emissions by sector in the CRD scenario

Renewable energy grows to more than 90% of the power mix by 2030

The Australian electricity sector underpins the early phase of rapid decarbonisation by accelerating the transition from fossil to renewable fuels (Figure 2):

- The share of the nation's electricity needs that are met by renewable sources is projected to more than triple between 2020[1] and 2030.
- Solar capacity is projected to grow four-fold and its share of electricity generation to triple to over 30% by 2030, with capacity growing twelve-fold and share of generation to over 40% by 2050 (compared to 2020).
- Wind capacity is projected to grow more than five-fold and the share of electricity generation more than four-fold to 45% by 2030.

To enable a shift to solar and wind as predominant electricity sources, a large investment in energy storage and electricity infrastructure is projected. Short duration low-capacity storage (such as batteries) increases to 8% of capacity (or 3 GW) and long duration high-capacity storage (such as pumped hydropower) doubles in the period 2020 to 2030. Together, long- and short-duration storage are projected to make up over 15% of available supply by 2050. Altogether with investment in transmission, distribution, and other electricity infrastructure, projections suggest

[1] Based on 2020 reported renewables generation at Department of Climate Change Energy, the Environment and Water (2022), Australian Energy Update, September, Canberra. Source: https://www.energy.gov.au/publications/australian-energy-update-2022.

investment will need to increase by more than $70 billion over the next 30 years compared to the current trajectory.

