Australian Industry Energy Transitions Initiative

Pathways to industrial decarbonisation

Positioning Australian industry to prosper in a net zero global economy

PHASE 3 REPORT - FEBRUARY 2023

Australian Industry ETI is convened by Climateworks Centre and Climate-KIC Australia

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Acknowledgements

The Australian Industry Energy Transitions Initiative (Australian Industry ETI) is funded by a combination of philanthropy and industry participants, and has also received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program. The views expressed herein are not necessarily the views of the Australian government, and the Australian government does not accept responsibility for any information or advice contained herein.

The Australian Industry ETI is convened by Climateworks Centre, operating within the Monash Sustainable Development Institute, and Climate-KIC Australia, in collaboration with the Energy Transitions Commission and delivery partners CSIRO, RMI (formerly Rocky Mountain Institute) and BloombergNEF.

The Australian Industry ETI's industry participants and supporters have contributed to the research, findings, conclusions and messages in this report. Industry participants have collaborated in the development of, and have had oversight of, the model inputs and architecture of the report. Industry participants endorse, in a general way, the central themes and findings of the report relating to the need for ambitious, coordinated action to meet the significant challenges involved in transitioning Australia's energy system and broader economy in order to limit warming to 1.5°C above preindustrial levels, and in relation to the potential opportunities for Australia's economy if strong, effective and coordinated action is achieved. While this report provides an evidence-based, independent analysis informed by consultation with industry, it does not necessarily reflect the position of each individual participant.

This report contains statements that are, or may be deemed to be, forward looking statements, including goals, pathways and ambitions for the supply chains in focus. Such forward looking statements are not guarantees of future performance and involve known and unknown risks, uncertainties and other factors, many of which are beyond the control of the Australian Industry ETI.

Participants: Australian Gas Infrastructure Group, APA Group, Aurecon, AustralianSuper, BHP, BlueScope Steel, bp Australia, Cbus, the Clean Energy Finance Corporation, Fortescue Metals Group, HSBC, Orica, National Australia Bank, Rio Tinto, Schneider Electric, Wesfarmers Chemicals, Energy & Fertilisers, Westpac and Woodside Energy. Supporters: Australian Industry Group and the Australian Industry Greenhouse Network.

This report is the result of three years engagement with Australia's emissions-intensive industry and related businesses to coordinate learning and action, and develop pathways and projects towards achieving net zero emissions supply chains in Australia by mid-century.

This report was written by Climateworks Centre specialists and Paul Graham from CSIRO, with significant contributions from reviewers within Climateworks Centre, Climate-KIC Australia and the Energy Transitions Commission (ETC).

Jobs figures in this report were provided by Accenture Australia and developed from data provided by Climateworks Centre and CSIRO on a range of carbon abatement opportunities in Australian Industry ETI supply chains. A full analysis of jobs figures can be found in the companion jobs report.

We acknowledge and pay our respect to the Traditional Owners and Elders – past and present – of the lands and waters on which program participants operate nationally.

Pathways to industrial decarbonisation

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Phase 3 report, February 2023

Authors
Dr Tyra Horngren
Dr Tessa Leach
Ro Maxwell
Paul Graham
Rob Kelly
Kylie Turner
Anna Malos

Contributors
Peter Carton, Meredith England, Jay Gordon, Alasdair Graham, Mike Hemsley, Ita Kettleborough, Philip Lake, Rafal Malinowski, Hannah Maral, Jason Nielsen, Laura Simes

Climateworks Centre and Climate-KIC Australia 2023, 'Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy', Australian Industry Energy Transitions Initiative, Phase 3, Climateworks Centre.

ISBN: 978-0-9924232-6-1

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Foreword

Australian business understands the long game. Nowhere is this more apparent than in the steps business is taking to address Australia's, and the world's, decarbonisation challenge.

When we started the Australian Industry Energy Transitions Initiative (Australian Industry ETI) in 2019, we invited Australian businesses to come with us on a journey. We provided a space for robust and challenging discussion and we rolled up our sleeves to understand how we could act together because what is required is of such a scale, that it necessitates strong collaboration and coordination.

So much has changed since we began the program. We have lived through a global pandemic, fires and floods. We have seen firsthand, the terrible price some of us are paying for climate change and the ways in which our world is inextricably connected.

Our corporate participants have collaborated to develop pathways and actions towards achieving net zero emissions in critical supply chains by 2050, that should aim to limit warming to within 1.5 degrees Celsius. It's not an easy path, but we believe it's possible, and we know it's necessary. Change is rarely easy, and the pathway to net zero emissions is no exception. This is a complex transition, but there is also an opportunity to ensure Australia is positioned for global competitiveness.

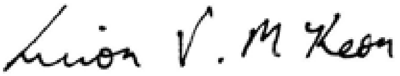
As a result of our work and the work of others, we all now know more about what is technically possible for the decarbonisation of heavy industry and importantly, more about what we don't know and where more research is needed.

Australian business has started to transform itself: testing technology, contemplating new markets, and challenging itself to meet the decarbonisation challenge head on. Business is working to shape a strategy for a future in which Australian energy-intensive industries are competitive in a decarbonised world.

This is a moment of opportunity. With a national target to achieve net zero emissions by 2050 and efforts to establish a framework for effective emissions reductions underway, it is now time for us to seize and create the future we want. The heavy industry sector has worked together to understand the pathway to net zero, to prepare for the heavy lifting. Now it's time for Team Australia to step up.

For every change we ask of our leaders, we must state what we are willing to do in support.

The only way we make the most of this moment is by working towards the same vision, together. All of us, working towards a common cause, getting used to being comfortable with being a little bit uncomfortable as we wrestle with both the challenges we know about, and those we can't yet see. The pathways outlined here are challenging, the risks of action into the unknown are uncomfortable but this pathway is also less challenging and less uncomfortable than what we will face if we fail to act decisively. At stake is a planet that we must pass on in good condition to future generations and a prosperous economy that can sustain them. A challenging pathway, but if anyone can do it, Australians can.



SIMON McKEON AO
Chair, Australian Industry Energy Transitions Initiative

Executive summary

In 2023, there is international accord that urgent action is required to reduce emissions in line with Paris Agreement goals and limit warming to below 2°C, and preferably to 1.5°C. The global average temperature has risen by around 1.1°C since pre-industrial times, with each decade recording successively warmer temperatures than the last (Intergovernmental Panel on Climate Change [IPCC] 2021). As the rise in global temperature is directly related to cumulative greenhouse gas emissions, time is fast running out to prevent warming beyond 1.5°C and the worst effects of climate change. For Australia, rapid and deep emissions reductions are needed if this nation is to contribute to global emissions reductions in line with Paris Agreement goals.

The Australian Industry Energy Transitions Initiative (Australian Industry ETI) has spent the past three years undertaking an extensive program to collectively explore and address the challenges associated with decarbonising the emissions-intensive industry sector. The Australian Industry ETI focuses on five supply chains (iron and steel, aluminium, other metals, chemicals, and liquefied natural gas (LNG)) that are significant in terms of their emissions, energy use, and contributions to the Australian and global economies. Collectively, heavy industry is responsible for 17.3 per cent of Australia's GDP. These five supply chains generate exports worth approximately A$236 billion each year and directly employ an estimated 414,000 people (Australian Bureau of Statistics 2020; 2022a; 2022b). Australia's industry sectors account for around 44 per cent of Australia's total emissions, with the five supply chains that are the focus for the Australian Industry ETI contributing an estimated 25 per cent.

Combining multi-year engagements with some of Australia's largest companies and evidence-based, independent analysis, the Australian Industry ETI has identified potential pathways to net zero emissions across heavy industry supply chains, as well as tangible projects for action towards the net zero emissions goal. As economies worldwide increasingly align to net zero, this report presents the pathways for Australia's heavy industry decarbonisation and priority actions needed across key supply chains to support the transition.

This report analyses three techno-economic scenarios developed to explore and compare key drivers of industrial decarbonisation in Australia. A scenario approach was applied due to the inherent uncertainty in the transition. The first scenario – called the 'Incremental scenario' – was modelled to represent limited domestic action leading to slow decarbonisation throughout Australia, a scenario that ultimately fails to limit warming to below 2ºC and does not meet government targets. The second scenario – called the 'Industry-led scenario' – was modelled to represent strong climate action and leadership from industry, with limited action across the broader economy. The third scenario – called the 'Coordinated action scenario' – was modelled to inform the level of ambition and action needed to limit warming below 1.5°C and realise opportunities within a decarbonising global economy.

Achieving a transition in line with 1.5°C requires strong ambition, coordinated action and government support

This report focuses on the 'Coordinated action scenario', which shows industry emissions could be reduced by 92 per cent by 2050, decreasing from 221MtCO_2e/year in 2020 to 17MtCO_2e/year in 2050. This scenario shows the outcomes of a major transformation across all sectors of the economy, with Australia reducing its fair share of emissions in line with a 1.5°C future.[1]

The 'Coordinated action scenario' shows what is needed to limit warming to 1.5°C while maintaining a strong industrial economy. A range of technology solutions are deployed along an ambitious implementation timeline that the model finds to be the least-cost emissions reduction pathway, based on technology assumptions and other changes across the Australian economy.[2]

1 See the companion technical report for details of the scenarios and the methodology for estimation of Australia's relative carbon budget.

2 Not all technology solutions that may play a role in decarbonising the supply chains are represented by the model. Technologies may be available before the model implements them. Assumptions regarding which technologies were included in the modelling are provided in the companion technical report.

The pathway to 1.5°C will be challenging, but we cannot afford to fail

While the coordinated action scenario shows what is needed for a 1.5ºC pathway, key measures required to achieve this target are not yet in place. The scale of emissions reductions needed in this scenario will require a transformational shift in Australia's energy system. This will be extremely challenging, requiring considerable effort and coordinated action across all sectors of Australia's economy to overcome the barriers to develop and demonstrate the full range of technologies needed, deploy solutions for the transition of existing operations, integrate the systems and infrastructure for the effective decarbonisation of industry, and establish a large-scale, cost-competitive, decarbonised energy system of the future. However, the costs of failure are unacceptable.

Modelling from the Australian Industry ETI shows that over 350TWh of electricity generation could be needed per year by 2030, and nearly 600TWh per year by 2050. To achieve this, Australia must more than double its total current electricity generation by 2050, achieved through multi-gigawatt renewable generation and storage developments (Department of Industry, Science, Energy and Resources [DISER] 2022b). In the same scenario, by 2030, around 60GW of wind generation, 20GW of large-scale solar PV and 45GW of rooftop solar could be required. And by 2050, around 80GW of wind generation, 90GW of large-scale solar PV and 80GW of rooftop solar could be needed, as well as 70GW of storage.[3]

Strong, effective and coordinated action now is critical to achieve the pathway set out in this report, to develop the capabilities needed for the transitions, and to avoid the risks of stranded assets, relatively higher long-term energy costs and being left behind. Many key export markets, including Japan, China and South Korea, have each set net zero emissions targets and momentum towards net zero emissions is building internationally (see Information Box 8.01). As other countries act, mechanisms such as the European Union's (EU)'s carbon border adjustment mechanism (CBAM) impose a carbon penalty on imports (Chahim n.d.).

While significant investment is needed, the scale required is comparable to investments made through other major efforts

The investment required in industry abatement technologies and transitioning the energy system[4] could be as high as A$625 billion by 2050. Over a 30-year period, the annual investment equates to roughly A$20.8 billion per year if Australia is to remain on track to limiting warming to 1.5ºC. While this represents a substantial financial commitment, it is a tenth of the export value of the five supply chains in focus for the Australian Industry ETI – approximately A$236 billion each year – and is comparable to investments made through other major efforts. For example, in Australia, A$305 billion has been invested in new LNG projects over the past 13 years (Department of Industry, Science and Resources [DISER] 2022a) and the economic response to COVID-19 has reached A$291 billion since the start of the pandemic (The Treasury n.d.). In fact, investment in technologies and infrastructure to achieve decarbonisation will need to be accelerated similarly to the scale of investment and action seen during the COVID-19 pandemic.

Transition offers significant opportunities both for the industry sector and Australia's economy as a whole

There are significant potential benefits for Australia, if strong, effective, and coordinated action is achieved. The Australian Industry ETI modelling shows there is potential for lower electricity system costs in the long term, facilitated by the integration of customer-owned storage and load balancing from a large-scale hydrogen industry. There is also the potential for growing industrial production and new export-oriented industries if Australia can leverage its renewable energy advantages in a decarbonising global economy. As examined by a sensitivity study called 'Coordinated action with exports sensitivity', if Australia develops hydrogen and green iron export industries, around 1450TWh of electricity generation will be needed each year by 2050. This represents an almost six-fold increase in Australia's total electricity generation, requiring the build-out of just over 230GW of wind, 240GW of large scale solar PV and industry and energy system investments of up to A$1.4 trillion by 2050 to meet this demand (CSIRO 2018; DISER 2022b).

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3 Total capacity needed (not per annum figure). Breakdown of capacity into wind, solar and other kinds of generation is a modelling output. A summary of the model features and methodology can be found in the companion technical report.

4 Including generation, transmission, fuel, operation and maintenance, storage, and system security

Australia could develop thriving green industries if the necessary action is taken now to decarbonise supply chains

Alongside the environmental benefits of early action, Australia could become a leader in the transition to lower-emissions supply chains, leveraging abundant renewable energy and mineral resources, home-grown intellectual property and a skilled, experienced workforce to drive a competitive advantage for low-emissions production. Economies of scale and efficient supporting service industries could enable Australia to form a sustained, long-term competitive advantage. Australia could also position itself strategically to develop new markets and meet the needs of the future in terms of ores, refined metals, chemicals, manufactured products and energy.

Because of these potential advantages, the Business Council of Australia advocates for Australia to be an early mover in achieving a net zero economy (Business Council of Australia 2021). Focusing on how Australia might achieve these advantages, while addressing how costs and risks can be appropriately distributed, requires a national strategy on developing competitiveness in a globally decarbonising economy. This should include an understanding of the challenges of action and acknowledge Australia's relative strengths, weaknesses and ability to drive the capabilities and culture needed to compete in a net zero world.

With net zero consensus now in place, there are five priority objectives for action

With targets now set at state, territory and national levels, there is willingness to drive towards net zero from government, industry and investors alike. Australia now has a moment of opportunity to take strong, effective and coordinated action.

The Australian Industry ETI has identified the following objectives to ensure Australian industry can transition to net zero emissions (Figure 1.0). These objectives present priorities, rather than sequential steps and in many cases will need to be developed concurrently to achieve the required rate of transition. Each objective is applied to each of the five key industrial supply chains and detailed in the full report.

FIGURE A: Priority objectives for action

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia's industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower	Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	Develop **integrated regions, supply chains and energy network** solutions

Recommended actions to unlock 1.5°C-aligned pathways

With targets now set at state, territory and national levels and a willingness to drive towards net zero in place from government, industry and investors alike, there is now a moment of opportunity to take strong, effective and coordinated action towards net zero emissions. Chapter 8, 'Enabling the transition to net zero emissions in Australian industry' outlines key recommended actions and enablers, aligned to the 1.5°C trajectory. The objectives of the recommended actions and enablers are to:

- Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry
- Transition to the large-scale, cost-competitive, renewable energy system of the future

- Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower
- Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy
- Develop integrated net zero regions, supply chains and energy network solutions.

While the challenges will be significant, a potential pathway for Australian industry aligned to limiting temperature rise to 1.5°C does exist

This is a moment of opportunity for Australia to align and focus efforts to create a globally competitive, equitable, net zero industrial economy.

The transition will only be achieved if strong, effective and coordinated action is taken across the economy. Despite the significant short-term hurdles, industry has a critical role to play in decarbonising the energy system to support decarbonisation and economic prosperity.

Importantly, momentum is building across Australia's economy to decarbonise heavy industry supply chains and commitment from industry is also building towards the long–term transition.

FIGURE B: Findings for key enablers of the transition

600TWh/yr by 2050

of electricity needed, requiring a **2-fold increase** in Australia's total current electricity generation

Around **1450TWh/yr** by 2050 needed to establish new green iron and hydrogen export markets

A$440 billion by 2050 (cumulative)

needed for energy system investment including:

A$220 billion for generation
A$130 billion for transmission
A$50 billion for storage

Total energy system expenditure is **12 per cent** greater than business-as-usual

260GW renewable capacity by 2050

including:
80GW of wind
90GW of large scale solar PV
80GW of rooftop solar and
70GW of storage capacity by 2050

or **27 per cent** storage proportion

A$190 billion by 2050 (cumulative)

needed for investment in industry technologies, electrification and energy efficiency

Industry technology investment is **81 per cent** greater than business-as-usual

FIGURE C: Supply chain snapshot

The Australian Industry ETI has identified the potential for heavy industry in Australia to decarbonise while aiming to limit warming to 1.5°C. This transition will only be achieved if strong, effective and coordinated action is taken across the economy. The emissions reductions found for each supply chain in the ‘Coordinated action scenario’ are enabled by significant investment, renewable energy and hydrogen deployment, as shown below.

Iron & steel

	2020		2030	2040	2050
Emissions reduction	0%		53%	81%	99%
Technology investment (AUD)		2.9 billion		16.6 billion	
Renewable energy (TWh/yr)	5		10	19	29
Hydrogen (kt/yr)	0		40	260	480

Aluminium

	2020		2030	2040	2050
Emissions reduction	0%		77%	94%	98%
Technology investment (AUD)		9.5 billion		26.5 billion	
Renewable energy (TWh/yr)	22		34	40	44
Hydrogen (kt/yr)	0		1	6	12

Other metals

	2020		2030	2040	2050
Emissions reduction	0%		48%	77%	90%
Technology investment (AUD)		0.8 billion		8.4 billion	
Renewable energy (TWh/yr)	6		13	25	26
Hydrogen (kt/yr)	0		3	9	26

Chemicals

	2020		2030	2040	2050
Emissions reduction	0%		89%	94%	96%
Technology investment (AUD)*		11.7 billion		16.6 billion	
Renewable energy (TWh/yr)	1		2	5	10
Hydrogen (kt/yr)	0		98	170	205

*including expenditure on hydrogen

LNG

	2020		2030	2040	2050
Emissions reduction**	0%		72%	90%	91%
Technology investment (AUD)		8 billion		31.6 billion	
Renewable energy (TWh/yr)	9		16	7	6

**including production decrease

1. Introduction

The Australian Industry Energy Transitions Initiative (Australian Industry ETI) brings together some of Australia's largest companies to share knowledge and accelerate action towards achieving net zero emissions supply chains aligned to 1.5°C. It is working collaboratively with participants across heavy industry and business, focusing on five key industrial supply chains: iron and steel, aluminium, other metals (copper, nickel, zinc, and lithium), chemicals (ammonia, fertilisers and commercial explosives), and liquified natural gas (LNG).

The Australian Industry ETI supply chains are significant in terms of their emissions and energy use – and contribution to the Australian and global economy

Collectively, these supply chains are responsible for 17.3 per cent of Australia's GDP, generating exports worth approximately $236 billion each year and directly employing an estimated 414,000 people (Australian Bureau of Statistics 2020; 2022a; 2022b).

Heavy industry comprises a significant proportion of Australia's annual energy use and emissions. Industry in Australia accounts for around 44 per cent of total emissions, while the five supply chains in focus for the Australian Industry ETI contribute an estimated 25 per cent (Figure 1.01). Industrial processes (such as mining and manufacturing) are energy-intensive, consuming 44 per cent of Australia's energy and 40 per cent of electricity each year[5] (Department of Climate Change, Energy, the Environment and Water [DCCEEW] 2022a; DISER 2020). Most emissions result from the combustion of fossil fuels, either on-site to power boilers, turbines, and haulage or through electricity use. Remaining emissions come from non-energy sources such as fugitive and process emissions. For the Australian Industry ETI supply chains, 85MtCO_2e of energy-related emissions and 39MtCO_2e of non-energy emissions are released each year (Figure 1.01).

INFORMATION BOX 1.01:

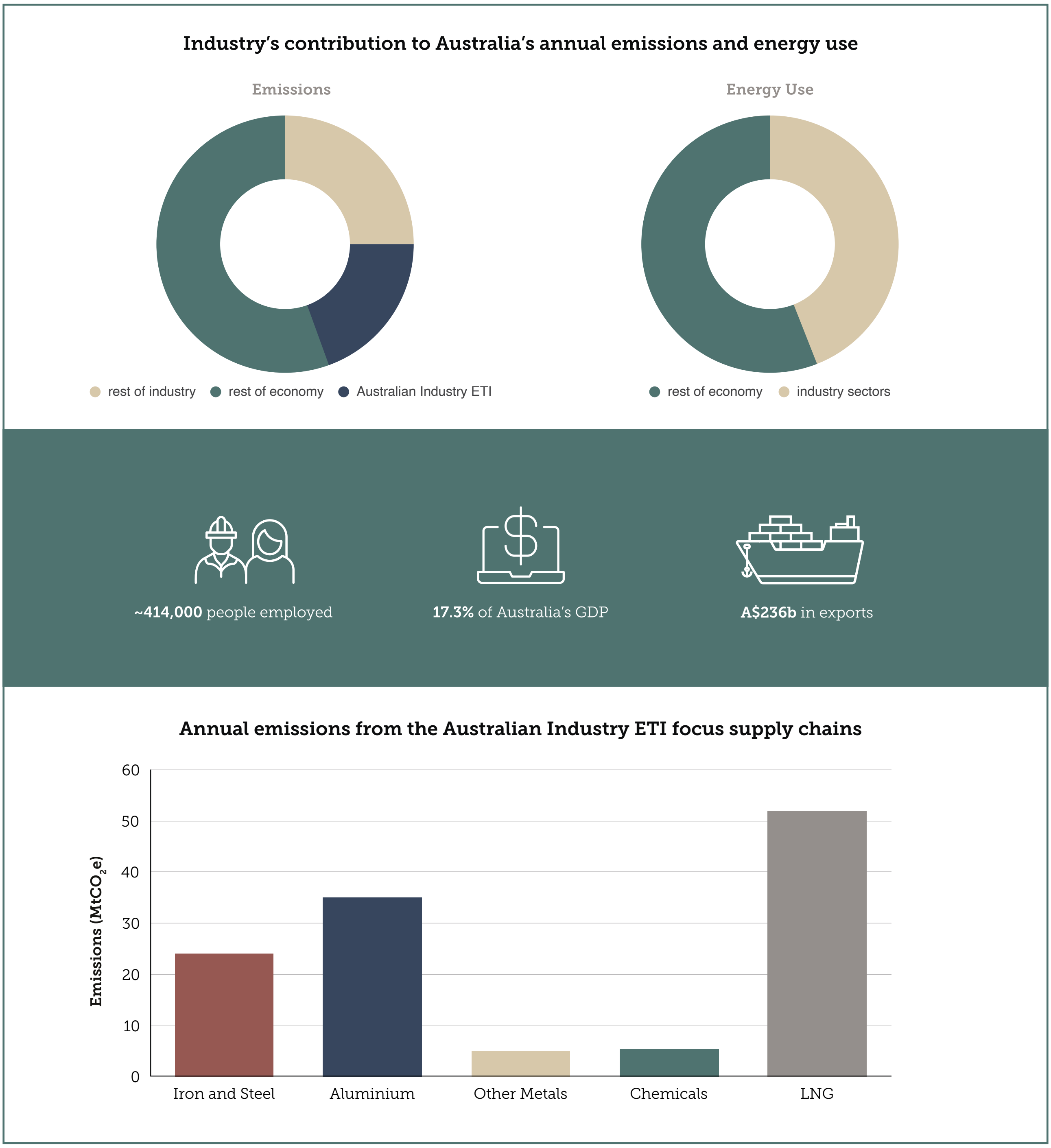
The Australian Industry ETI brings together Australia's emissions-intensive industry and related businesses

To produce this report, the Australian Industry ETI engaged extensively with a diverse group of program participants who have contributed to the insights and messages of this report. Engagement spanned almost 3 years, beginning in 2020 with industry input on scenario development, and key abatement technology options and assumptions. In 2021, a research reference group was established to facilitate industry feedback on emerging modelling results informed by on-the-ground industry experience and perspectives. In 2022, the Australian Industry ETI established a pathways reference group where discussions between program participants were facilitated, to identify the challenges and opportunities for heavy industry decarbonisation in Australia, and what would be needed to achieve net zero emissions supply chains aligned to a 1.5°C carbon budget.

The work presented in this report is the culmination of multi-year, evidence-based and independent analysis, complemented and informed by industry knowledge and experience. The analysis presented in this report does not necessarily reflect the position of each individual participant.

5 Based on 2019 energy use for industrial sectors according to ANZSIC classifications

FIGURE 1.01: The significance of the Australian Industry ETI supply chains



Most Australian Industry ETI supply chains are heavily export-focused, feeding into global supply chains and the emissions of many downstream industries abroad. Australia is the world's largest producer of iron ore, bauxite, and lithium with some of the world's largest copper, nickel, and lead reserves. The significance of Australia's exports in global supply chains means that Australia is connected to a much larger share of global emissions than is currently recorded in national or company inventories (Figure 1.02). The Australian emissions from producing these exports will be impacted by other countries' actions to avoid or abate emissions: these actions will influence the demand and costs of these commodities and Australia's resulting supply volumes. Though emissions associated with Australian exports are not modelled in this study, demand has been aligned to scenarios such as BloombergNEF's New Energy Outlook (BloombergNEF 2021b) and the International Energy Agency (IEA) 'Net zero by 2050' (IEA 2021c) which show changes in production and export demand as key trading partners reduce their emissions consistent with a 1.5°C trajectory.

FIGURE 1.02: Estimated emissions from downstream use of selected Australian commodity exports (2511 $MtCO_2e$ in 2021) compared with Australia's domestic emissions (498 $MtCO_2e$ in 2021)

Momentum is building towards net zero emissions, with decarbonisation commitments accelerating globally. This presents risks and opportunities for Australian exports

Under the Paris Agreement, 196 parties agreed to the goal of limiting global warming to well below 2°C above pre-industrial levels, and to pursue efforts to keep warming preferentially to 1.5°C (UNFCCC 2015). These commitments are laid out in a country's nationally determined contribution (NDC), where ambition is increased every five years through a ratchet mechanism. In this context, 134 countries submitted new NDCs leading up to the United Nations Climate Change Conference (COP26) held in Glasgow in November 2021. The latest round of NDC submissions now covers 91 per cent of global emissions and 73 per cent of the global population (Climate Action Tracker 2022a). Despite this, in their sixth assessment report, the Intergovernmental Panel on Climate Change (IPCC) projected that the world would likely reach 1.5°C warming in the early 2030s, highlighting the need to increase ambition with credible emissions reduction targets (IPCC 2021).

Globally, emissions reduction plans are being developed and implemented, presenting both risks and opportunities for Australia's export markets. America's Inflation Reduction Act 2022 directs nearly US$400 billion to clean energy, with the goal of substantially lowering carbon emissions by the end of this decade. The EU's Green Deal not only pertains to EU domestic targets but includes ways of reducing emissions beyond its borders. In June 2022, the EU Parliament voted to approve the Carbon Border Adjustment Mechanism (CBAM), which puts a price on emissions embedded in products exported to the EU (European Parliament 2022). Other carbon pricing initiatives have been implemented or are under consideration in 33 countries, including Australia's major trading partners (The World Bank 2022). These countries are the destinations of A$246 billion out of Australia's A$382 billion in total, worth of exported goods.

Global decarbonisation could shift demand for Australian exports. The IEA projects that global gas use will peak in 2030, then decline in a 'Net zero by 2050' scenario, which causes a reduction in Australian LNG exports (IEA 2022f). Decarbonisation of global steel production aligned to net zero by 2050 scenarios could also significantly reduce demand for Australian iron ore (Energy Transitions Commission 2019a). Conversely, Australia's competitive advantages in renewable energy could support the development of new green industries, such as renewable energy exports and value-added products (e.g. green reduced iron) that can reduce the need for emissions-intensive processes overseas.

Given the Australian Industry ETI focus supply chains contribute approximately 25 per cent of Australia's annual emissions, urgent action is required to reduce emissions in line with the Paris Agreement goals and stay within Australia's fair share of the global carbon budget.

The global average temperature has already risen by around 1.1°C since pre-industrial times, with each decade successively warmer than the last (IPCC 2021). As the rise in global temperature is directly related to cumulative greenhouse gas emissions, time is fast running out to prevent warming beyond 1.5°C and the worst effects of climate change.

The total amount of greenhouse gases that can be emitted to keep warming below a specific temperature is known as a 'carbon budget'. According to the IPCC, from the start of 2020, to have a 67 per cent chance of limiting global warming to 1.5°C, the world has a remaining carbon budget of 400 gigatonnes (Gt); an alarming figure considering that 71Gt was released in just two years (2020-2021), against approximately 2460Gt of carbon dioxide emitted since the industrial revolution (IEA 2022e; IPCC 2021). To have a greater chance of staying below 1.5°C warming, the remaining global carbon budget is less, just 229Gt (Figure 1.03). Weighed against current emission levels, budgets will be exhausted in nine or six years respectively.

FIGURE 1.03: Global carbon budget (in $GtCO_2e$) at different likelihoods of limiting warming to 1.5°C

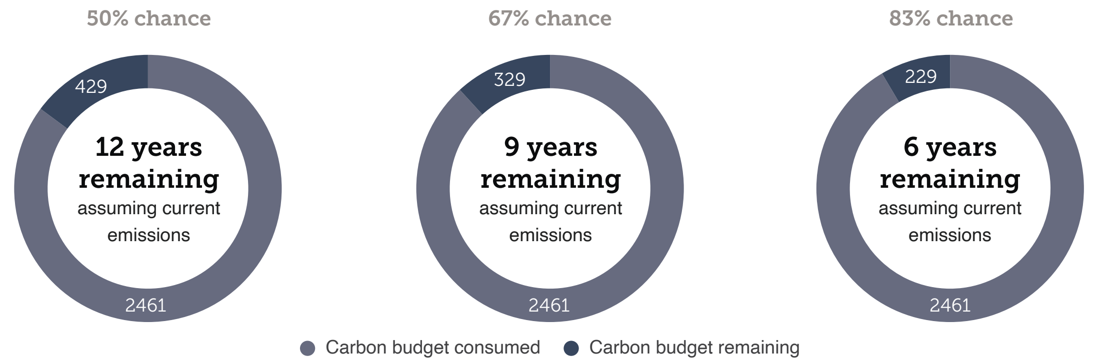


Table 1.01 shows Australia's 'fair share' of the global carbon budget.[6] To have a 67 per cent chance of limiting warming to 1.5°C, Australia has a remaining carbon budget of 2.94Gt. Australia's emissions peaked in 2007, when 646.5MtCO2e were released[7] (DCCEEW 2021b). According to current emissions projections, by 2030, Australia's emissions will fall by 13 per cent compared to 2021 levels (489.9$MtCO_2e$): this falls well short of reductions needed to stay within Paris Agreement goals (Climate Action Tracker 2022b; DISER 2021d). Unless emissions are reduced rapidly, Australia's carbon budget for a 67 per cent chance of limiting warming to 1.5°C will be consumed within the next six years.

TABLE 1.01: Australia's 'fair share' of the global carbon budget

Climate goal	Australia's share of global carbon budget ($GtCO_2e$)	Years remaining at current emissions levels[8]
≤1.5°C, 50% chance	3.78	7.5
≤1.5°C, 67% chance	2.94	5.9
≤1.5°C, 83% chance	2.09	4.2
≤2°C, 83% chance	7.18	14

6 Calculated by Climateworks Centre. The calculation of Australia's carbon budget is based on global carbon budgets in the IPCC's Assessment Report 6. The share was found to be 0.78 per cent of global cumulative emissions. Methodology used to calculate Australia's fair share of the carbon budget can be found in the companion technical report

7 Including removal of greenhouse gas emissions from land-use, land-use change, and forestry (LULUCF)

8 Assuming 2021 emissions of 498.9 Mt including LULUCF (DCCEEW 2021b)

Abating emissions from the supply chains in focus for the Australian Industry ETI is critical to remaining within these carbon budgets. Importantly, industrial processes are typically considered hard to abate, as addressing them poses more technological and commercial challenges than other sectors of the economy.

Companies are embracing this challenge however, with some of the world's largest industrial companies committing to net zero targets. The world's five largest iron ore producers have set net zero by 2050 targets, except Anglo American and Fortescue Metals Group, who have brought their targets forward to 2040 and 2030, respectively (AngloAmerican 2021; Fortescue 2020). Similarly, some of the world's largest steel producers – ArcelorMittal, HBIS Group and Nippon Steel – have committed to net zero, with some investigating low-emissions steel production, in partnership with iron ore producers (ArcelorMittal 2020; HBIS Group 2021; Nippon Steel n.d.). New projects are being announced at a rapid pace, from gigawatt (GW) scale green hydrogen projects, to the ELYSIS pilot in Canada aiming to develop zero-carbon aluminium smelting and the HYBRIT green steel pilot in Sweden (Collins 2021; ELYSIS 2018; Hybrit 2021).

Australia must keep pace with its international peers to maintain a leadership role in the energy and metals industries. Provided decarbonisation occurs quickly and effectively, Australia's natural assets in mineral resources, renewable energy capacity and strong industrial capabilities position Australia to make the most of the global net zero opportunity. These steps should not be underestimated. While commitments from industry to the long-term transition have been a step forward, there will be significant short-term challenges to navigate in the decarbonisation of existing operations and associated infrastructure.

The Australian Industry ETI aims to position Australian industry to maximise opportunities in the shift to net zero emissions supply chains aligned to 1.5°C and help Australia build an economy that takes advantage of the transition

The Australian Industry ETI's first report, *Setting up industry for net zero*, identified the range of existing and emerging solutions that can address almost all emissions in heavy industry supply chains (Australian Industry ETI 2021b). In the second report, *Setting up industrial regions for net zero*, opportunities in five key industrial regions were identified, highlighting the scale of transformation required and the need for coordination, collaboration, and urgent action to realise these opportunities (Australian Industry ETI 2022). This, the third and final report (*Pathways to industrial decarbonisation*), outlines potential pathways for heavy industry decarbonisation, identifying key challenges and enablers across five supply chains and the broader energy system.

The Australian Industry ETI engaged extensively with a diverse group of program participants who contributed to the insights and messages in the development of this report (see Information Box 1.01). The pathways presented in this report were developed through techno-economic modelling of the least-cost technology deployment, leveraging AusTIMES; an Australian implementation of the TIMES model co-developed by Climateworks Centre and CSIRO. To achieve emissions reductions, the Australian Industry ETI modelling imposes a carbon budget in AusTIMES; with the aim of reducing emissions within supply chains, using offsets to complement rather than substitute direct abatement.[9]

9 Modelling inputs and assumptions are described in the companion technical report

INFORMATION BOX 1.02:

Australia's current gas shortage and high gas prices.

In 2022, Australia faced an extended period of higher than anticipated gas prices. International pressures and demand for Australian liquified natural gas (LNG) have led to a spike in international gas prices. Coupled with shortfalls in domestic supply, this has driven the average wholesale gas price on the east coast to increase more than threefold between Q2 2021 and Q2 2022 (Quarterly energy dynamics Q2 2022 2022).

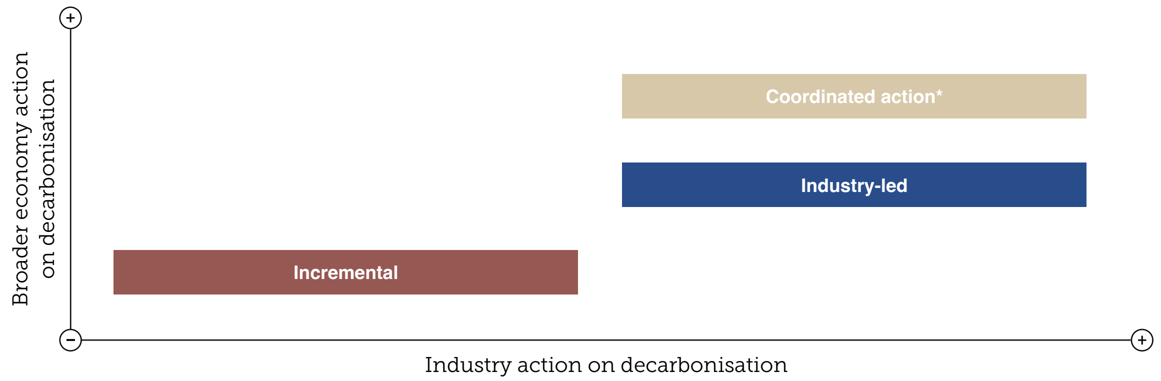
The supply chains in focus for the Australian Industry ETI include a range of processes that depend on gas as a fuel or feedstock, most notably alumina refining and ammonia production. Furthermore, the Australian Industry ETI modelling includes a range of new low-emissions technologies that use gas, such as low-emissions iron and steelmaking technology, and gas-direct reduced iron (gas-DRI).

The deployment and operation of these technologies may be affected by a continuation of the high gas prices currently being experienced in Australia. The Australian Industry ETI modelling does not take gas price spikes into consideration, but rather, considers the long-term cost of gas extraction aligned to the 2022 Integrated System Plan (Australian Energy Market Operator 2022a). Differences in gas prices in the near and medium term may affect the speed with which technologies are deployed; potentially acting to slow deployment of new technologies that rely on gas, fast-tracking the replacement of technologies that currently use gas or delaying action when a replacement technology is not yet commercially proven. Where possible, this report discusses these effects qualitatively and through a sensitivity study that examines the potential effect of high gas prices on technology deployment.

The Australian Industry ETI modelling employs a scenario approach to explore different pathways to achieving emissions reductions due to the uncertainty associated with the transition. Three core modelling scenarios were designed to compare key drivers of industrial decarbonisation (Figure 1.04):

- 'Incremental scenario': A lack of domestic and industry action leads to slow decarbonisation throughout the economy that fails to keep emissions below a 2°C carbon budget. As a result, Australian industry is subject to carbon border adjustments and less-preferential supplier status due to higher carbon products. This leads to losses in market share over time, relative to other modelled scenarios. This scenario was designed to reflect Australia's historical trends across climate policy and low-emissions technology development and deployment.
- 'Industry-led scenario': Leadership in existing heavy industry accelerates technology deployment and abatement, but significant extra investment is needed as action is not borne equally across the economy. Overall, emissions stay within a carbon budget to limit temperature rise below 2°C, despite an accelerated pathway for industry. Australian industry is better able to maintain market share by supplying lower-carbon products in key export sectors but has limited capacity to build new markets. This scenario was designed to examine a possible future that sees strong climate action and leadership from industry yet limited action across the broader economy.
- 'Coordinated action scenario': Australian industry decarbonises rapidly with substantial government incentives that complement industry leadership, driving strong abatement in all sectors, with far less land-based sequestration required to remain within a 1.5°C-compatible budget compared to other scenarios. The speed and scale of the transition helps Australia establish a competitive advantage in green industries, leading to new export sectors and sustained market share in existing markets. This scenario was designed to inform the level of ambition and action needed to limit temperature rise to below 1.5°C. It represents a significant stretch beyond current efforts across climate policy and low-emissions technology development and deployment. Achieving the emissions reductions seen in this scenario will require concerted effort – and coordinated action – across all sectors.

FIGURE 1.04: Climate ambition in the three core scenarios



Coordinated action will facilitate a system-wide transition, enabling Australian industry to prosper in a 1.5°C scenario but will require a significant stretch in efforts

In this report, the Australian Industry ETI will present potential pathways needed to decarbonise heavy industry, identifying the barriers and key recommended actions that will ensure Australia is on track to reach net zero emissions and limit warming to 1.5°C.

The 'Coordinated action scenario' shows that coordinated action is needed for Australia to achieve the rapid and deep emissions reductions required to remain within a 1.5°C carbon budget. This scenario has the potential for lower electricity system costs in the long-term and is compatible with growing industrial production and new industries. In the 'Industry-led scenario', industry can play a leading role in decarbonising the economy, but will ultimately fail to prevent warming beyond 1.5°C without support from the broader economy. The 'Incremental scenario', which sees low climate ambition from both industry and the broader economy, risks higher energy system costs, low international competitiveness, and warming beyond 2°C.

The modelling lays the groundwork for the next task, to identify the challenges that prevent the 'Coordinated action scenario' from being realised along with what's needed for technology and infrastructure development, finance and investment, policy and regulation, and partnerships and collaboration.