ELECTRICITY SECTOR EMISSIONS INTENSITY IN THE CRD SCENARIO

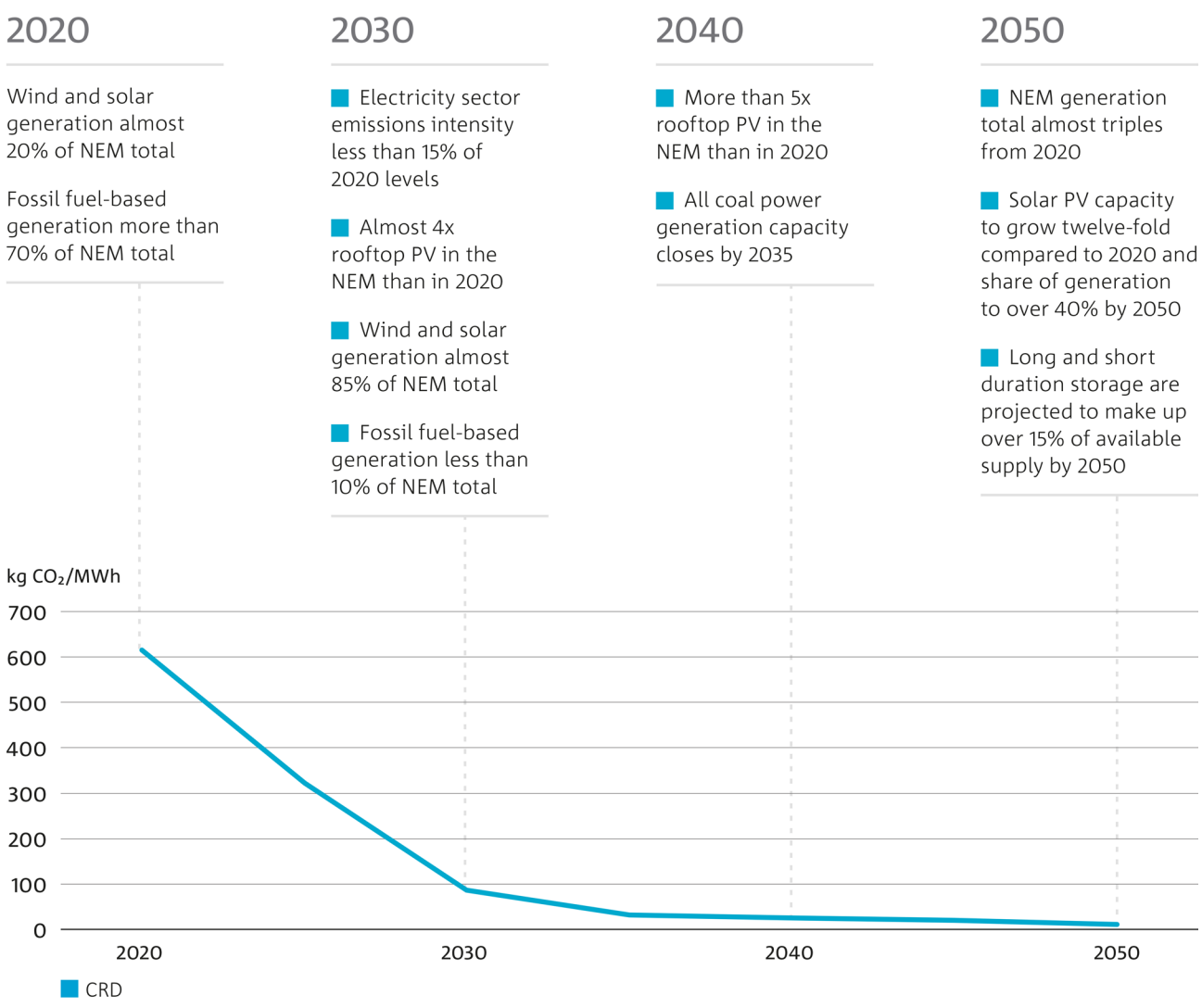

Figure 2 Summary of key transition milestones - Electricity

Residential and commercial buildings

The emissions footprint of energy use in our residential and commercial buildings largely follows the decarbonisation pathway of the electricity sector. Rooftop solar (from residential and commercial buildings) is a significant contributor to the transition and is projected to grow to nearly half of all homes by 2030 and 17% of electricity. Improvements in energy efficiency and fuel switching from gas to electricity are important but relatively minor contributors to the overall shift. Decarbonisation of the electricity sector along with these efficiency improvements and switching fuels (e.g., water heating) are projected to reduce building emissions to well below 5% of 2020 levels by 2050 (Figure 3).

BUILDING SECTOR EMISSIONS IN THE CRD SCENARIO

2020

Building operation makes up about 18% of total emissions

Existing building stock have poor energy efficiency

One third of detached homes have rooftop solar

Half of water heating and cooking are electrified

Electricity makes up half of household energy

About one third of space heating is electrified

2030

- Emissions from commercial buildings at 20% of 2020 levels
- Half of detached homes have rooftop solar, or 3000 more homes fitted each week
- Emissions from residential buildings at 18% of 2020 levels
- Electrification of residential buildings means the fraction of electricity making up total energy consumption increases to 58% (from 49% in 2020)

2050

- Emissions from commercial buildings at 3.4% of 2020 levels
- Almost half of commercial floorspace is now built to higher energy efficiency standards
- Emissions from residential buildings at 1.4% of 2020 levels
- Two thirds of residential buildings built at higher energy efficiency rating (since 2020)
- Further electrification of residential buildings sees the fraction of electricity making up total energy consumption increase to 62% (from 49% in 2020)
- Water heating and cooking are 100% electrified for residential buildings