2.0 Pathway for heavy industry decarbonisation

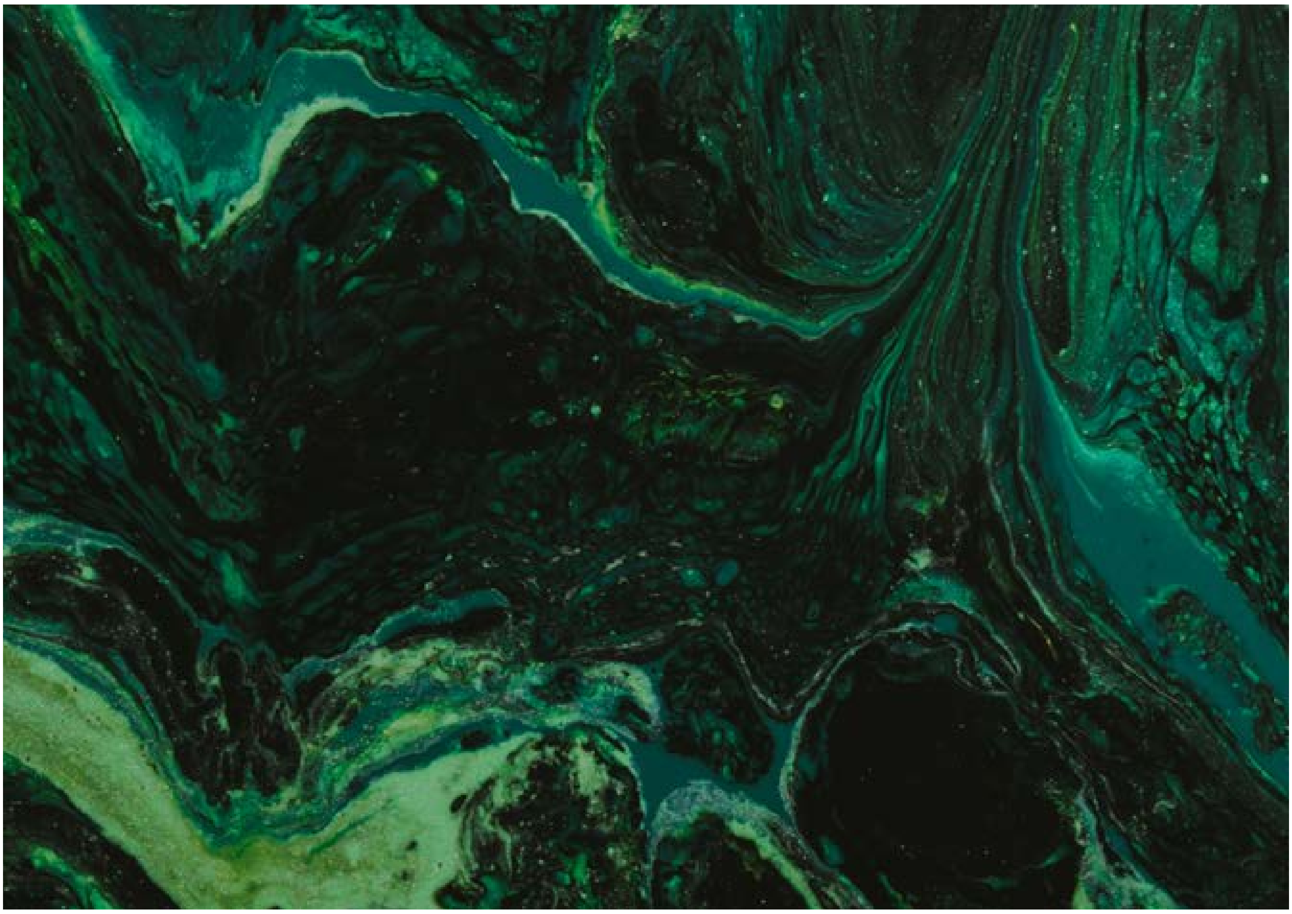
2.1 Decarbonisation aligned to 1.5°C requires a significant stretch in efforts

There is significant uncertainty and complexity surrounding potential future decarbonisation pathways for Australia. Therefore three scenarios developed by the Australian Industry ETI explore different potential emissions reductions pathways across the Australian economy, within a global context of action consistent with limiting global warming to 1.5°C (see chapter 1 'Introduction'). Detail on the modelling methodology and assumptions can be found in the companion technical report.

Rapid and deep emissions reductions are needed across all sectors of Australia

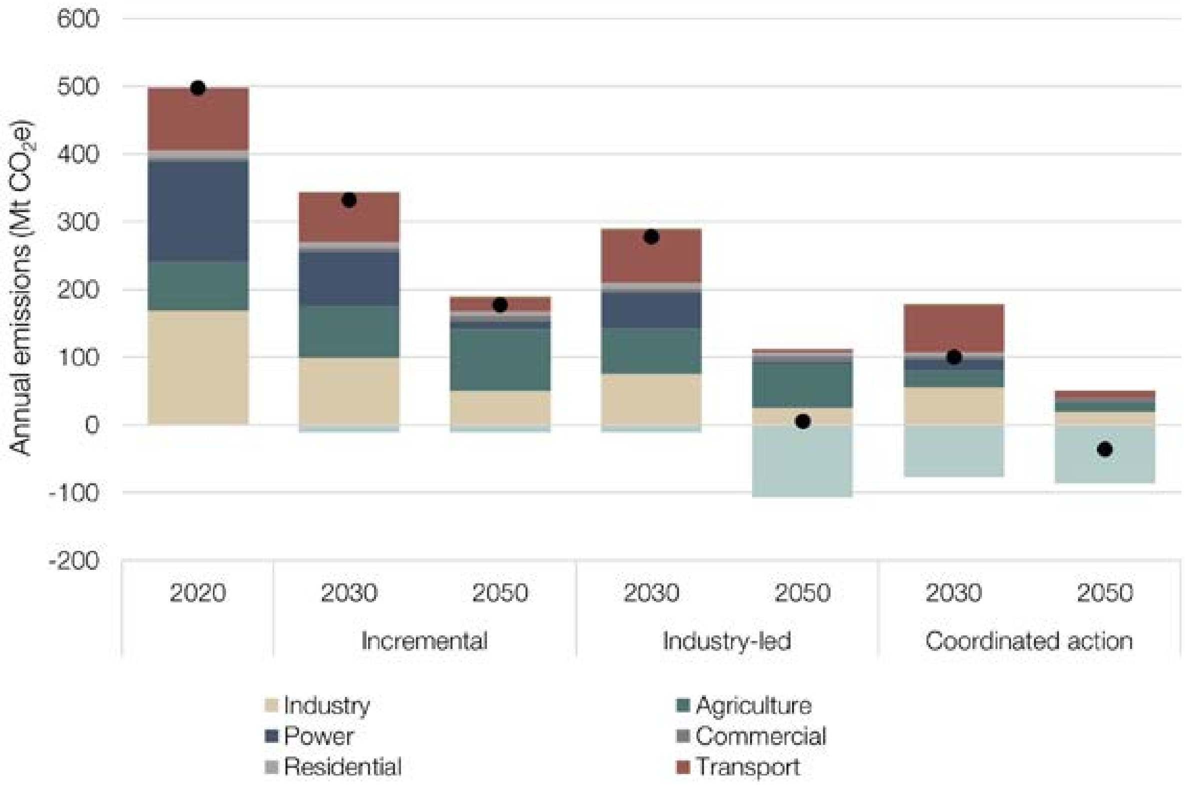
With 498MtCO_2e emitted[10] from Australia in 2020, rapid and deep emissions reductions are needed if Australia is to contribute its fair share towards limiting warming to 1.5ºC. The Australian Industry ETI scenario modelling shows the scale of action needed to achieve this goal, demonstrating a possible pathway if strong ambition, action and support is in place.

As shown in Figure 2.01, abatement in the 'Coordinated action scenario' is driven by action in all sectors of the economy. By 2030, emissions reductions of 65 per cent could be achieved compared to a 31 per cent reduction in the 'Incremental scenario'. By 2050, Australia could reduce its emissions by 90 per cent, declining to 50MtCO_2e/year. When emissions reductions from land use, land use change and forestry (LULUCF) are taken into consideration, by 2030, net emissions reduce by 80 per cent. By 2050, net emissions decline by 107 per cent, showing that Australia could exceed its net zero emissions target.



10 Net emissions including removal of greenhouse gas emissions from LULUCF.

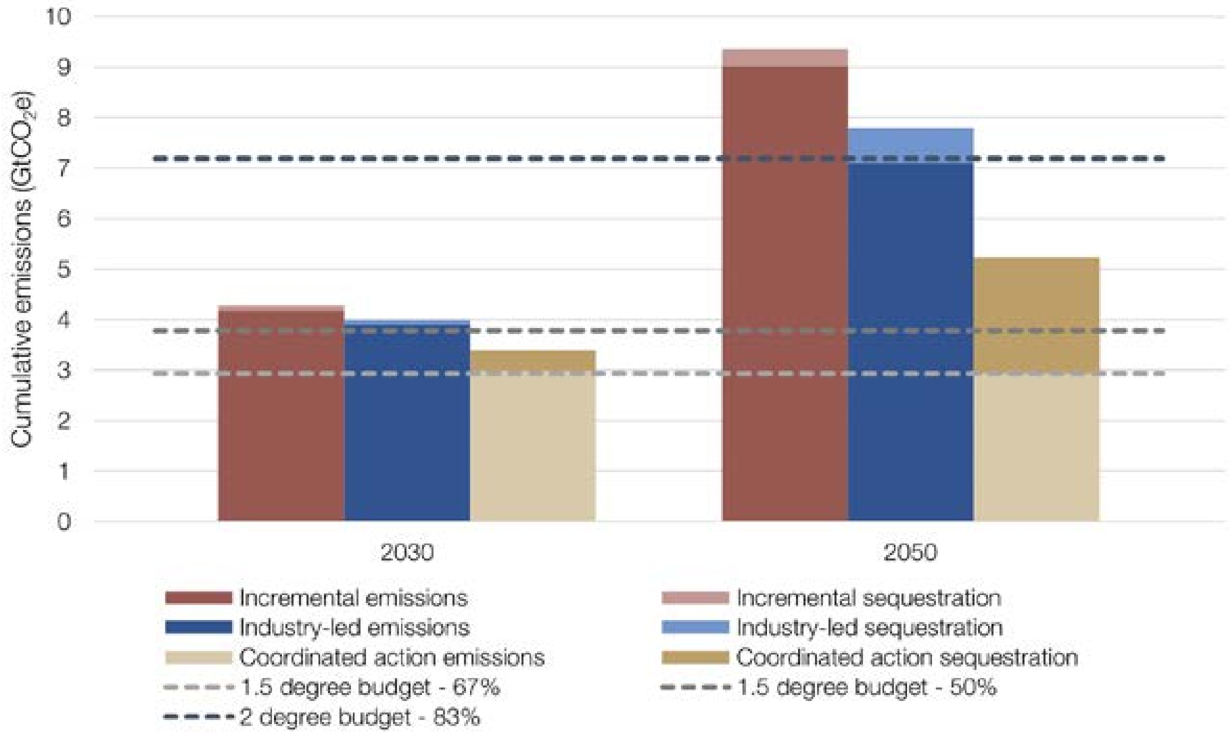
FIGURE 2.01: Annual emissions in the Australian Industry ETI scenarios[11]



'Coordinated action' results in cumulative emissions that are roughly 40 per cent lower than the 'Incremental scenario' and 30 per cent lower than 'Industry-led' (Figure 2.02). The stronger decarbonisation in 'Coordinated action' results in a far lower overshoot of the 1.5ºC carbon budget, and so requires only 2.3GtCO_2e in negative emissions such as land-based solutions by 2050. This is within the bounds of Australia's estimated land-based sequestration potential (Bryan et al. 2015). Conversely, the cumulative emissions in the 'Incremental' and 'Industry-led' scenarios require a significantly higher 6.4GtCO_2e and 4.9GtCO_2e in negative emissions by 2050, respectively, for a 67 per cent chance of limiting warming to 1.5°C. These figures also incorporate sequestered emissions from carbon capture and storage (CCS), which in the 'Coordinated action scenario' reaches approximately 0.014GtCO_2e per year by 2050, compared with 0.082GtCO_2e of land-based sequestration.

11 Includes emissions reductions from land use, land use change and forestry (LULUCF) in 2030 and 2050. Net emissions are the sum of emissions in all sectors minus the emissions removed due to LULUCF. Emissions from the production of hydrogen are comparatively much lower than other sectors as by 2050, hydrogen is mostly produced through low-emissions production routes (see discussion later in this chapter).

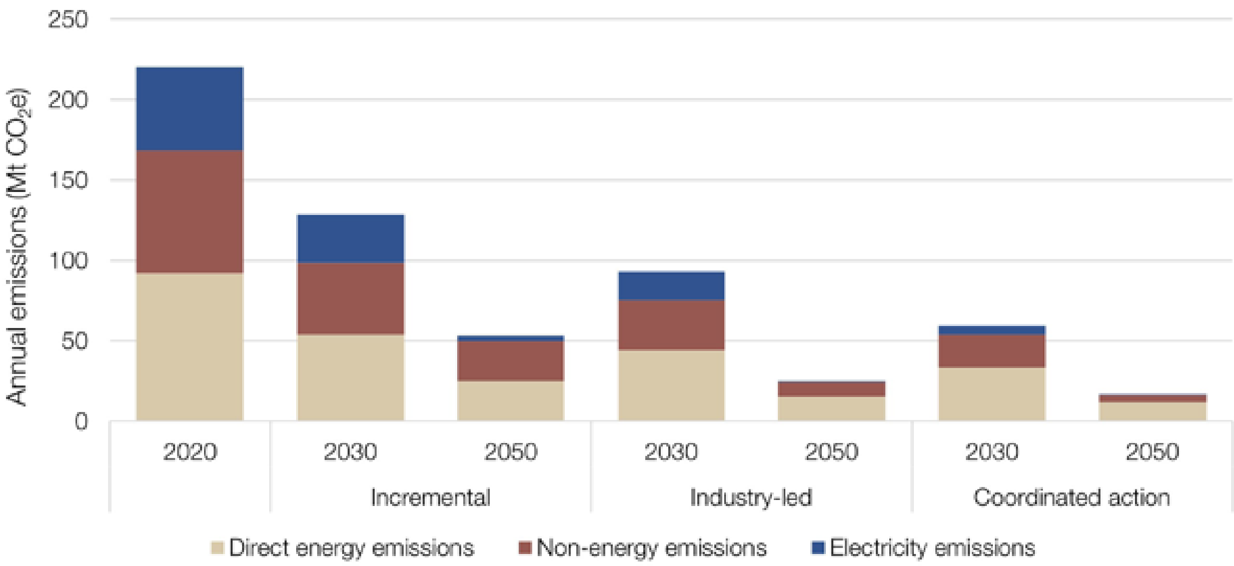
FIGURE 2.02: Cumulative emissions in the Australian Industry ETI scenarios



Coordinated action can keep Australian industry aligned to a 1.5°C warming trajectory

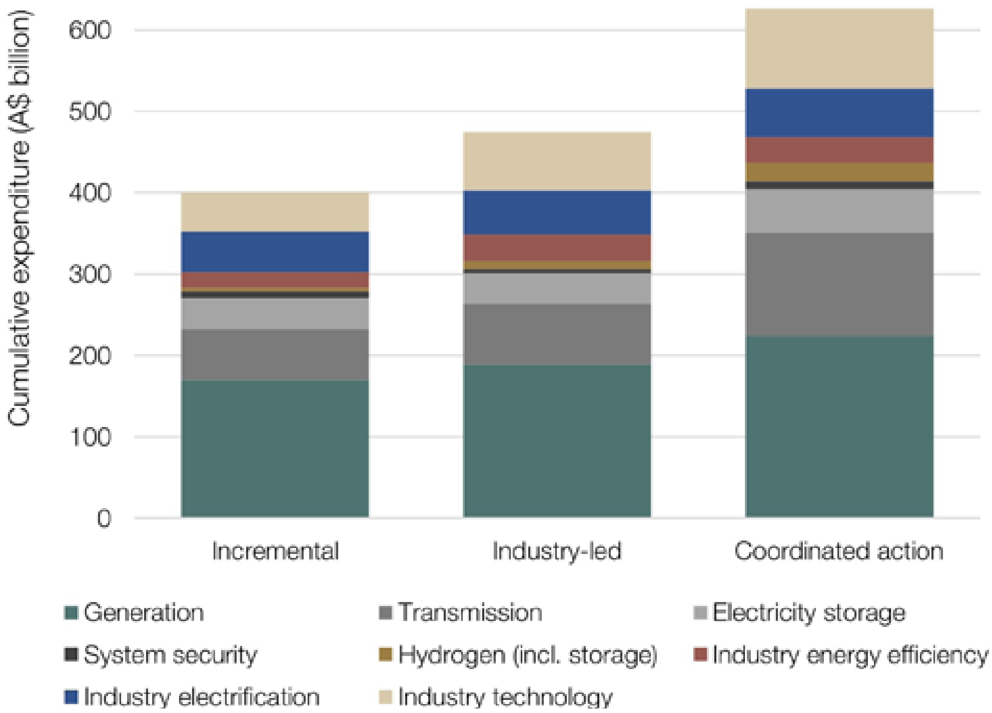
Industry emissions could be reduced by 92 per cent in the 'Coordinated action scenario', decreasing from 221MtCO_2e/year in 2020 to 17MtCO_2e/year in 2050 (Figure 2.03). Significant reductions in emissions from electricity use can be achieved, facilitated by economy-wide action leading to greater grid decarbonisation compared to the 'Incremental' and 'Industry-led' scenarios. Increased electrification and fuel switching decrease emissions from the direct combustion of fossil fuels by 86 per cent; while switching to zero emissions feedstocks reduces non-energy emissions by 94 per cent by 2050.

FIGURE 2.03: Annual emissions from industry in the Australian Industry ETI scenarios



Achieving the scale of decarbonisation needed will require significant investment. To roll out the necessary industry abatement technologies and transition the energy system, this investment could be as high as A$625 billion by 2050 (Figure 2.04).[12] Over a 30 year period, this equates to roughly A$20.8 billion per year if Australia is to remain on track to limiting warming to 1.5°C. Taken as the percentage of electricity used by the industrial sector, the cumulative investment in new generation, transmission and storage between 2025 and 2050 just to support industry could be roughly A$120 billion in the 'Coordinated action scenario'. Adding the energy system investment means an additional 60 per cent on top of the investment in industrial technologies, energy efficiency and electrification. While this represents a substantial financial commitment, it is comparable to other expenditures. For example, in Australia, A$305 billion has been invested in new liquified natural gas (LNG) projects over the past 13 years (DISR 2022a) and the economic response to COVID-19 has reached A$291 billion since the start of the pandemic (The Treasury n.d.). In fact, investment in technologies and infrastructure to achieve decarbonisation will need to be accelerated similarly to the scale of investment and action seen during the COVID-19 pandemic.

FIGURE 2.04: Cumulative investment in renewable energy and industry abatement technologies by 2050[13]



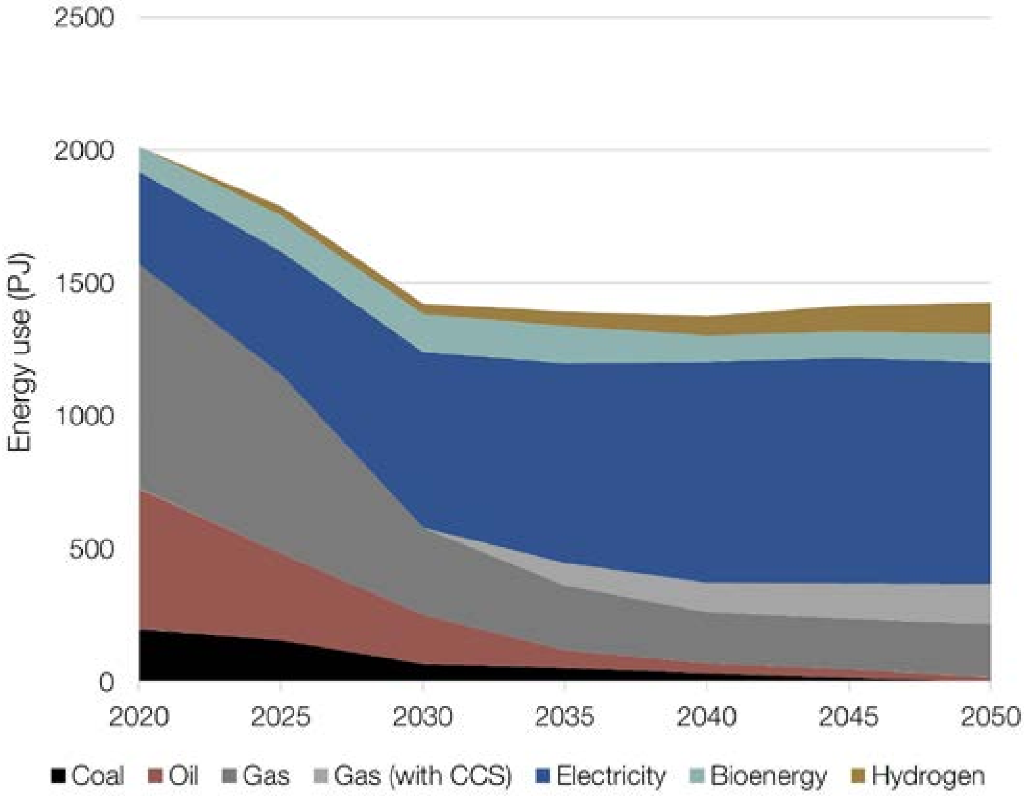
2.2 The decarbonisation of Australia's industrial supply chains will require a transformational shift in Australia's energy system

The 'Coordinated action scenario' represents a significant stretch beyond current efforts across investment, technology development and policy, as well as in industry leadership (see chapter 1, 'Introduction'). For example, this scenario makes significant use of customer-owned storage to help balance the grid; it includes ambitious efforts to bring on new decarbonisation technologies, renewable energy and green hydrogen; and it requires substantial investment in energy systems. The results show that a widespread shift away from fossil fuels, resulting in a substantial change in the energy mix in the sector, and increased electrification is needed to achieve the decarbonisation of industry (Figure 2.05). Under the 'Coordinated action scenario', gas with CCS steadily increases after 2035, with unabated gas use declining in the near to medium term. In this scenario, electricity use could increase by approximately 140 per cent compared to today, making up 58 per cent of energy used by industry by 2050.

12 Not including infrastructure investment.

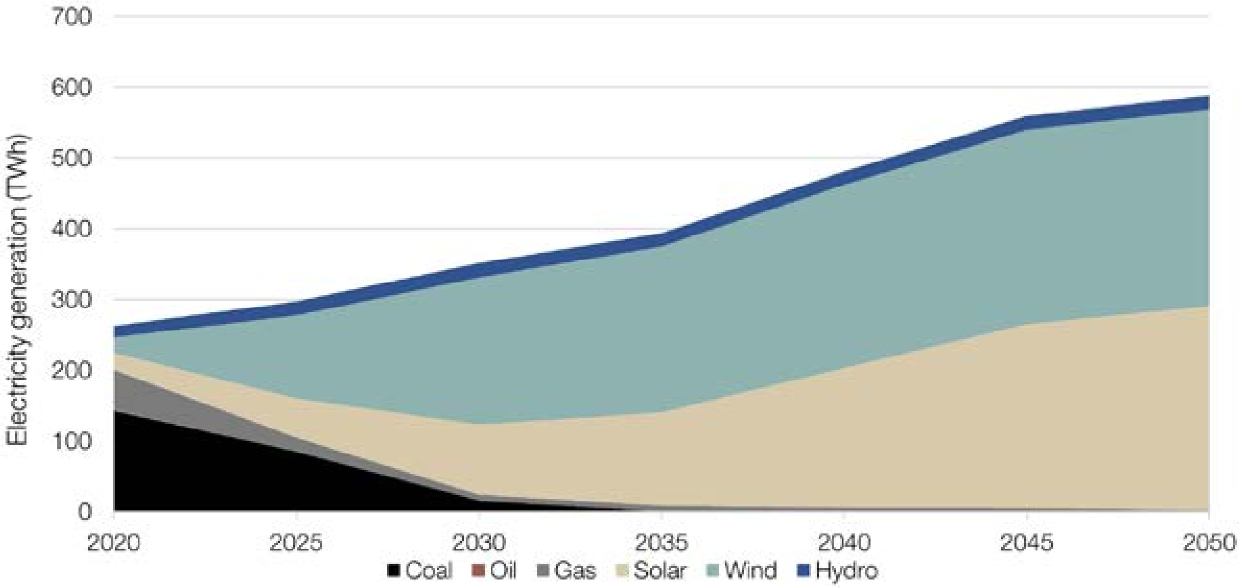
13 Investment costs are derived in the modelling from the value of the Australia dollar in 2015. Inflation rates are not built in, but are accounted for in decision-making in the model using a 'discount rate' (see companion technical report). Industry investment includes the entire Australian industry sector (excluding agriculture), including the supply chains in focus for the Australian Industry ETI. Numbers may not sum due to rounding.

FIGURE 2.05: Changes in industry energy use over time in the 'Coordinated action scenario'

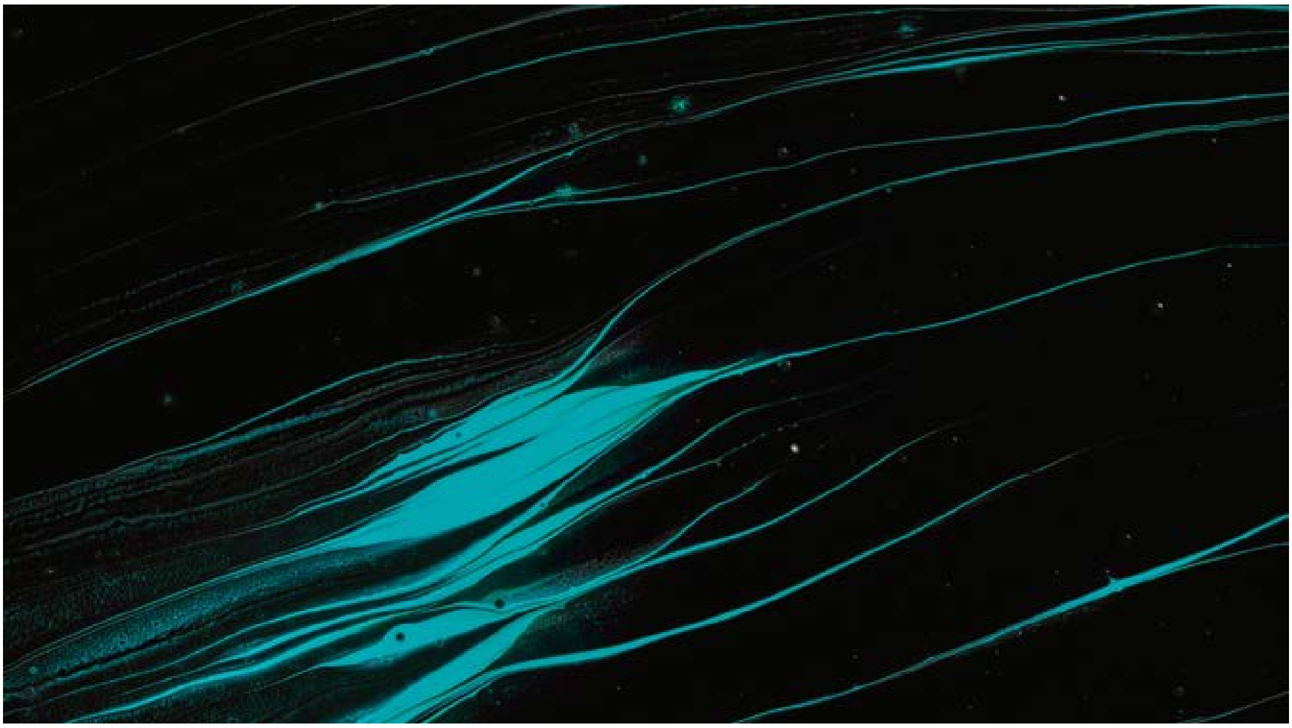


In the 'Coordinated action scenario', the shift away from fossil fuels and increased electrification will require an unprecedented transformation of Australia's energy system. As shown in Figure 2.06, around 350TWh of electricity generation could be needed per year by 2030, and nearly 600TWh by 2050 – enough to power around 110 million households. This will require Australia to more than double its current electricity generation (DISER 2022b). Increasing grid decarbonisation could be achieved, with almost 100 per cent of the electricity mix consisting of renewables by 2035, with solar photovoltaics (PV) and wind generation making up most of this.

FIGURE 2.06: Electricity generation mix in the 'Coordinated action scenario'



The scale of energy system transformation needed will be greatly affected by the establishment of new export markets from Australia, such as hydrogen (Information Box 2.01) and green iron and steel. To evaluate the energy system implications of this, the Australian Industry ETI modelled an export sensitivity scenario (called 'Coordinated action with exports sensitivity') aligned to the National Hydrogen Strategy 'Energy of the Future' scenario (DISER 2019), and the Australian Energy Market Operator's (AEMO), 'Hydrogen superpower' scenario (AEMO 2021). Using these reports as input, the sensitivity assumes that Australia produces around 18Mt of hydrogen per year for export in 2050 (equivalent to the energy that would be consumed by more than 61 million average Australian homes with gas heating) and 58Mt of green iron per year for export by 2050.[14]



14 This does not include the energy that would be needed to liquefy the hydrogen or convert it to ammonia or other chemicals for export. All assumptions for the Australian Industry ETI modelling can be found in the companion technical report

INFORMATION BOX 2.01

Exporting Australian renewable energy to the world

There are many opportunities for Australia to produce and help to provide the energy needed for a decarbonising global economy. Australia is currently the world's largest exporter of metallurgical coal, and second-largest exporter of thermal coal, mostly to Asia (DISR 2022b). However, as economies seek to decarbonise but maintain or increase energy use, there will be greater demand for low-emissions energy supply. And there are many opportunities for Australia to produce and help to provide the energy needed for this decarbonising global economy. In addition to exporting fuel, the onshoring of the energy-intensive production of products such as green iron production with green hydrogen and the processing of other minerals for export could also be considered a form of energy export (Net Zero Australia 2022). Existing capabilities and infrastructure would need to be modified in order to deliver zero emissions fuels or other forms of energy exports.

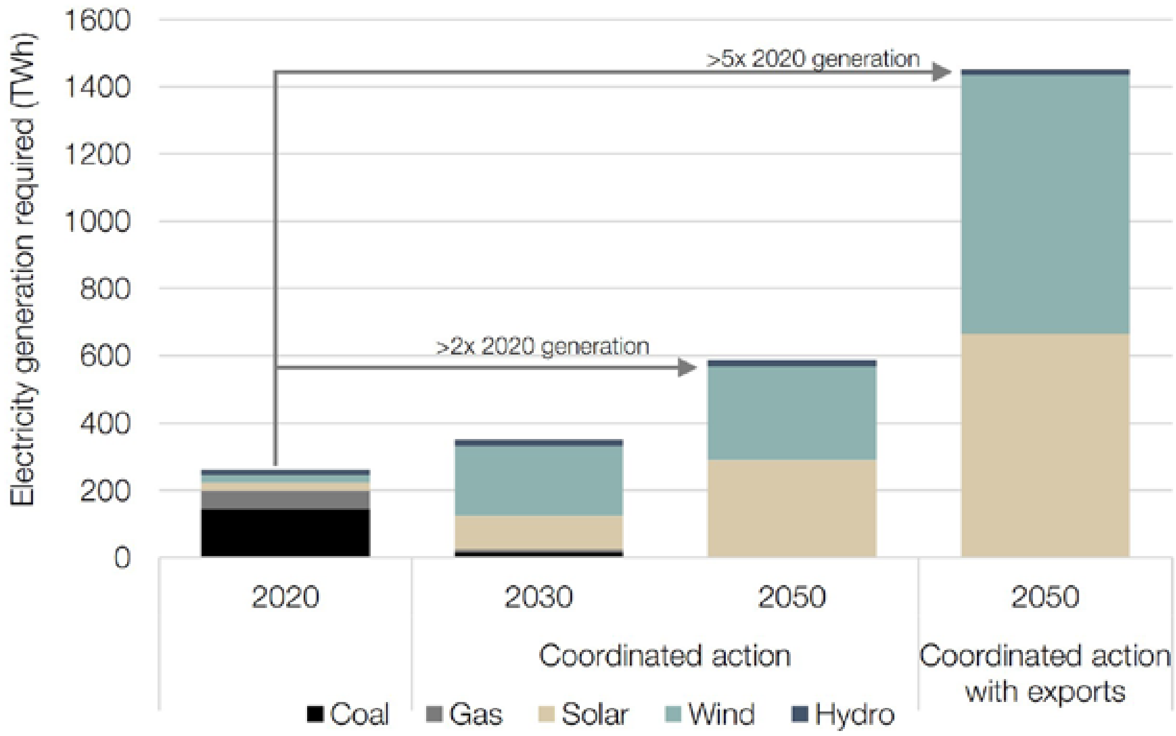
A green hydrogen industry has been proposed as a way for Australia to continue to provide for the energy needs of export markets in a decarbonising world, leveraging rich natural renewable energy resources and proximity to large energy consumers in Asia. Green hydrogen is produced with electricity from renewable energy sources and water through electrolysis. The IEA's 'Net zero by 2050' scenario results show that global production of hydrogen could be 520Mt/year by 2050, of which 322.4Mt/year may be electrolysis-based hydrogen and the remainder gas-based (IEA 2021c). If Australia produces the quantity of green hydrogen modelled in the 'Coordinated action with exports sensitivity', it would supply approximately 5.6 per cent share of this potential global green hydrogen demand in 2050, or around 3.5 per cent of the total blue and green hydrogen global demand. Blue hydrogen (gas-based with CCS) exports from Australia have also been proposed as an option (Department of Industry, Science, Energy and Resources 2019).

As a general rule it is more efficient to use electricity directly (IPCC 2022). However, not all geographical regions have the option to produce abundant, affordable renewable energy, and this is where other fuels, such as hydrogen, can act as a carrier of renewble energy, used directly as a fuel or to produce electricity. Electricity-to-hydrogen-to-electricity efficiency could increase to 50 per cent by 2030 (IPCC 2022). Hydrogen can be exported as a compressed liquid, but this may not always be the best option (see chapter 6 'Focus on chemicals'). Shipping liquid hydrogen is expensive and inefficient compared with many other fuels (International Renewable Energy Agency 2022). Liquid organic hydrogen carriers such as ammonia and methylcyclohexane (MCH) may be easier to transport, but could face other challenges (Aziz et al. 2019).

The energy system transition needed to decarbonise Australian industry is dwarfed by the scale of energy requirements needed to establish new export markets for Australia. As seen in Figure 2.07, if Australia was to develop the significant hydrogen export industry as examined by the 'Coordinated action with exports sensitivity', around 1450TWh of electricity generation will be needed per year by 2050. This would be equivalent to powering roughly 265 million households[15] and would require Australia to increase its current electricity generation almost six-fold (CSIRO 2018; DISER 2022b).

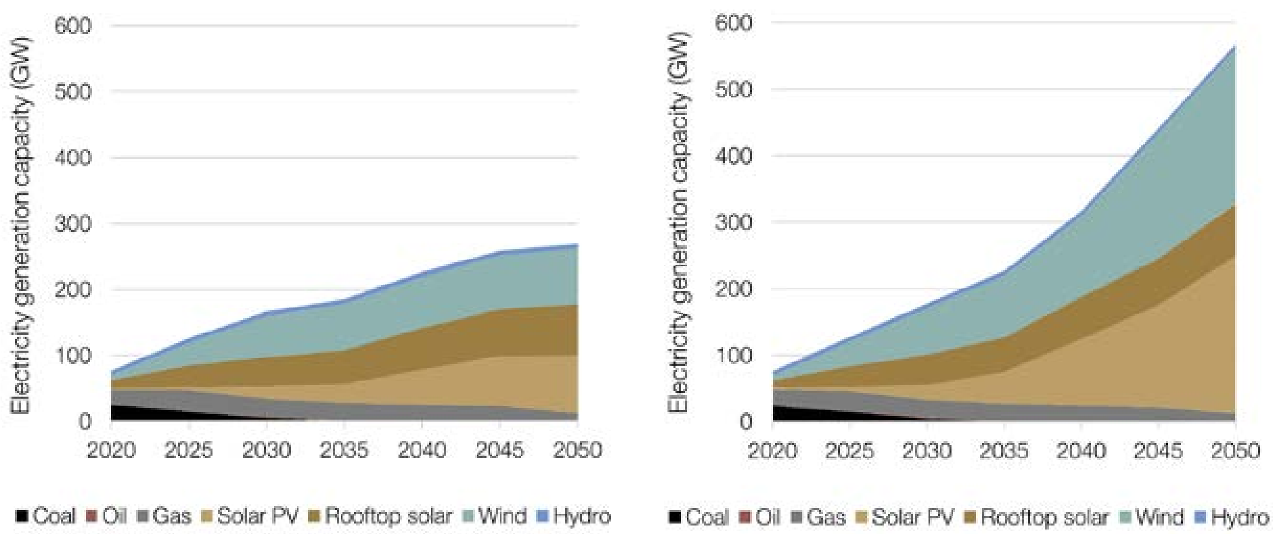
15 Assuming the average household consumes 5469kWh a year (based on Table 9 in (Frontier Economics 2020))

FIGURE 2.07: Electricity required for the 'Coordinated action with exports sensitivity'



To meet the scale of renewable energy needed in both the 'Coordinated action' scenario and 'Coordinated action with exports sensitivity', multi-gigawatt renewable generation developments will need to be built. By 2050, 84GW of wind generation, 87GW of large-scale solar PV and 79GW of rooftop solar are needed in the 'Coordinated action scenario'. In the 'Coordinated action with exports sensitivity', 232GW of wind, 243GW of large-scale solar PV and 79GW of rooftop solar[16] are required (Figure 2.08).

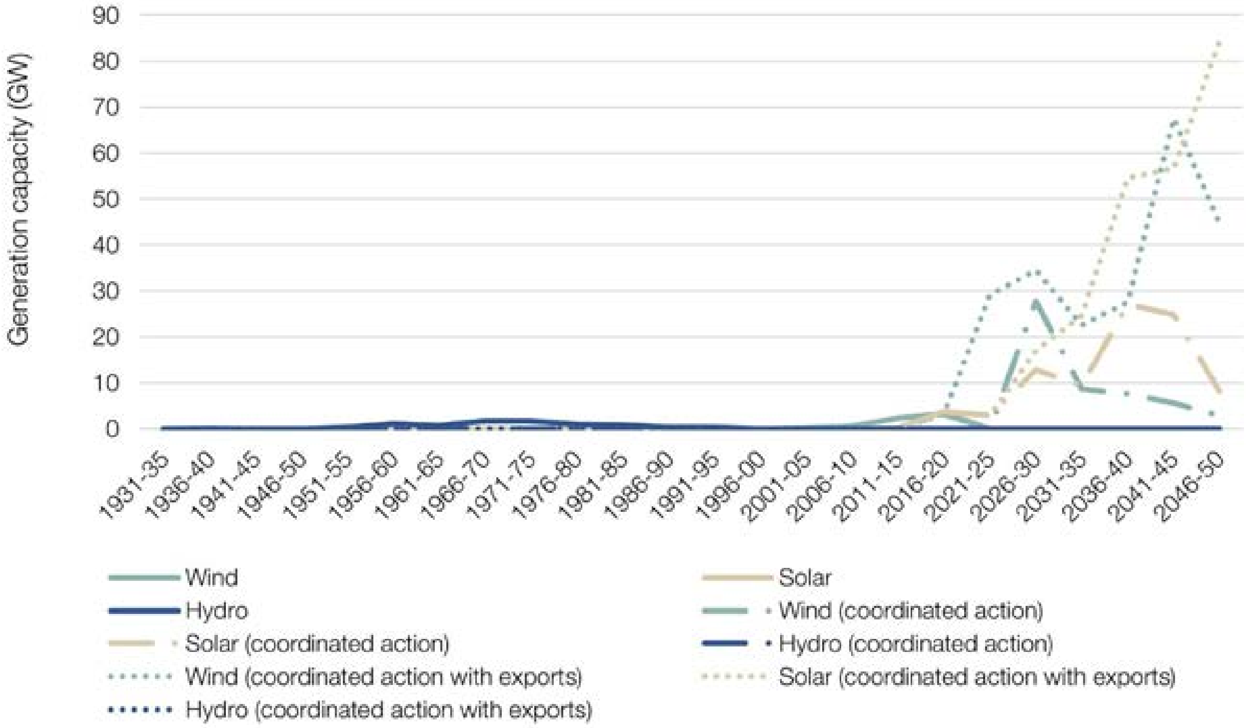
FIGURE 2.08: Renewable energy capacity in the 'Coordinated action scenario' (left) and 'Coordinated action with exports sensitivity' (right)



16 Rooftop solar does not change between the 'Coordinated action scenario' and 'Coordinated action with exports sensitivity' as a limit is imposed in the model as to how much rooftop solar can be installed.

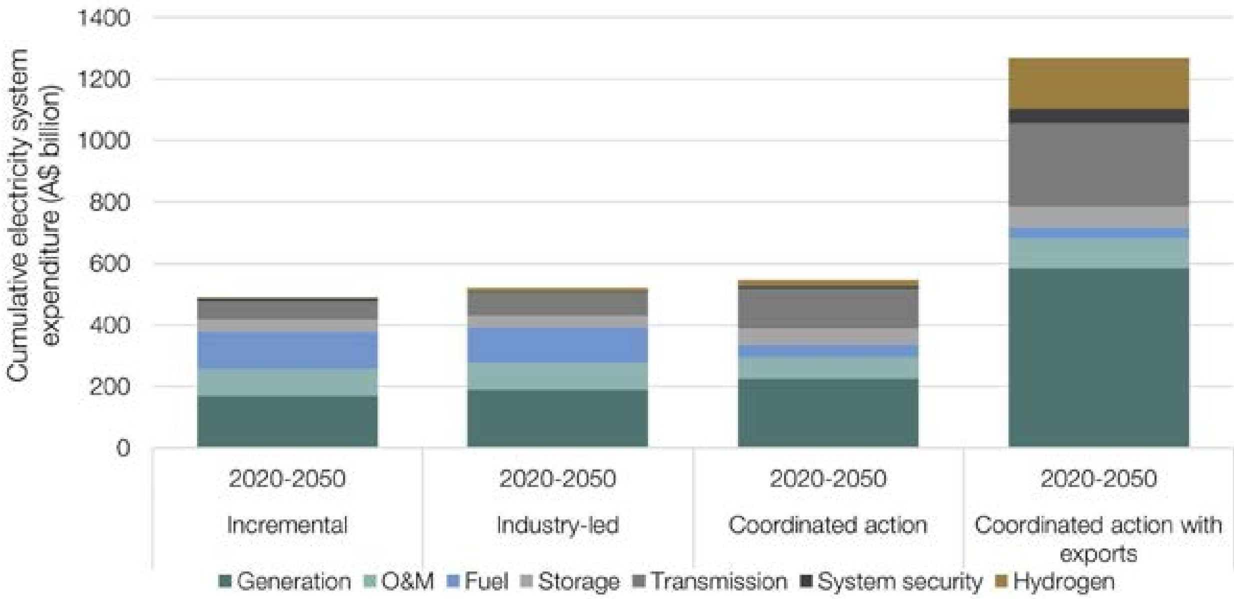
Currently, the world's largest solar power plant is 2GW and the world's largest wind farm is 10GW – both of which are in China (Cranney 2021; Wolfe 2021). Figure 2.09 shows Australia's historical renewable energy capacity instalments, contrasted against the scale of renewable energy build-out required in the 'Coordinated action scenario' and 'Coordinated action with exports sensitivity'.