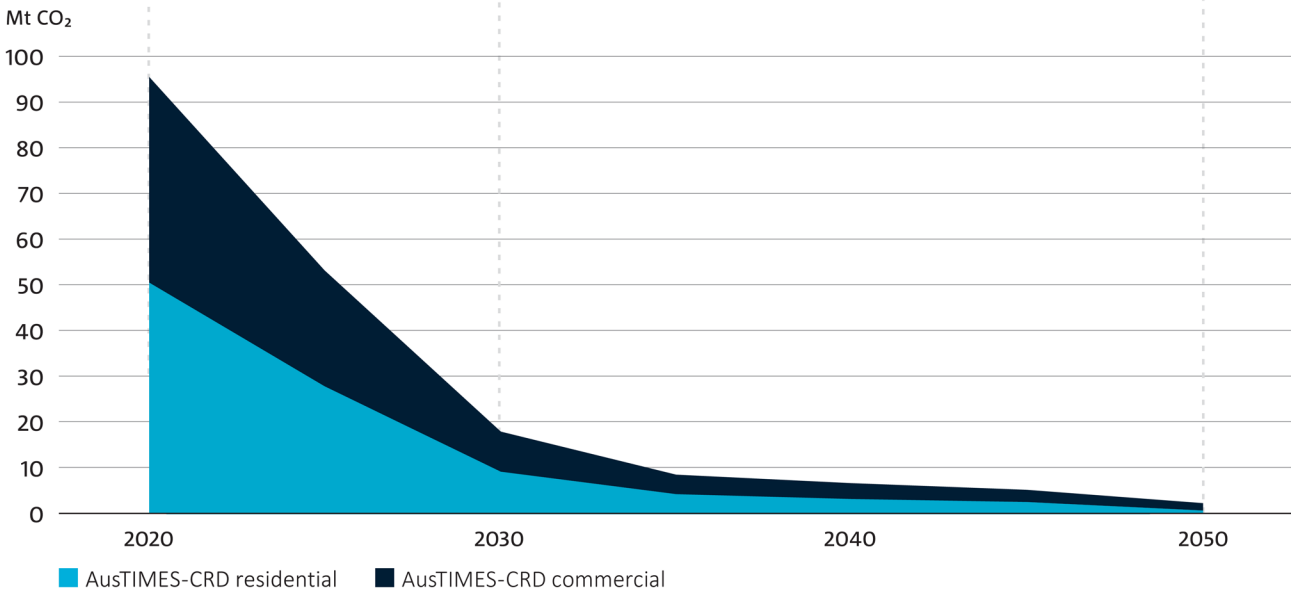

Figure 3 Summary of key transition milestones - Residential and commercial buildings

Key findings from: "Pathways to Net Zero Emissions – an Australian Perspective on Rapid Decarbonisation"

Decarbonisation of transport is vital but complex, and plays out differently across modes

Transport contributed just under a fifth (19%) of Australia's total emissions in 2021 with the majority coming from road transport where Australia lags behind our global peers (Figure 4). The CRD transition projects Australia rapidly electrifying light vehicles, with sales of electric vehicles growing to 55% of all new vehicles by 2030 (and nearly a quarter of vehicles on road). Furthermore, by 2035 all new sales of light vehicles are electric (and nearly three quarters of all light vehicles on road are electric by 2040). Decarbonisation of long distance and heavy transport is projected to be slower than light vehicles. Heavy road transport rapidly decarbonises in the 2030s using a mix of electric and hydrogen fuel cells; electric heavy road vehicles make up more than 50% of all heavy road vehicles by 2050.

Rail and shipping, as key enablers of Australian exports in a low carbon economy, are also projected to decarbonise as relevant technologies become commercialised with the CRD scenario suggesting emissions per tonne falling to less than 10% levels of 2020 levels by 2050 (Figure 4). Air transport, although a hard to abate sector, is projected to adopt new technologies in the 2040s across a mix of electric, hydrogen and biofuel options (along with offsets) to reduce emissions by nearly two thirds.

DOMESTIC TRANSPORT SECTOR EMISSIONS IN THE CRD SCENARIO

2020

Australia lags other jurisdictions in fuel efficiency standards

The transport sector is Australia's 3rd largest emissions source making up 19%

EVs make up 2% of new car sales

2030

EVs make up 23% of passenger and LCVs on the road

EVs reach cost parity with new internal combustion vehicles

EVs make up more than half of new car sales

2040

Shipping decarbonisation via hydrogen and biofuels has begun

Air transport has begun to decarbonise via biofuels

EVs make up 73% of passenger and LCVs on the road

The sale of new internal combustion engine vehicles ceased by 2035

2050

All heavy road transport is a mix of electric and hydrogen (by 2045)