FIGURE 2.09: Renewable generation capacity instalments in Australia and the scale of instalments needed to achieve the 'Coordinated action scenario' and 'Coordinated action with exports sensitivity'.



Significant investment will be needed to achieve this scale of renewable energy development. By 2050, cumulative investment in the energy system could be as much as A$440 billion for the 'Coordinated action scenario' and as much as A$1.27 trillion for the 'Coordinated action with exports sensitivity' (Figure 2.10). Most of this would be spent on generation but transmission infrastructure would also be a significant investment. In addition to the investment needed, there are cumulative operations and maintenance (O&M) and fuel costs of A$110bn in the 'Coordinated action scenario'. However, renewable energy generation has comparatively low O&M and fuel costs. Increased grid decarbonisation means O&M and fuel costs are lower for the 'Coordinated action scenario' compared to 'Incremental' and 'Industry-led' scenarios.

FIGURE 2.10: Cumulative electricity system expenditure in the Australian Industry ETI scenarios (2020-2050)

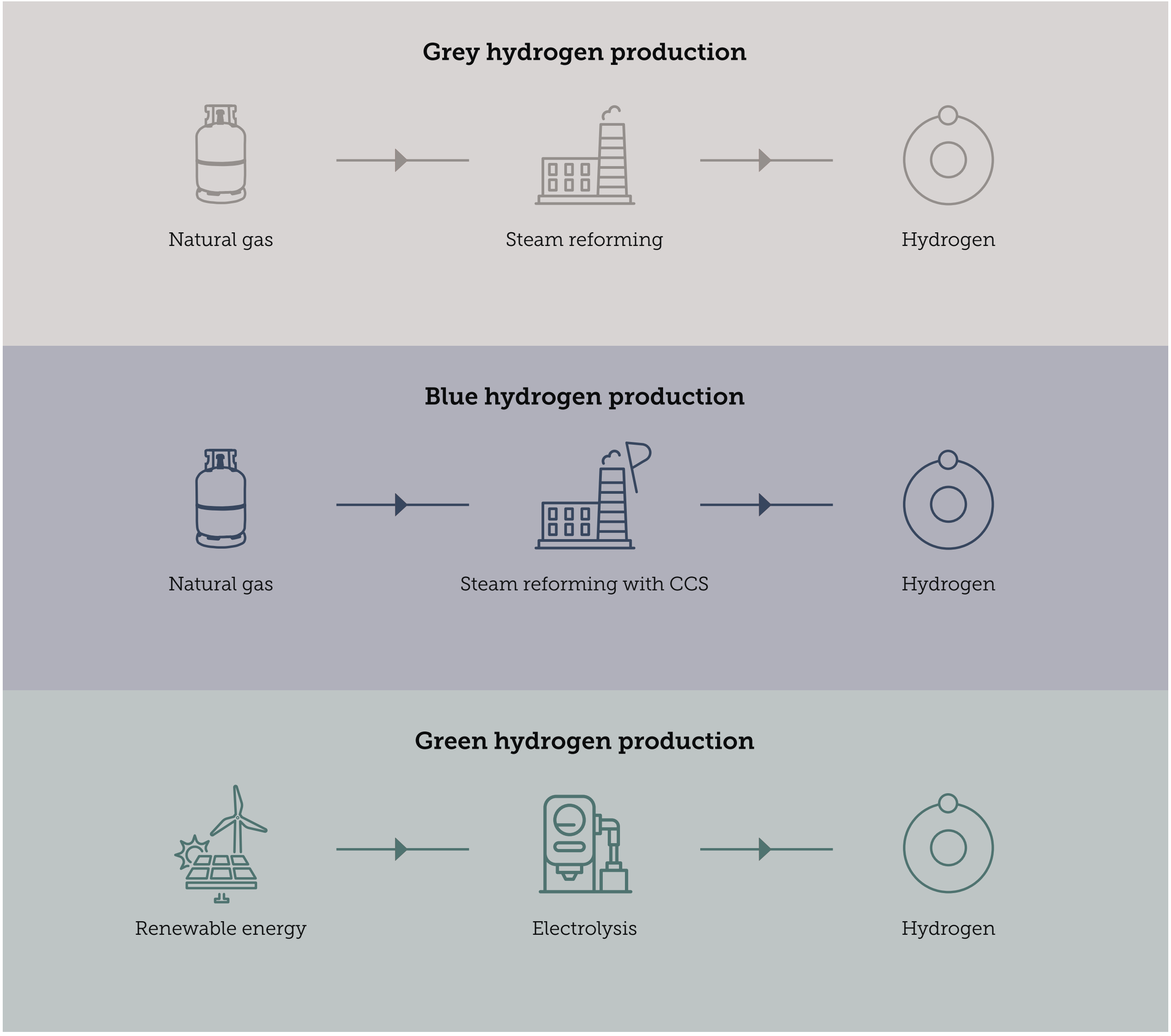


Hydrogen is expected to play a significant role in the decarbonisation of heavy industry

Hydrogen has been produced and used for over 100 years as a feedstock for ammonia production and in oil refineries (Det Norske Veritas 2022). Hydrogen can be produced in a variety of ways, with varying emissions intensities. As shown in Figure 2.11, there are three primary methods of producing hydrogen that are included in the Australian Industry ETI analysis – known as grey, blue, and green hydrogen.[17] Grey hydrogen is produced from natural gas in a process called steam methane reforming (SMR) and produces a concentrated stream of CO_2 emissions during this process. Blue hydrogen is produced via SMR; however, CCS is used to capture the CO_2 emissions before they enter the atmosphere making this a lower net carbon production route than if no CCS is used. Green hydrogen is produced by splitting water into hydrogen and oxygen using renewable electricity in a process known as electrolysis, which produces no greenhouse gas emissions. Two methods currently exist, alkaline electrolysis (AE) and proton exchange membrane (PEM) electrolysis.

17 This report uses the convention of 'grey', 'blue' and 'green' hydrogen rather than other common terminology, such as 'clean hydrogen'. The techno-economic approach of the study means that it differentiates the origin of hydrogen based on production type. No other kinds of hydrogen were modelled although other methods to produce hydrogen do exist, such as coal gasification. Coal gasification with CCS could also be considered blue hydrogen, but this was not modelled. All blue and grey hydrogen in the model is produced using gas.

FIGURE 2.11: Hydrogen production routes considered in the Australian Industry ETI analysis

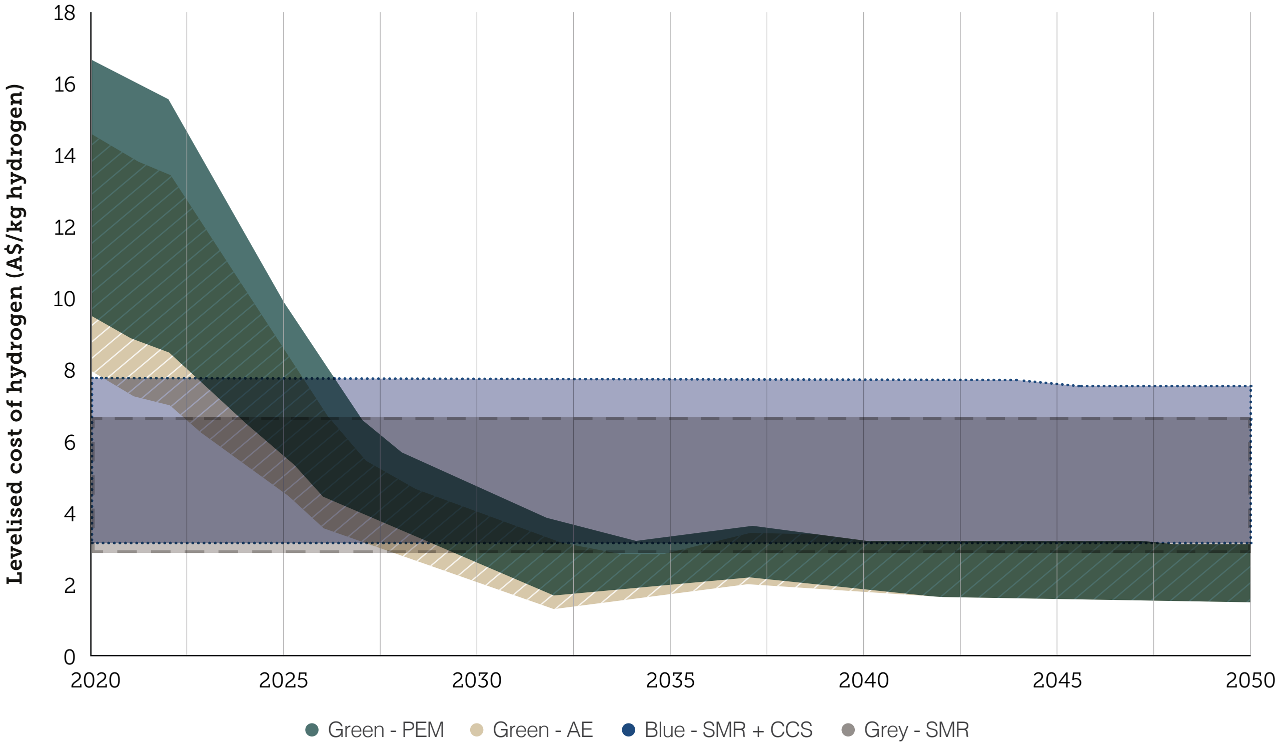


Hydrogen could play an important role in Australia's industrial decarbonisation, acting as both a fuel and chemical feedstock for industrial processes. It will be especially important in instances where electrification is not technically possible or is cost prohibitive. Hydrogen is also an emerging energy storage solution. Using the flexibility provided by electrolyser-based production, hydrogen can be ramped up when electricity supply is high and ramped down during periods of low electricity supply. The hydrogen can then be used as a direct combustion fuel or used in hydrogen fuel cells to generate electricity.

The cost of green hydrogen currently prohibits its widespread uptake. However, analysis by CSIRO, in partnership with the Australian Industry ETI, shows that the cost of green hydrogen (produced via AE or PEM) will start to decrease, becoming cost-competitive with grey and blue hydrogen by the mid-2030s (Figure 2.12). This result may be affected by the current context of extended periods of high gas prices, potentially lowering the cost-competitiveness of blue and grey hydrogen and making green hydrogen more attractive.

To evaluate the effects of gas prices on hydrogen, we conducted a sensitivity study for the 'Coordinated action scenario' in which varying elevated gas prices are assumed in the National Energy Market (NEM) (east coast) states. This showed that the lowest cost production of hydrogen is highly sensitive to the relative cost of green, blue or grey hydrogen, and affects the year that it becomes cost-competitive. This is discussed later in Information Box 2.04.

FIGURE 2.12: Levelised cost of hydrogen in NEM states in the 'Coordinated action scenario'

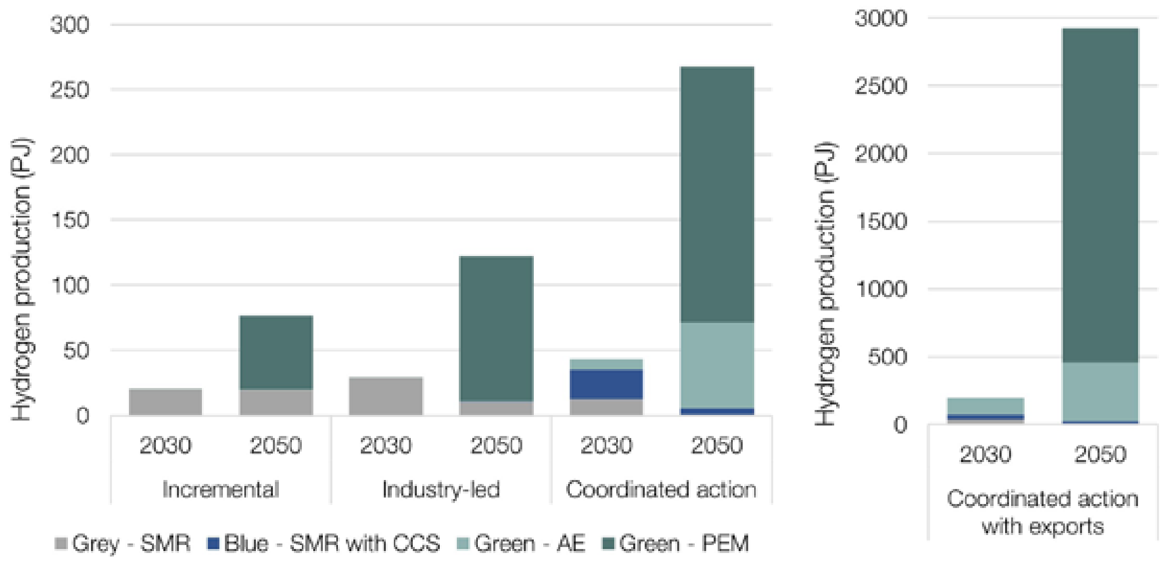


As the cost declines, green hydrogen uptake occurs in 2030 in the 'Coordinated action scenario' with an initial preference for AE (Figure 2.13). By 2050, almost all hydrogen is produced via electrolysis, with PEM being the dominant production route owing to the convergence of AE and PEM capital investment and a slightly higher load flexibility of PEM.[18] To achieve emissions reductions in line with a 1.5°C pathway across Australia, the 'Coordinated action scenario' shows that demand for hydrogen could be as high as 268PJ/year (2.2 million tonnes) in 2050, two and three times more than what's needed in the 'Industry-led' and 'Incremental' scenarios respectively (see Information Box 2.02). Most of this is produced through electrolysis (PEM: 197PJ/year and AE: 65PJ/year) with a small contribution from steam methane reforming with CCS (5PJ/year). Establishing new export markets for green hydrogen and green iron, while maintaining a 1.5°C trajectory, could require 2924PJ (24 million tonnes) of hydrogen in 2050 as shown by the 'Coordinated action with exports sensitivity'.

18 Alkaline electrolysers currently require lower investment than PEM electrolysers. The modelling uses GenCost projections which assume a convergence in the investment needed between the two technologies. The modelling does not presume a specific PEM type and does not allow for alternative PEM technologies to emerge which use less costly raw materials. Given similar investment requirements assumed in the long run, the model selects the PEM technology on the basis of it having slightly better flexibility in terms of ramping down demand if needed. If AE is able to maintain its cost lead or improve its ramping capability it could maintain its lead over PEM into the long term.

FIGURE 2.13: Hydrogen production in the Australian Industry ETI scenarios

(Note: axes are different scales)



INFORMATION BOX 2.02

Scaling hydrogen: A petajoule explained

One joule is equivalent to one watt of power delivered for one second. A petajoule is equivalent to one million billion joules (1,000,000,000,000,000 joules) (Energy.gov.au 2016).

This is the same as:[19]

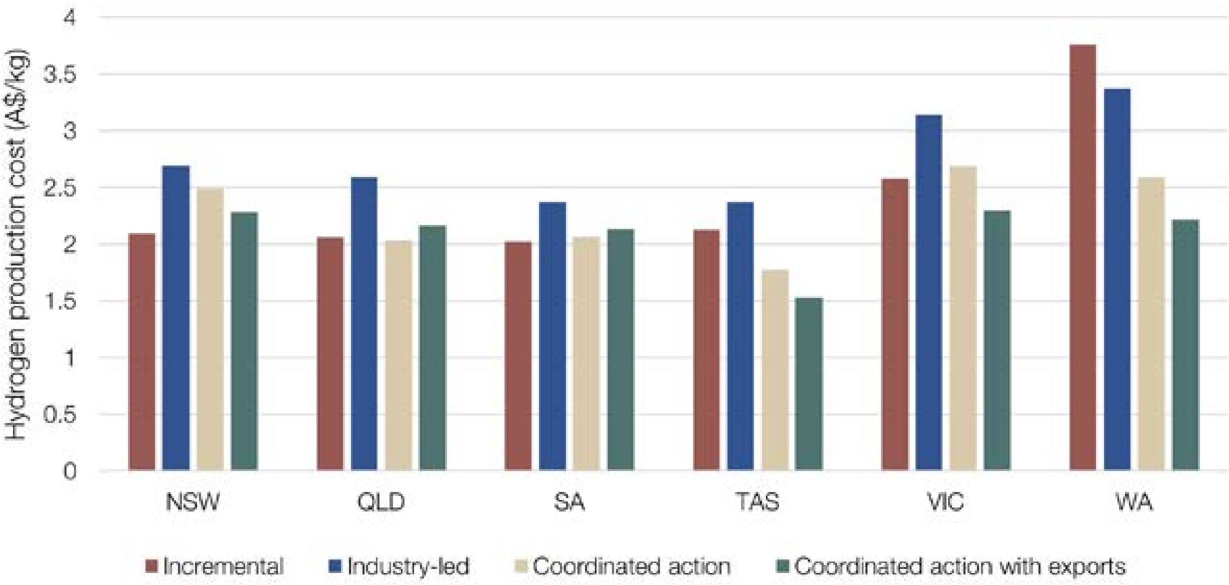
- filling a 55 litre petrol tank 533,000 times
- powering 45,725 houses for 1 year
- powering 868,750 televisions for 1 year

The scale of hydrogen needed in the 'Coordinated action scenario' is therefore the same as filling a 55 litre petrol tank 143 million times (or 1.5 billion times for the 'Coordinated action with exports sensitivity').

19 Assuming a 55 inch television consumes 320KWh per year and the average household consumes 22 GJ of electricity based on 2018-19 data.

Green hydrogen production costs vary between scenarios and regions of Australia (Figure 2.14). On average, the cost of green hydrogen is highest in the 'Industry-led scenario' (A$23.0/GJ or A$2.8/kg) followed by 'Incremental' (A$22.0/GJ or A$2.6/kg) and 'Coordinated action' (A$19.0/GJ or A$2.3/kg) scenarios. In the 'Coordinated action scenario', the cost of green hydrogen is cheapest in Tasmania (A$15.4/GJ or A$1.8/kg) and highest in Victoria and Western Australia (A$22.2/GJ or A$2.7/kg).

FIGURE 2.14: State-level green hydrogen production costs in 2050



As mentioned previously, an emerging strategy for minimising renewable electricity storage is to use the flexibility provided by electrolyser-based hydrogen production to allow electricity demand to partially follow changes in supply from variable renewable energy generation. However, if a hydrogen electrolyser is ramped up and down too often it means that the hydrogen production facility will have to include more hydrogen storage on their site to ensure it can supply a steady rate of hydrogen production to its offtakers in industry.

Hydrogen storage costs, at the scale expected to be required, are uncertain but are likely to decline over time. Hydrogen can be stored in pressurised tanks, cryogenic liquid hydrogen storage, or in geological features such as salt caverns or depleted oil and gas fields. Pipelines can also be considered as hydrogen storage solutions; however, hydrogen-compatible transmission pipelines would be required. In all cases, hydrogen leakage poses risks so should be carefully monitored and avoided (Derwent et al. 2006) (Information Box 2.03).

INFORMATION BOX 2.03

While low-emissions hydrogen offers opportunities to decarbonise heavy industry, it also poses risks if not managed effectively

Hydrogen is a powerful tool to help decarbonise heavy industry both as a chemical feedstock and as a fuel. When burnt, hydrogen does not release any harmful emissions, but rather results in the formation of water. However, the chemical properties of hydrogen pose risks during its use, if not managed effectively.