More than 90% of road vehicles are electric by 2045

Shipping and air transport emissions intensity is less than 10% of 2020

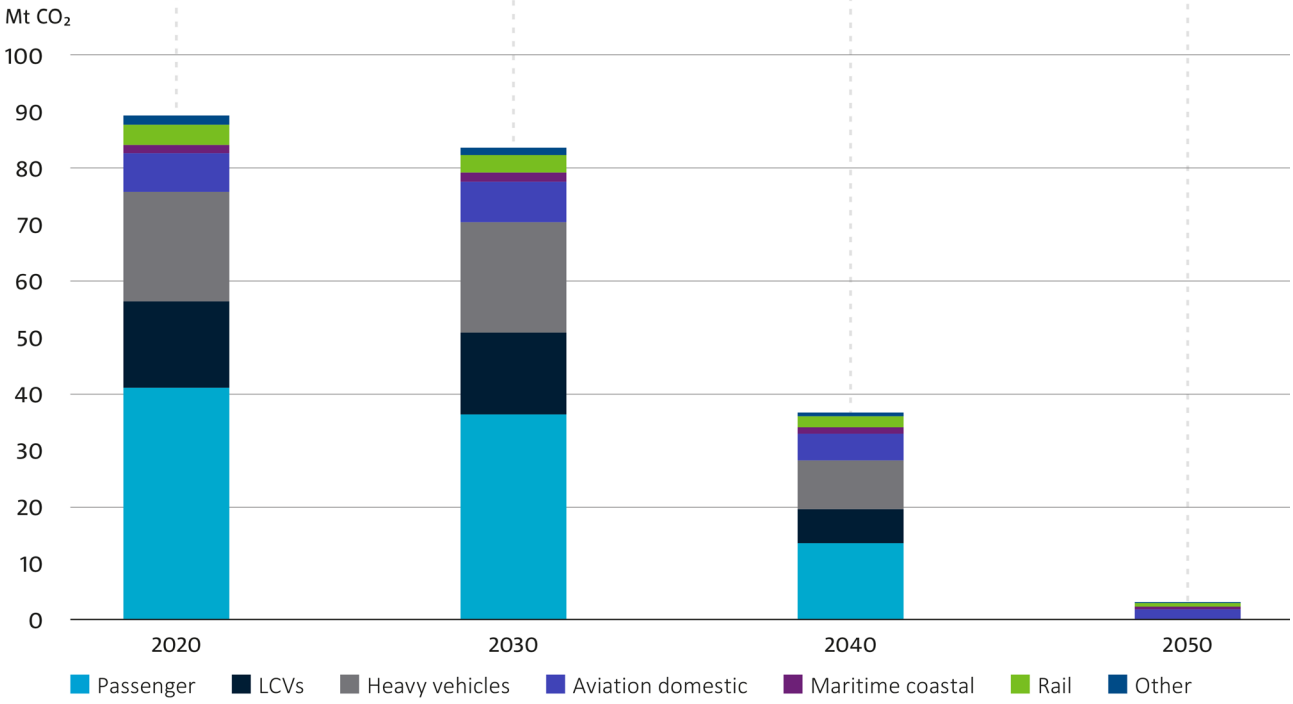

Figure 4 Summary of key transition milestones - Transport

Key findings from: "Pathways to Net Zero Emissions – an Australian Perspective on Rapid Decarbonisation"

There remain challenges to fully decarbonise the Australian economy and innovate to address hard to abate sources

Australia's population is projected to grow towards 33 million by 2050,[2] driving continued growth in our infrastructure needs. Cement production is projected to increase by more than a quarter (27%) even while emissions fall by 82%. Emissions reductions draw on a mix of fuel switching, using biofuels and technologies that are currently in early demonstration or prototype phase (such as hydrogen and carbon capture, utilisation and storage (CCUS)), which will require significant investment (Figure 5). Cement is a sector not projected to achieve net zero emissions by 2050, in part because of carbon dioxide emissions from clinker production, and is anticipated to draw on negative emissions to achieve net zero objectives.

Australia's iron ore and bauxite sectors are projected to continue to grow as key metals supporting transition (iron ore by nearly 70% and bauxite by nearly 50%). Mining activities are projected to decarbonise relatively rapidly through electrification with some use of hydrogen. The emissions reduction trajectories for steel and alumina refining and processing activities are projected to be more complex. New technologies in development and trial phases will need to be commercialised at scale (in order to drive projected reductions) complemented by fuel switching to hydrogen.

Though modelled detail is lower for critical metals, similar transitions to low-emissions mining will be required in these sectors to ensure that overall emissions fall even as production is projected to grow substantially.

[2] Australian Bureau of Statistics

HEAVY INDUSTRY SECTOR EMISSIONS IN THE CRD SCENARIO

2020

In cement production, 84% comprises clinker

In alumina refining, more than two thirds fuel use is natural gas

In bauxite and iron ore mining, more than half fuel use is diesel

2030

In concrete, post-construction recarbonation is recognised

In alumina refining, mechanical vapour recompression technology encourages electrification fuel switching from natural gas

In bauxite and iron ore mining more than two-thirds fuel use is electricity or biofuel

2040

In cement production, some CO_2 capture by 2040

In steel refining, some production by direction Reduction Iron (hydrogen) electric arc furnace by 2040

In steel production, emissions intensity reduced by 22% on 2020 levels by 2040

Some aluminium smelting exploits inert anode technology

2050

In cement production, less than 61% is clinker

In Iron ore mining and cement production, hydrogen provides 10% or more of fuel used

For steel smelting, more than half of production is by Direction Reduction Iron (hydrogen) electric arc furnace

In alumina refining, fuel use is more than half electricity and less than a third natural gas

In bauxite and iron ore mining, use of diesel is eliminated

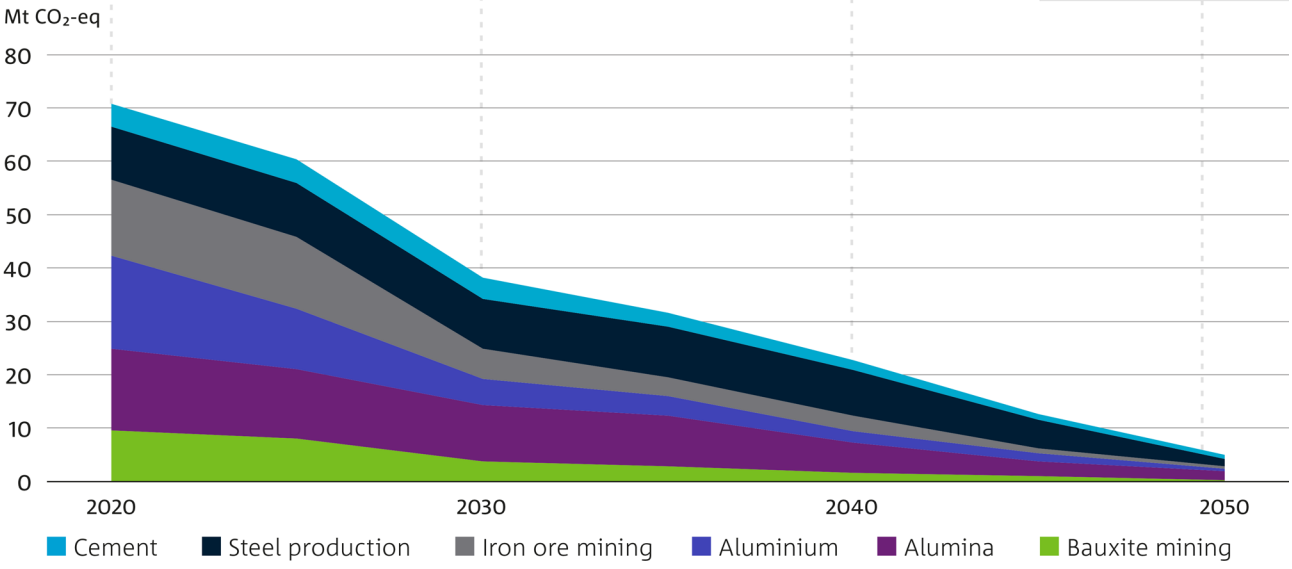

Figure 5 Summary of key transition milestones - Heavy industry

Key findings from: "Pathways to Net Zero Emissions – an Australian Perspective on Rapid Decarbonisation"

The land and agriculture sector can move from a net-positive emitting sector to net negative to support Australia's decarbonisation path

Agriculture is a complex sector where land use, land clearing, carbon plantings and other activities all impact on Australia's emissions profile.