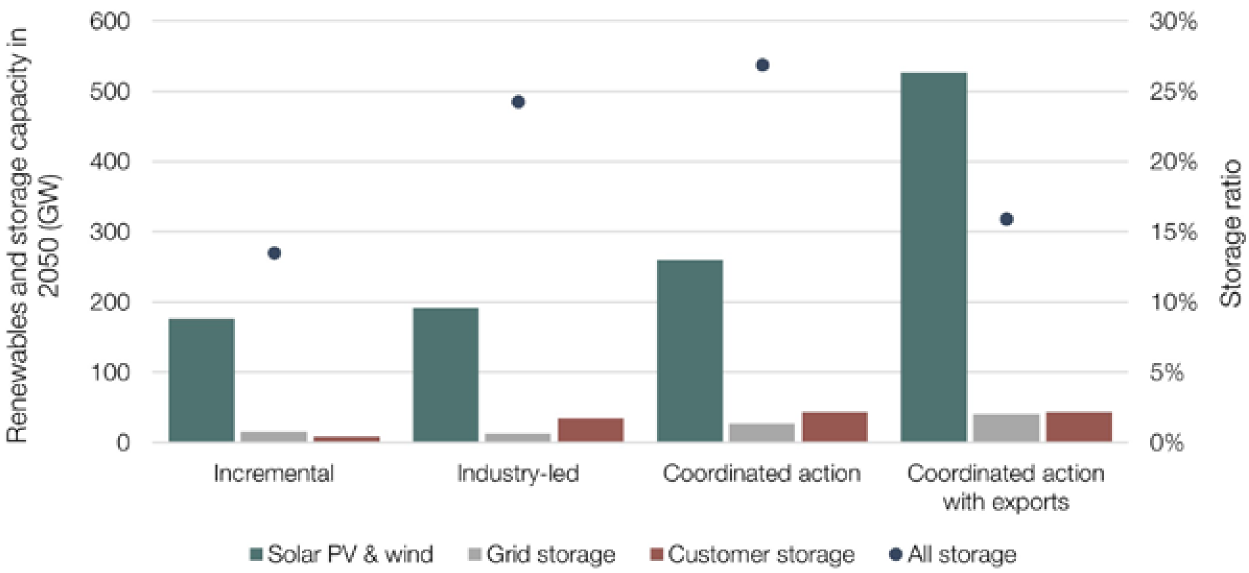
When released directly into the atmosphere, hydrogen can contribute to the accumulation of greenhouse gases such as methane, water vapour, and ozone and can therefore be considered as an indirect greenhouse gas (Derwent et al. 2006). In fact, studies estimate that hydrogen could be 11 times more potent than CO_2 as a greenhouse gas (Warwick et al. 2022). Hydrogen leakages during production, transport, and storage must therefore be minimised through engineering solutions and careful monitoring and reporting standards.

Ensuring cost-competitive, low-emissions electricity is available

With widespread uptake of electrification technologies seen in the 'Coordinated action scenario', ensuring access to cost-competitive, reliable, low-emissions electricity will be a critical driver of decarbonisation. The key to affordable electricity is minimising renewable integration costs including storage, transmission and system security. Transmission investment is difficult to avoid, with co-locating renewable energy generation with end-users as the main opportunity to lower the investment needed. Long and short-duration storage is required to ensure a reliable supply of renewable energy. Customer-owned storage (home batteries and vehicle-to-grid), large-scale batteries, pumped hydro and hydrogen are key storage resources.

Storage requirements increase with renewables share. For the 'Coordinated action scenario', with a 100 per cent share of renewables by 2050, a storage proportion of 27 per cent is needed (i.e. 70GW of storage is needed for 260GW of renewable energy capacity) (Figure 2.15). The lower penetration of renewables in the 'Incremental' and 'Industry-led' scenarios mean that only 14 and 24 per cent storage ratios are needed, respectively. The increased load flexibility in the 'Coordinated action with exports sensitivity' (due to higher rates of hydrogen production) requires only a 16 per cent storage ratio despite high renewables penetration.

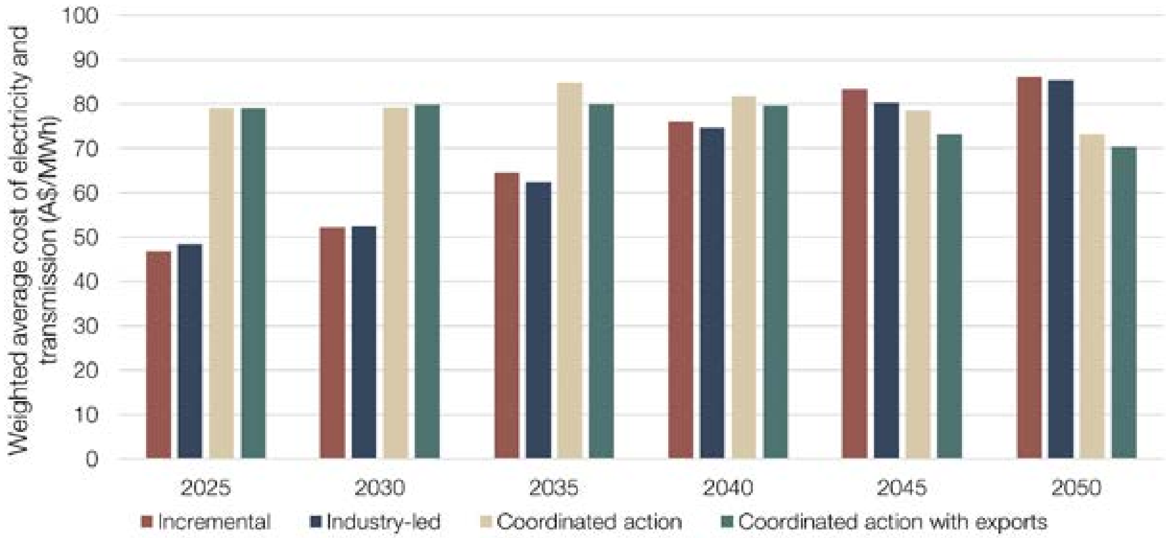
FIGURE 2.15: Storage capacity requirements in 2050 relative to renewable capacity



The 'Coordinated action scenario' leads to the lowest average cost of electricity in the long term, despite more widespread decarbonisation and greater shares of renewables penetration (Figure 2.16). There is, however, a relatively higher electricity price in the near term due to faster deployment of storage and transmission compared to other scenarios. Although the price is higher in the 'Coordinated action scenario', it is considerably lower than many of the prices seen in 2022. In Q2 2022, the average NEM wholesale spot price was A$264/MWh (AEMO 2022b). Renewable energy prices are less subject to fluctuations in fuel costs.

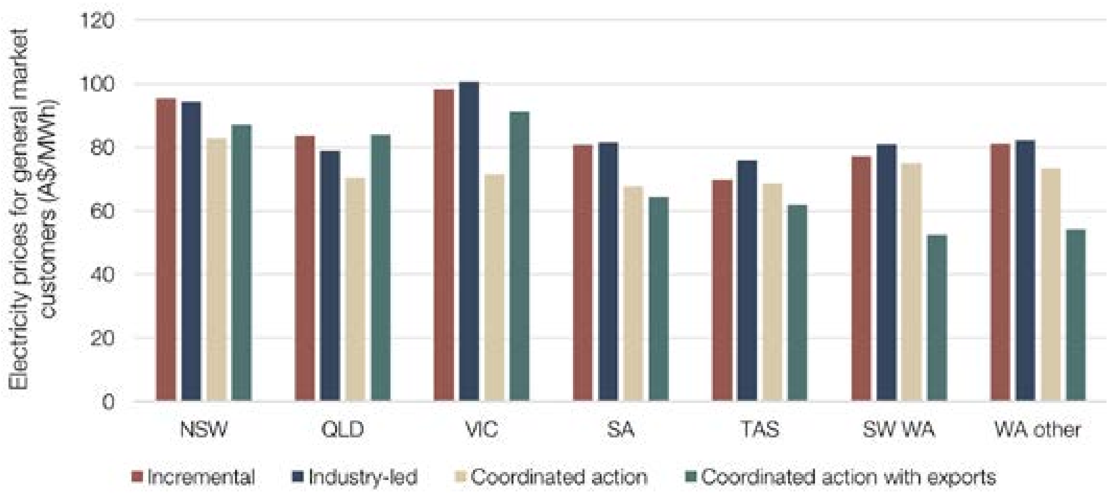
Over the long term, cost savings in the 'Coordinated action scenario' arise from the integration of customer-owned storage and load balancing from a large-scale hydrogen industry. Customer-owned storage sees greater deployment compared to grid storage due to stronger investment incentives. For grid storage, the cost difference is only between high and low wholesale prices, whereas the difference between retail prices and solar costs is much greater.

FIGURE 2.16: Weighted average cost of electricity and transmission over time



Electricity costs will vary across states and customer segments. General market customers benefit from increased participation of customer storage resources and higher levels of flexible electrolyser loads. New South Wales and Victoria have the highest electricity cost, reflecting higher transmission expenditure due to their geographic position in the NEM (Figure 2.17).[20] Limited access to pumped hydro in Western Australia means storage costs are higher, leading to higher general market electricity prices than most states in the 'Coordinated action scenario'.

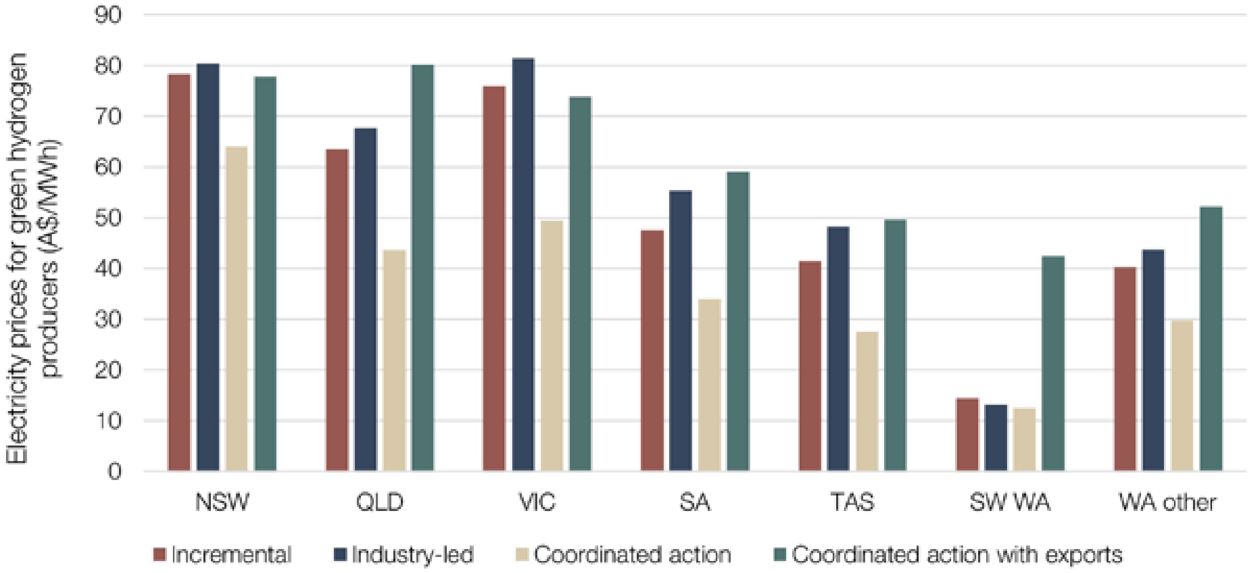
FIGURE 2.17: Electricity prices for general market customers in 2050



20 Transmission costs in the electricity cost calculations because of their key role in enabling efficient renewables deployment. In practice transmission costs are recovered separately from wholesale electricity charges.

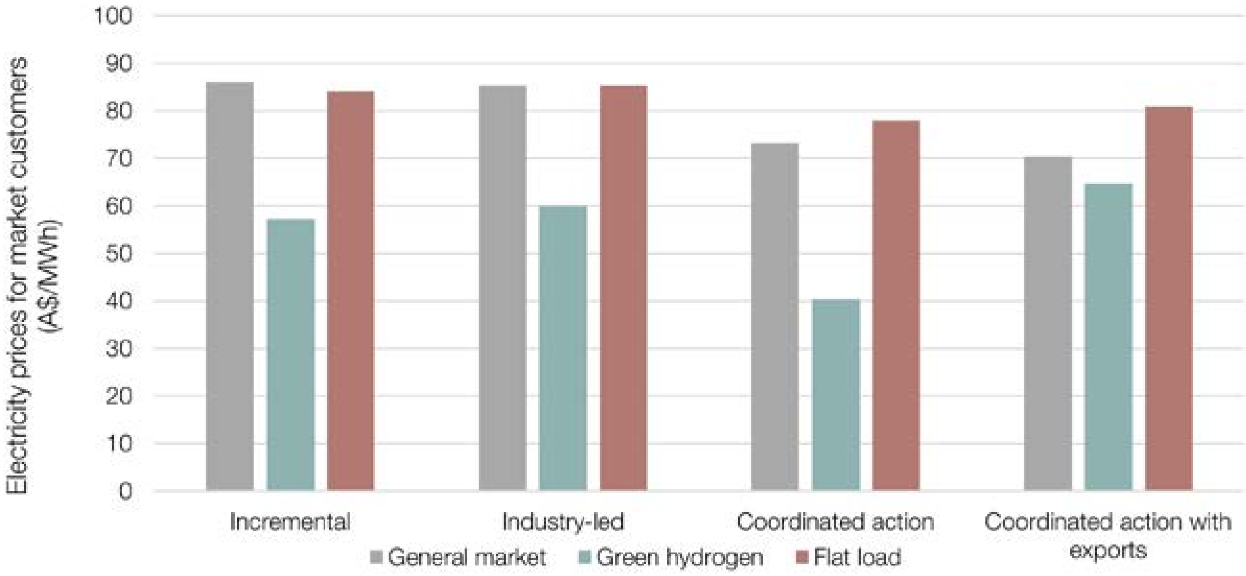
Green hydrogen producers could reduce their exposure to high electricity price periods by using their load flexibly to produce hydrogen when the cost of electricity is low, and ramp down hydrogen production when electricity costs are high. However, due to our assumed costs for hydrogen storage, in the modelling results, hydrogen electrolyser facilities still run at high capacity factors of around 80 per cent. If hydrogen storage were to cost less than expected, it could be least cost to run electrolysers at a low capacity factor to match their production to renewable supply profiles. This low capacity factor approach would increase the capital component of the levelised cost of hydrogen but would be offset by lower energy costs. The resulting moderate level of ramping resulted in electricity costs of between A$12-64/MWh compared to A$68-83/MWh for general market customers in the 'Coordinated action scenario' (Figure 2.18). Dis-economies of scale are seen in the 'Coordinated action with exports sensitivity' (compared to the 'Coordinated action scenario') as more distant renewable resources are required to meet the increased demand for hydrogen. This finding is significant in the current context of the existing natural gas sector experiencing an extended period of high prices due to high export demand. This finding also leads to the consideration of the importance of developing and prioritising the domestic hydrogen market before exports, to ensure the competitiveness of local industries that will rely on hydrogen for their decarbonisation.

FIGURE 2.18: Electricity prices for green hydrogen producers in 2050



While industries such as hydrogen production have some flexibility in their demand, allowing for ramping down of production for many hours or even days, the flexibility of other industries such as aluminium smelting or steel production is more limited. These industries require a stable, constant supply of electricity – known as a flat electricity supply. In Australia, this has typically been met by coal-fired generation or hydroelectricity. There are no major new sources of hydropower available in Australia and coal-powered plants are ageing, with many retiring in coming years (Government of Western Australia 2022b). With the switch to renewable generation, the cost of a flat electricity supply will increase due to the capital investment required in storage, whereas existing supply relies on coal-powered plants whose capital expenditure has already been incurred. Consequently, flat loads will pay a premium of around A$3/MWh on average compared to general market customers (Figure 2.19).

FIGURE 2.19: Electricity prices for different customer segments in 2050



While this presents a challenging environment for industries requiring flat loads, it is a common problem that will be faced globally by heavy industries making the transition from fossil fuels to variable renewable energy. The challenge for Australia will be to produce renewable electricity for heavy industry at or below the cost incurred by other countries (see section 2.3 for further discussion).

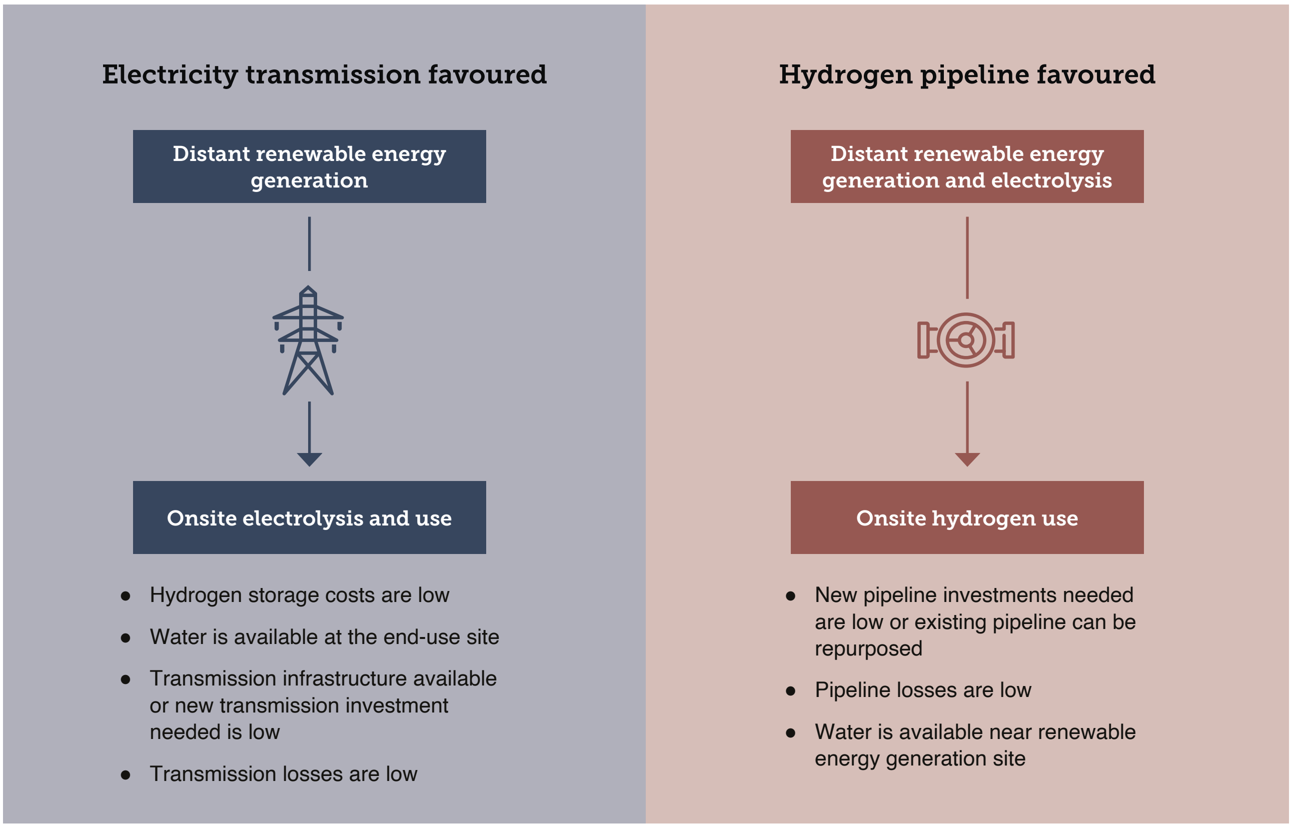
The transition will require the build-out of energy system infrastructure

A transition to a zero-emissions electricity system will require an expansive build-out of supporting energy system infrastructure including renewable generation, transmission and storage, as well as hydrogen production, transport and storage solutions. The development of this system needs to consider a range of regional factors such as existing infrastructure, skilled workforces, geography, distances between generation and use of energy (as well as water availability for green hydrogen production).

The optimal location of new electricity and hydrogen infrastructure will depend on a combination of complex factors that will also vary by region (Figure 2.20). If hydrogen storage is expensive, it may be most economical to produce hydrogen in a way that avoids the need for storage of high quantities. To achieve this, relatively flat loads of electricity may be required, to ensure consistent hydrogen production can be delivered to industry offtakers. In this case, it may be most economical to locate hydrogen production near industrial ports, with transmission infrastructure used to access distant renewable generation (Figure 2.20, left). It may also be advantageous to locate hydrogen production close to major cities, where lower electricity prices could be driven by the deployment of customer-owned storage as seen in the modelling results discussed previously.

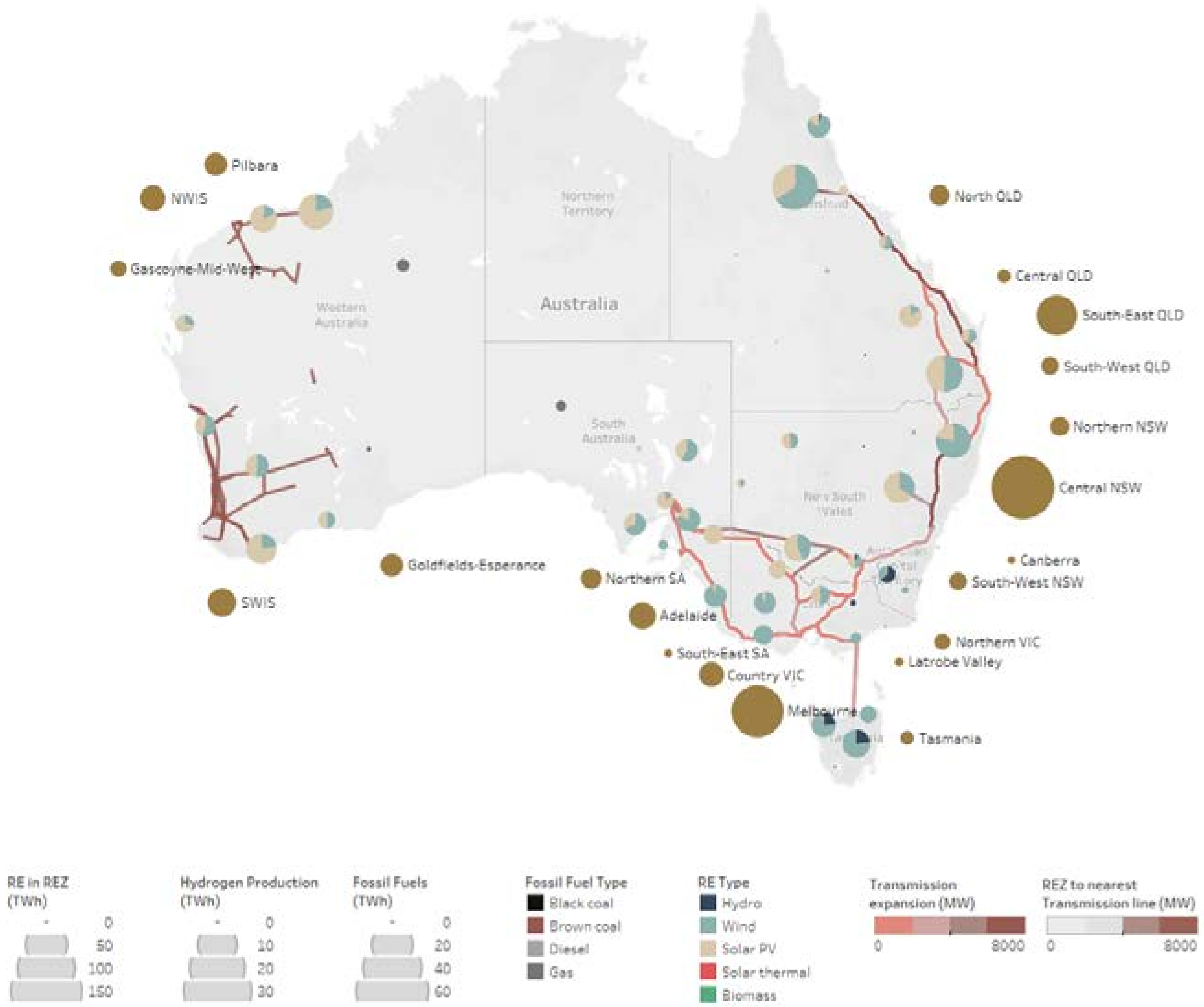
If hydrogen storage costs are low, it may be cheaper to store more hydrogen over electrical storage. If so, there may be more options to locate hydrogen electrolysis plants further away from capital cities in areas with better renewable generation. In this case, hydrogen transport options will be needed, including the use of pipelines, if the development of hydrogen-compatible pipelines requires little investment or if existing pipelines can be repurposed (Figure 2.20, right).

FIGURE 2.20: Potential drivers of green hydrogen production location and transport



The modelling results show a relatively strong preference for locating hydrogen production close to capital cities (Figure 2.21). This may reflect the importance of access to lower-cost, firmed renewable electricity (capable of producing a flat supply) through customer-owned storage, access to a skilled workforce, water and bulk material handling ports. The east coast of Australia has many established bulk commodity ports and these are the most likely centres of activity. This particularly applies to coal exporting ports that may be looking to diversify their industry over time as coal exporters face a likely declining world market. On the west coast where there are fewer existing bulk commodity ports, this opens the possibility of new, dedicated port facilities being developed to maximise access to key energy resources.

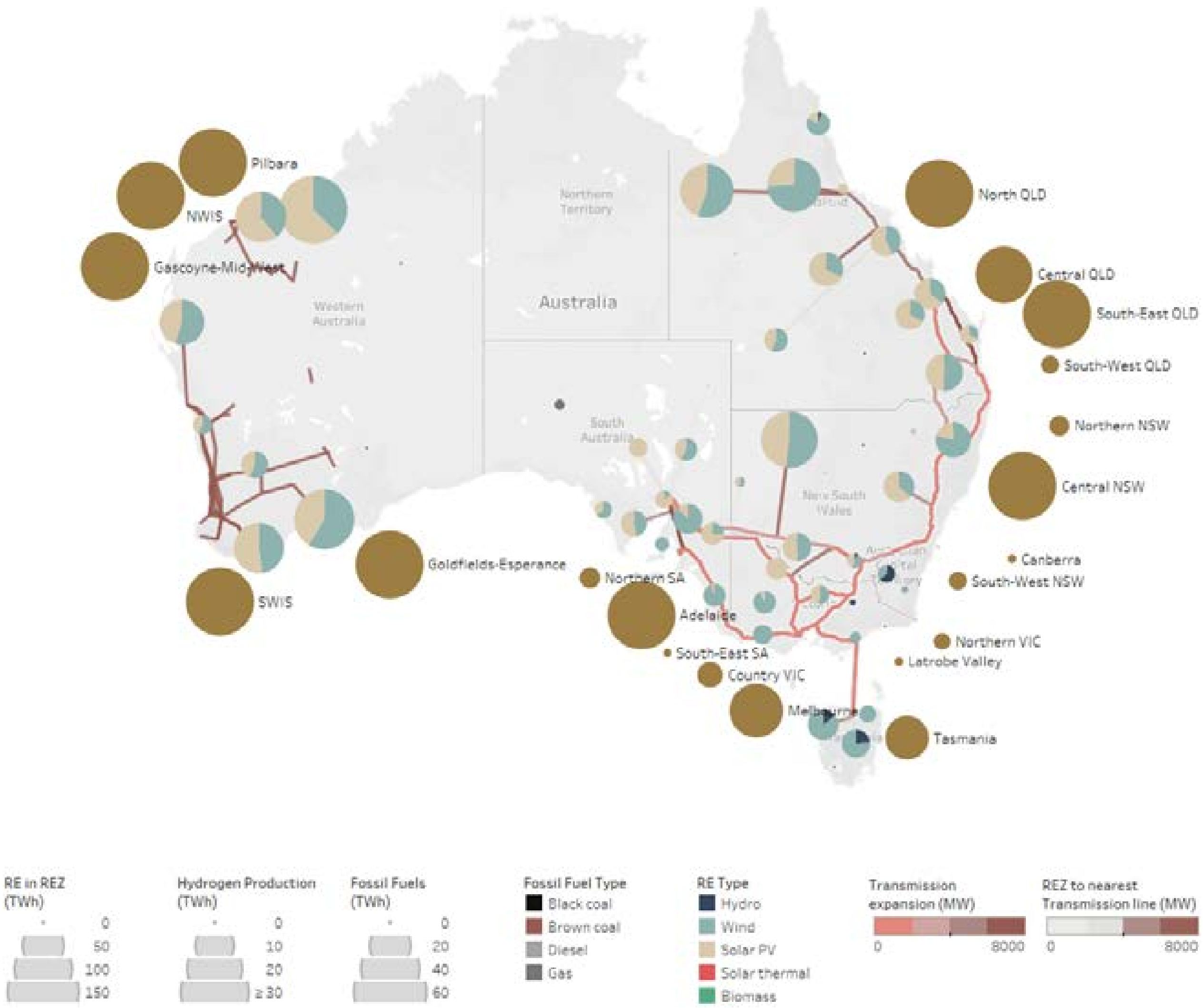
FIGURE 2.21: Model findings for hydrogen production locations in the 'Coordinated action scenario' in 2050.



The brown circles represent the amount of hydrogen production in each region. Hydrogen circles are placed outside the map for clarity, but refer to areas labelled.

The high demand for hydrogen in the 'Coordinated action with exports sensitivity' shows that all locations for hydrogen production will need to keep pace with the scale of production (Figure 2.22). After capital cities, a preference for north Queensland, Tasmania, and Western Australia locations is seen.

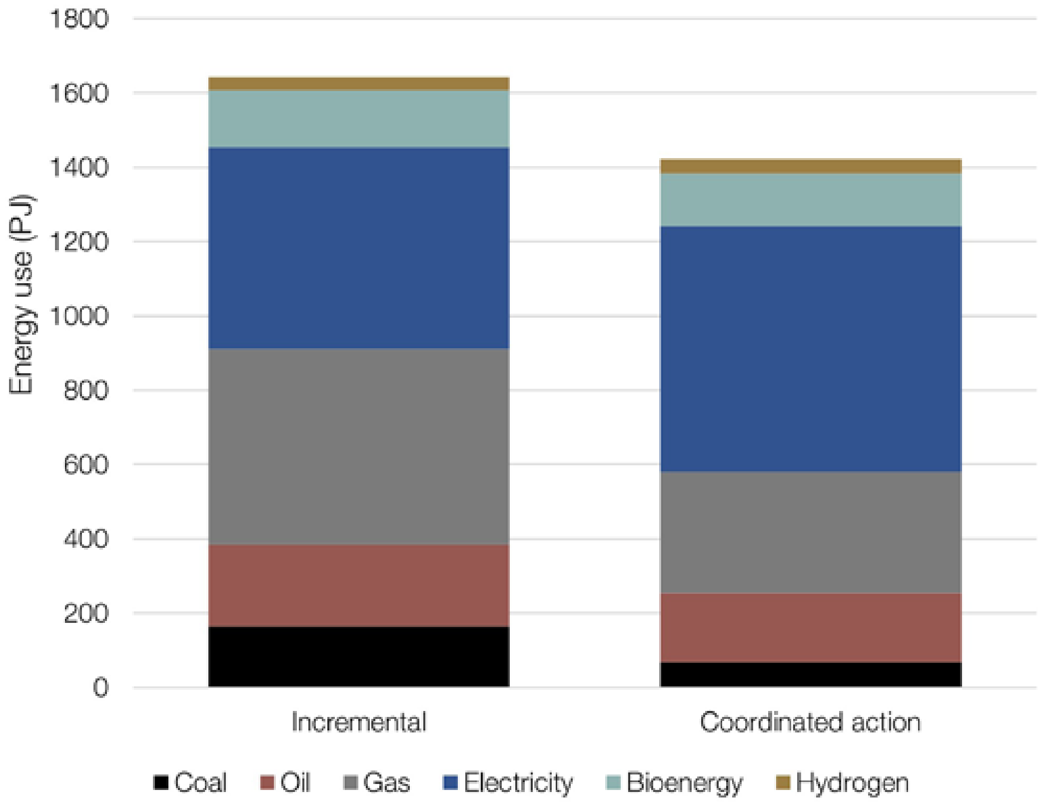
FIGURE 2.22: Model findings for hydrogen production locations in the 'Coordinated action with exports sensitivity' in 2050



Adding to this complexity are questions around the overall role of hydrogen in energy system planning. The model principally considers that demand for hydrogen will be for applications where there are few alternatives to fossil fuels – such as in high heat industrial processes and in heavy transport. In some situations, however, there could be a preference for hydrogen simply as a method of transporting energy – for example, pairing offshore wind generation with electrolysers to transport energy as hydrogen, rather than via electricity transmission lines. This could require additional pipeline infrastructure into industrial regions and a lower-than-predicted need for renewable electricity generation in proximity to those industrial regions.

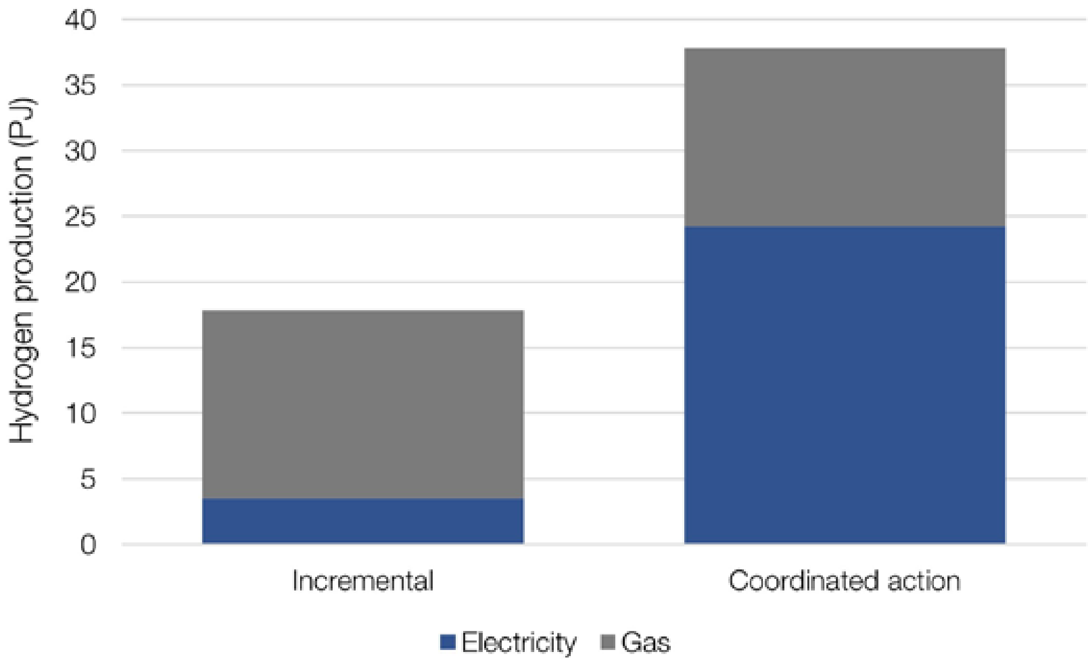
Industrial energy needs depend on the technologies available, but they are also dependent on the policy environment. Differences seen between the 'Incremental' and 'Coordinated action' scenarios are the result of both economy-wide trends and decision-making by industry. Under the right conditions, industry could make a much larger shift towards electricity consumption and away from gas (Figure 2.23), but it can only do so if energy sources are available in the most appropriate locations. Likewise, gas, hydrogen and electricity transmission are unlikely to be built in the most appropriate locations without the expectation of more demand. This could result in a mismatch between the proportion of gas and electricity needed to meet industry's emissions reduction ambitions and the energy supply available.

FIGURE 2.23: Australian industrial energy needs in 2030 under two scenarios



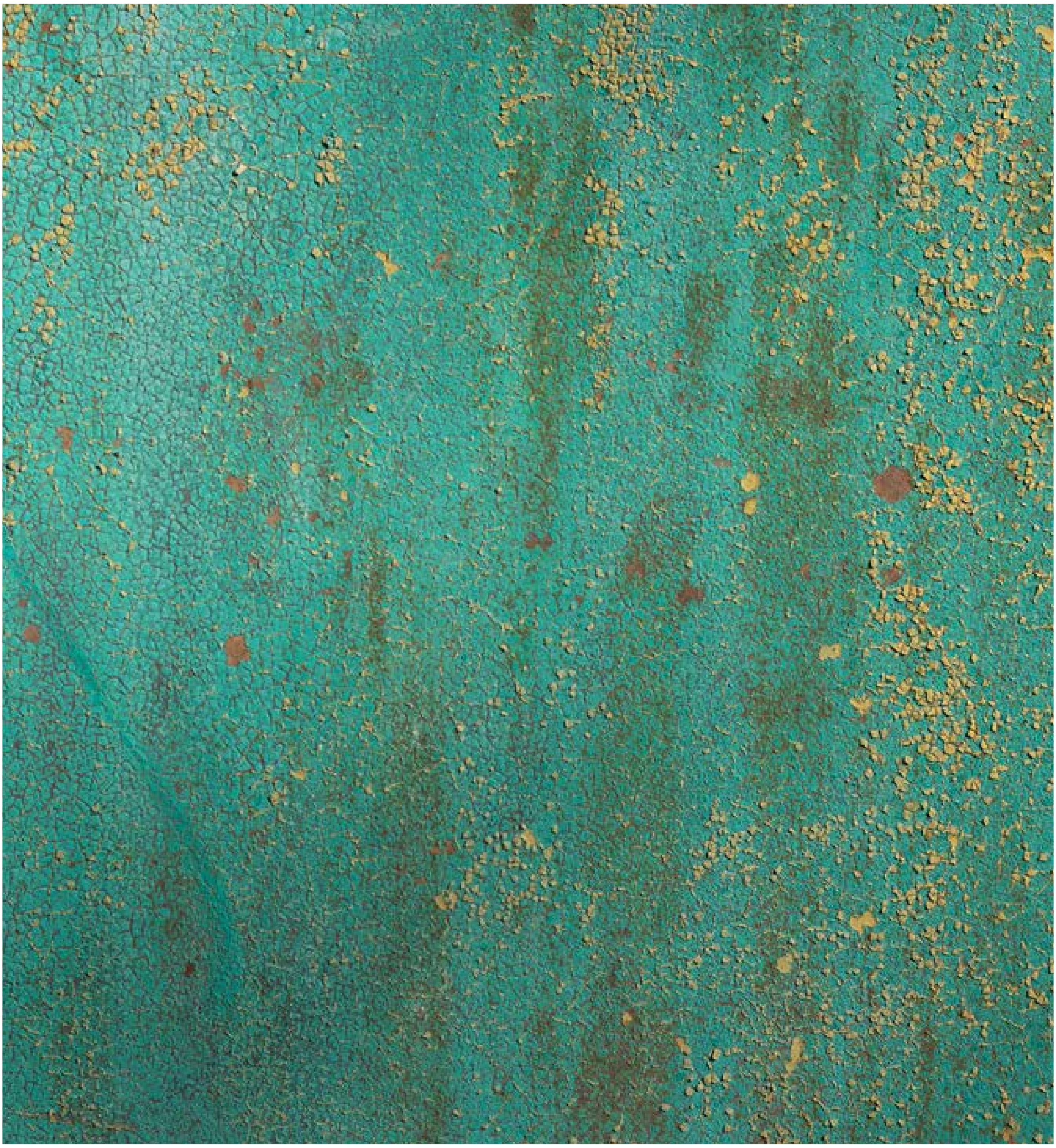
These differences become even more distinct at a regional level. A comparison of two scenarios at a point in time reveals a significant difference in fuels needed for hydrogen production in the South West Interconnected System (SWIS) (Figure 2.24). Less hydrogen is produced overall in the 'Incremental scenario', and more gas is used.

FIGURE 2.24: Amount of hydrogen produced (PJ) using gas or electricity in the SWIS in 2040 under two scenarios



The complex interplay of regional factors that are likely to affect energy system infrastructure developments will require robust system planning and precinct-level analysis to design the most efficient energy system. Precinct-level analysis will be better able to define the key inputs, such as whether renewable energy production zones are nearby or distant, existing electricity storage resources, existing transmission connections and terrain to be covered by possible pipelines.

AEMO's Integrated System Plan (ISP) is helping to define the transmission connections that are needed along with timing for their deployment in alternative scenarios for electricity system transition, including for a 1.5°C world (AEMO 2022a). The ISP also provides clarity on likely renewable energy zones, their capacity and transmission connection investment. Western Australia's Whole of System Plan (WOSP) suggests how Western Australia's SWIS might look in coming decades across four scenarios of changing demand and technology, in order to help guide investments in the electricity system (Government of Western Australia 2022a). To meet the needs of a changing energy landscape, the scope of the ISP and WOSP could be expanded to support more holistic infrastructure planning, including pipelines to support the energy transition. Detailed energy system and infrastructure planning studies, coordinated between industry and energy planners in key regions, could enable AEMO (or another body) to integrate industry's future energy needs into the ISP and WOSP.



INFORMATION BOX 2.04

Industrial pathways are sensitive to gas prices

International sanctions on Russian gas in response to their invasion of Ukraine, extreme weather events, and a lack of investment in other energy sources internationally has driven increases in liquid natural gas (LNG) prices and exports from Australia to the Asia-Pacific region. This has pushed much higher netback prices for natural gas[21] on the east coast in Q2 2022 (Australian Competition and Consumer Commission [ACCC] 2018). AEMO reported that average wholesale gas prices on the east coast were $28.4/GJ in Q2 2022 compared with $8.20 in Q2 2021 (AEMO 2022b).