The agriculture, forestry and other land use (AFOLU) sector, encompassing both agriculture and land use, land use change and forestry (LULUCF) moves from being a net emissions source to a net carbon sink by increasing sequestration in vegetation and soils. AFOLU as a contributor becomes a negative carbon emitter by 2030, though some of this sequestered carbon may be sold as Australian Carbon Credit Units (ACCUs) to buyers outside the AFOLU sector. Livestock emissions remain the largest and most difficult-to-abate agricultural source. Innovation will help to reduce emissions but will be insufficient for the agricultural sector to reach net zero. A combination of demand-side changes (to preferences and diets) and supply-side changes (for efficiency, waste and circularity) will be required.

Future work will be required to refine the opportunities to reduce emissions across the agricultural sector along with the likely impacts of climate change on production.

New forms of negative emissions will be required to support net zero emissions

Negative emissions result from technologies that remove carbon dioxide from the atmosphere and either use or store it. Negative emissions from AFOLU including carbon offsets on agricultural land are already in use and are projected to contribute some 129 Mt CO_2 of negative emissions by 2050. Other forms of negative emissions technologies still in development and yet to be commercialised are projected to deliver a further 66 Mt CO_2. A further 18 Mt CO_2 are projected to come from bioenergy with carbon capture and storage.

Fossil fuel exports decline as the transition to alternative fuels builds

Coal, oil and gas, have historically played a critical role in Australia's economic prosperity. They currently make up more than 40% of our exports by value, generating over AUD$200 billion per annum. As the global economy decarbonises, the outlook for these industries is rapidly shifting. Renewable energy, storage, and the electrification of transport will contribute to the near-term displacement of fossil fuels in Australia and other developed nations (Figure 6). The Australian modelling results show a similar effect where fossil fuel use falls by three quarters by 2050 with

renewable electricity production growing to around 600TWh to become the primary energy source, accompanied by substantial improvements in energy use efficiency.

As coal rapidly declines in importance to the global energy sector, Australian exports of coal fall by 20% by 2030 and three quarters (75%) by 2050. Remaining exports are projected to be metallurgical coal for steel production, though that too is at risk with commercialisation of new low-emissions steel production technologies. The global transition away from gas occurs over a longer period. Gas production is projected to peak by 2030 before falling by two thirds by 2050.

The modelled reduction in global demand for our fossil fuel exports will be challenging for Australia and some regions in particular; but is also offset to a substantial degree by projected growth in other mining exports including processed minerals, and a shift to services exports. Hydrogen production, primarily for domestic use is projected to reach scale in the 2030s, growing to around 200 PJ per annum by 2050. A shift to an export hydrogen industry could grow production much more rapidly. Similarly recent geopolitical events may support faster and larger growth in critical minerals to support net zero transitions.

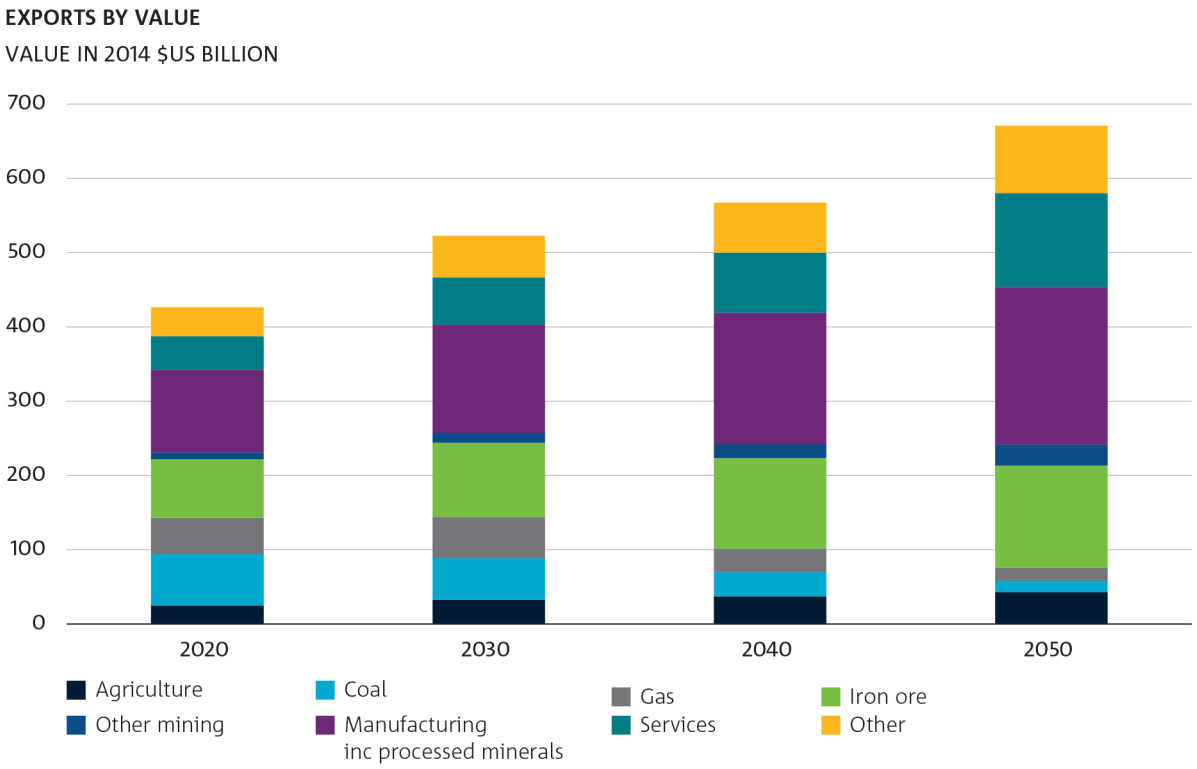

Figure 6 Australian exports by value

Economy-wide transitions

The journey to net zero emissions for Australia will need nuanced policy support. The CRD scenario projects one potential transition path with both opportunities and challenges for the Australian economy. Opportunities exist across a more secure domestic energy future, new export markets (hydrogen and transition minerals) and innovations in energy efficiency and emissions reduction technologies. Challenges result from factors such as more expensive energy during the phase out of fossil fuels, vulnerable regions facing significant shifts in industry and potential skill shortages

Key findings from: "Pathways to Net Zero Emissions – an Australian Perspective on Rapid Decarbonisation"

across newly emerging low-emissions industries. The modelling does not detail the risks facing companies in hard-to-abate sectors that will be relying on carbon capture and storage, hydrogen, or offsets to help the transition to new technologies as part of a low-carbon future.

Significant ongoing investment will be required to replace our aging fossil fuel generators and position the electricity sector for a net zero transition. The modelling projects an additional $AU76 billion above the current trajectory will need to be spent on electricity capacity and associated transmission and distribution infrastructure over the period 2020 to 2050. The IEA suggests energy transition investment forms around half of all net zero transition costs worldwide. Irrespective of a net zero transition Australia would need to invest large sums to replace its aging energy infrastructure and support a growing population.

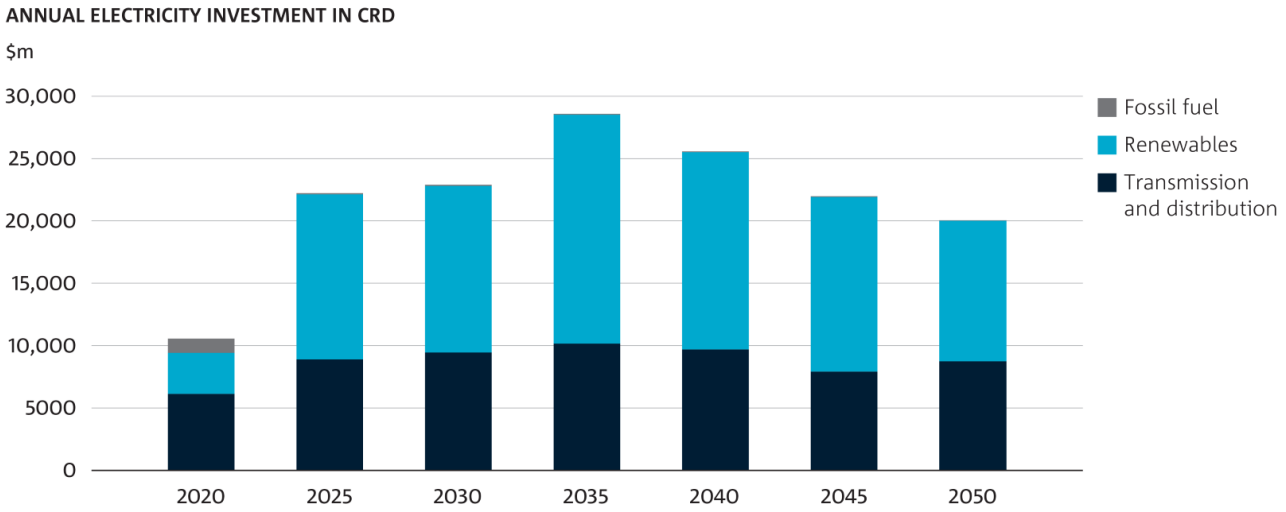

Figure 7 Annual electricity investment in the CRD scenario

CRD scenario investment projections (Figure 7) exclude developing complementary technologies, such as green hydrogen production, CCUS, and sustainable biofuels. De-risking the scale of investment required when other sectors beyond the electricity sector are included suggests government investment policy may need to include a focus on removing barriers to private sector investment and facilitating innovative finance models to reduce or spread risk.

The CRD scenario projects these types of shifts will have a range of economy-wide impacts including:

- Australia is projected to out-perform similar economies despite a challenging longer term GDP growth outlook irrespective of the net zero transition.
- Disruptions to employment in emission-intensive sectors as they transition to new technologies emphasises the need to plan these transitions.
- Reduced terms of trade for Australia (the ratio of export prices to import prices) from the global transition away from our fossil fuel exports, with a consequent flow-through to the wider economy.

These challenges, together with higher population growth than comparable economies, illustrate the challenges of supporting households through the transition, including energy affordability.

These projections may change if Australia were to enhance its competitive advantage in new export sectors such as transition metals and hydrogen or high value exports by leveraging decarbonised energy to process minerals onshore.

Method and motivation

This work draws on IEA energy and sectoral pathways at the global level by incorporating these into CSIRO's Global Trade and Environment Model (GTEM). Two further models (KPMG's Energy and Environment model (KPMG-EE) and CSIRO and ClimateWorks' Australian TIMES (AusTIMES) model) were used to develop detailed technology pathways across energy, transport, buildings, steel, aluminium and cement. Australia's emissions (CO_2 plus non-CO_2) budget for the period reflects (i) the response by Australian sectors to the global CO_2 and non-CO_2 carbon prices, and (ii) assumptions regarding land use, land-use change and forestry emissions and carbon removal technologies. Feedback on the detailed sector-by-sector pathways was obtained through consultation with a range of industry experts to assist in calibrating to the Australian context. A detailed agriculture sector pathway is planned for the future. Modelling has been completed by CSIRO as an independent subject matter expert and the primary authors of this report.

This work has been funded by the Commonwealth Bank of Australia (CBA) to contribute to our collective understanding of potential decarbonisation pathways for Australia, consistent with limiting global warming to 1.5°C above pre-industrial levels. In addition to providing funding for this work, CBA facilitated stakeholder consultation and reviewed the utility of this information for private-sector target setting. We thank participants from the Electricity, Buildings, Transport, Iron and Steel, Aluminium and Cement sectors for their input.

The views expressed in this report are those of the authors' and do not necessarily represent the views of the CBA or other stakeholders consulted throughout this work.

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