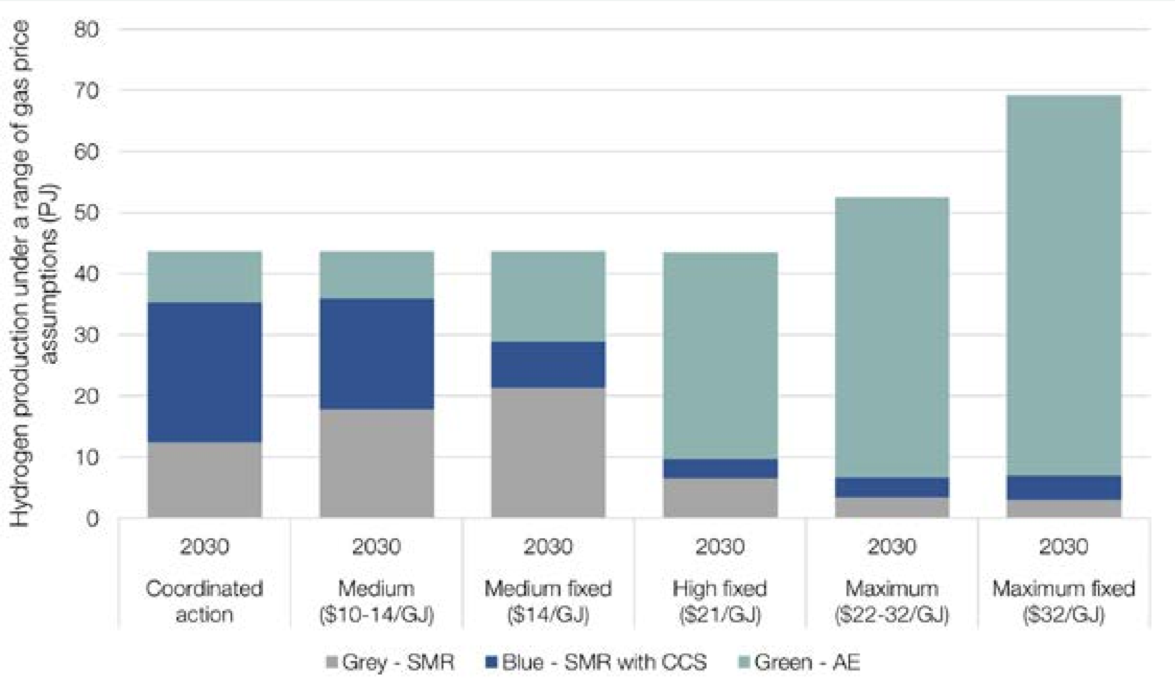
Large industrial gas users are usually insulated from high wholesale prices as they have long-term contracts with suppliers. However, changes in gas prices can impact the prices offered in contracts, and commercial and industrial customers have also expressed concern at high contract prices (ACCC 2022). Both incumbent and transition technologies may use high quantities of natural gas. To investigate the impact of gas prices on the 'Coordinated action scenario', a sensitivity analysis was conducted. The 'Coordinated action' prices, which are relatively low, were contrasted with medium, high and maximum prices, and either a variable or flat rate.[22]

The results of the analysis showed significant changes, particularly in iron and steel (see chapter 3 'Focus on iron and steel') and aluminium supply chains (see chapter 4 'Focus on aluminium').

The costs of blue and grey hydrogen are highly sensitive to gas prices. In the 'Coordinated action scenario', in 2030 most hydrogen is produced with gas. As the gas price increases, more green hydrogen (which uses electricity) is produced (Figure 2.25). The increase in production seen under 'maximum' gas prices may be due to the more rapid deployment of hydrogen technologies instead of gas-powered transition technologies.

It is important to note that the model has 'perfect foresight', meaning that it knows what the price of gas will be in the future and is able to optimise investment decisions.

FIGURE 2.25: Quantities and types of hydrogen produced in 2030 under different gas prices



21 LNG netback prices are based on Asian LNG spot market prices. This is intended to represent the price that a gas supplier would expect to receive if selling to a domestic gas buyer compared with exporting gas as LNG.

22 See the companion technical report for details on inputs and assumptions into the gas sensitivities

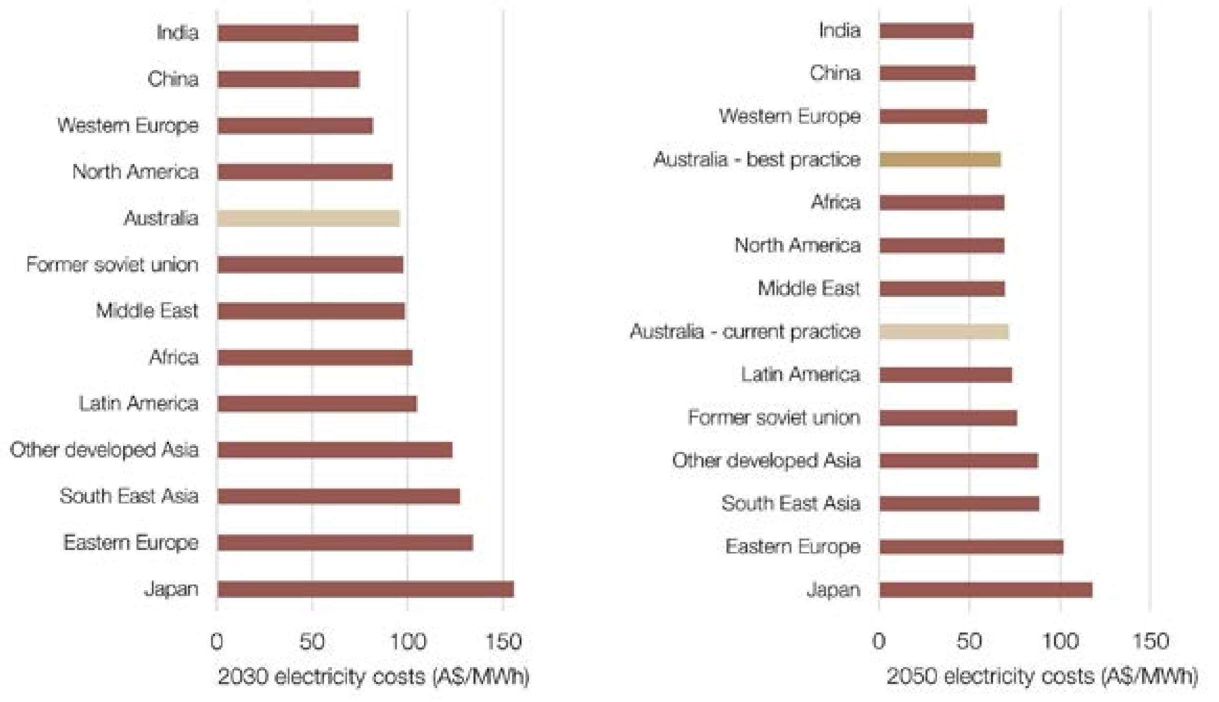
2.3 Australia is one of the better placed economies set to benefit from a global energy transition

Australia has abundant renewable energy resources including sun, and wind and extensive land area, all of which are limiting factors for other regions such as Japan and Europe. Capitalising on these renewable energy resources, a maximum of approximately 25,000GW of renewable energy capacity[23] could be installed in Australia, delivering about 86,000TWh of energy per year. This is well beyond what is required to achieve the scale of decarbonisation needed for either the 'Coordinated action scenario' or 'Coordinated action with exports sensitivity' (Climate Council 2014).

A comparison of global electricity costs for 24/7 industry supply shows that Australia could be in the lower third of global electricity generators in terms of low-cost electricity generation[24] by 2030 (Figure 2.26). This ranking reflects Australia's access to high quality solar and wind resources which overcomes the relatively higher investment needed in deploying generation technologies.

By 2050, the investment needed in technologies will fall further, particularly solar PV and battery storage, allowing countries with less access to wind and hydro power to improve their competitive positions. In this period of the transition it will be important for Australia to improve its global competitiveness in the installation of solar PV, wind and storage. As shown in Figure 2.26, if Australia's competitiveness in technology deployment remains the same as current practice, its ranking may slip to the middle, with Africa and the Middle East as key beneficiaries. However, through experience of deploying technologies more frequently and at larger scale, Australia may be able to match best practice in comparable Western countries. In this case, Australia could maintain or improve its ranking in electricity costs, helping to secure the competitiveness of electricity intensive industries.

FIGURE 2.26: Global electricity costs in 2030 and 2050



With its abundant renewable energy potential and skilled workforce, Australia is well placed to benefit from a global energy transition and establish itself as a producer and exporter of green energy and materials. Major opportunities exist for Australia to establish green iron and steel industries, green aluminium and green energy carriers such as ammonia and hydrogen – if an efficient renewable energy sector can emerge whilst decarbonising heavy industry and the broader energy system.

23 Including onshore and offshore wind, concentrating solar and solar photovoltaics, biomass and geothermal

24 This does not take into consideration transmission costs

2.4 Achieving the energy transition will involve challenges but these can be overcome

There will be significant short and long-term challenges to achieving an energy transition that supports the decarbonisation of heavy industry in Australia (Figure 2.27).

FIGURE 2.27: Challenges for the energy transition

Developing and utilising customer owned storage as a grid resource	**Deploying renewable energy technologies** while transitioning existing generators	**Integrating** hydrogen into the energy system	Developing the multi-GW **scale** of renewable generation needed

Developing multi-gigawatt scale renewable generation

The electrification of industrial processes and a switch from coal-powered generation to renewables require new renewable generation capacity exceeding Australia's current grid capacity. The 'Coordinated action scenario' shows that around 600TWh per year of electricity will be needed by 2050, if Australia is to limit warming to 1.5°C. Expanding into new green export markets while remaining within a 1.5°C carbon budget will require 1450TWh per year – an almost six-fold increase in Australia's current electricity generation. Meeting this demand with renewable electricity will require renewable generation developments at unprecedented, multi-gigawatt scales.

Industry looking to source new renewable capacity will either need to vertically integrate or find an electricity supplier large enough to offer a multi-gigawatt portfolio of renewable and storage capacity. Currently, there is a lack of electricity suppliers who could fulfill this scale of contracting in Australia. In addition, there may be supply chain considerations to ensure sufficient solar panels, wind turbines and other supporting grid infrastructure are available. Developing the scale of renewable energy projects needed could require investment of up to A$440 billion, including A$220 billion for generation and A$50 billion for storage. Developers will require an offtaker in order to finance the multi-gigawatt scale developments needed for the transition. Furthermore, grid infrastructure to support the connection of new multi-gigawatt scale renewable energy developments will be vital.

The existing grid was designed to connect coal and gas resources and is therefore not properly equipped for renewable resources. Major new transmission lines will be required to connect to new renewable energy developments. These will likely face social licence issues and require substantial investment. The Australian Industry ETI modelling shows that transmission costs become a larger share of energy system costs as ambition for climate action increases, as more distant renewable energy resources are needed to keep pace with the transition. In the 'Coordinated action scenario', 23 per cent of cumulative electricity system expenditure (between 2020 and 2050) arises from transmission (A$130 billion), contrasted against 13 per cent in the 'Incremental scenario' (A$62 billion). The scale of investment needed in transmission infrastructure to enable Australia to expand into new green export markets, as examined by the 'Coordinated action with exports sensitivity', could be as high as A$270 billion by 2050.

This scale of renewable energy developments will require vast amounts of land. Planning and development approval processes should include measures to ensure that environmental impacts of these projects are minimised. It should also include early and meaningful engagement with Traditional Owners for bilateral support in project development.

Transitioning existing generators

Existing coal-fired generators have sunk capital investments, allowing them to remain competitive even if not the lowest cost new-build generation technology. Coal powered plants cannot temporarily shut down at reasonable cost and must maintain minimum generation of between 30 to 50 per cent. Typically, when renewable generation is high, coal powered plants are forced to pay the market to continue generating. An increasing penetration of renewables in the electricity grid increases the hours per year where coal-powered plants are incurring such costs, and will likely result in faster than expected retirement of coal generators. A carefully planned transition to renewables will ensure Australia can maintain a reliable energy system and competitive advantages in the global market.

Utilising customer-owned storage

Projections by AEMO indicate that the future capacity of customer-owned storage, in the form of home batteries and electric vehicles, is likely to exceed conventional large-scale storage such as pumped hydro and grid-scale batteries. AEMO ISP modelling suggests that by 2050, approximately 31GW of storage capacity will be provided by customer-owned storage compared to 16GW provided by pumped-hydro and utility-scale batteries (Australian Energy Market Operator 2022a). Utilising customer-owned storage has the potential to reduce electricity supply costs relative to building new, large-scale storage if considered as a grid resource. Integrating customer-owned storage into current market systems as virtual power plants faces barriers to becoming a forecastable and dispatchable resource without changes to operational behaviour, control methodology and incentives for following forecast schedules (AEMO 2021).

Integrating hydrogen into the energy system

As discussed previously, hydrogen will play an important role in the decarbonisation of heavy industry, acting as a fuel, chemical feedstock and energy storage solution. Robust hydrogen supply chains will need to be integrated into Australia's current energy system, requiring the build-out of hydrogen production, storage and transport facilities.

With the 'Coordinated action scenario' showing electrolysis as the cheapest form of hydrogen production in the long-term, co-optimising renewable electricity and hydrogen supply chains is necessary but complex, with numerous regional factors affecting where new energy infrastructure should be built. Robust system planning will be needed to ensure Australia designs an efficient energy system. This should take into consideration the complex interplay between electricity and hydrogen in a changing energy landscape.

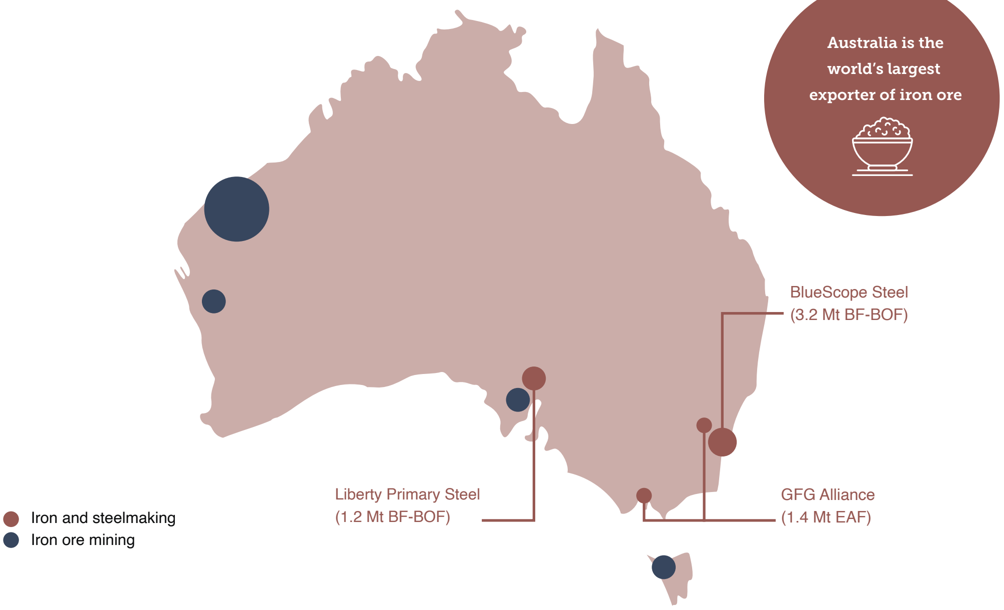
3. Focus on iron and steel

Steel is a key material in buildings, infrastructure and consumer goods. Steel shapes our homes, our cities, our transport and our industries. Globally, 1.9 billion tonnes of steel are produced every year, requiring 2.4 billion tonnes of iron ore (IEA 2020; Natural Resources Canada n.d.). By 2050, global steel demand is forecast to grow by a third to support growing populations and increasing urbanisation, and as a critical material to support the clean energy transition (IEA 2020).

For every tonne of crude steel produced, 1.4 tonnes of direct CO_2 emissions (scope 1) and 0.6 tonnes of indirect CO_2 emissions (scope 2) are released on a sectoral average basis. In 2020, the global iron and steel industry was responsible for around 3.1GtCO_2e, equivalent to 7 per cent of annual global greenhouse gas emissions (Mission Possible Partnership 2022). Steel production's large share of global emissions is due to the role of fossil fuels – such as coal – for energy and as a reductant during production (Hoffmann et al. 2020; IEA 2020). Secondary steel production – that is steel produced from recycled scrap – requires around one-eighth of the energy needed for primary steel production. However, producing steel through recycling alone is not sufficient to meet global steel demand due to limited scrap availability which will be exacerbated as steel demand increases and steel products are locked into long-lasting infrastructure projects (IEA 2020).

Overcoming the technological and commercial challenges of decarbonising iron and steel supply chains – high emissions intensity of primary steelmaking, limited steel scrap availability, and forecasted increases in demand – will be critical to achieving Paris Agreement goals.

Iron and steel in Australia



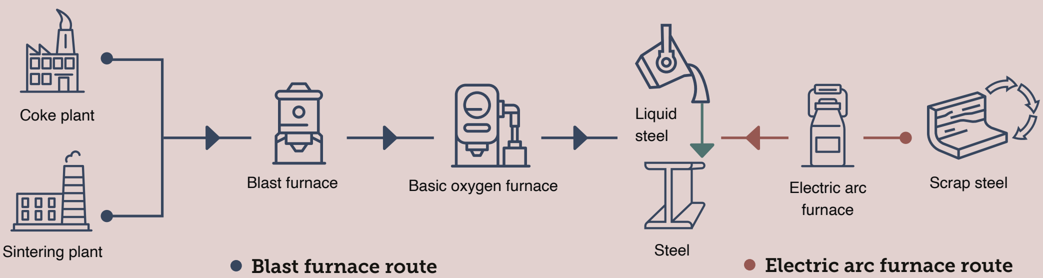
Australia is the world's largest exporter of iron ore

up to 105k jobs across the supply chain

913 Mt of iron ore produced, generating **A$153 b** in exports. **5.7 Mt** of steel produced for the domestic market

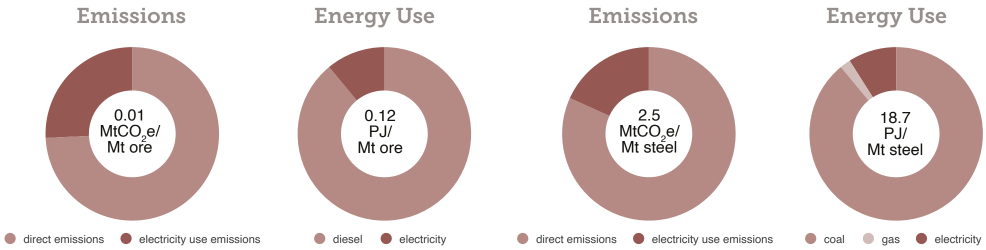
approximately **24MtCO_2e** emitted each year

Current iron and steel manufacturing occurs via blast furnace and electric arc furnace routes



Mining and Haulage

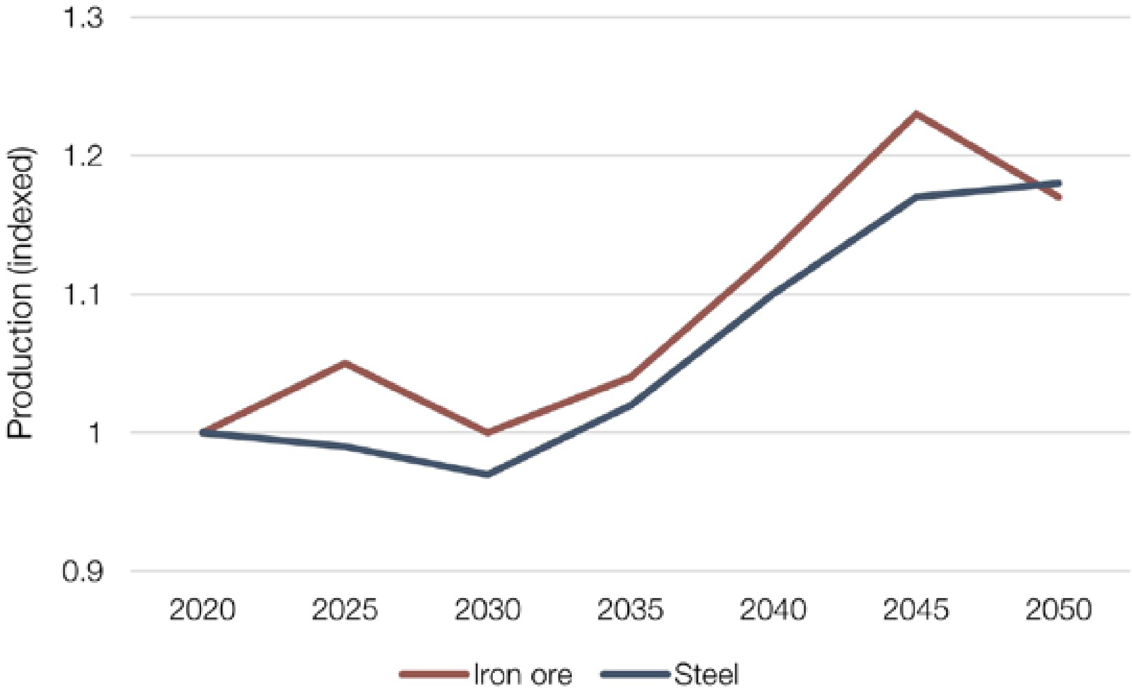
Iron and Steelmaking



3.1 Iron and steel production assumptions

The Australian Industry ETI modelling explores different production outlooks for iron ore and steel. The 'Coordinated action scenario', with a 1.5°C carbon budget, assumes that demand for iron ore and steel from Australia grows in line with projected global demand growth between 2020 and 2050 (Figure 3.01).[25] In line with scenario narratives, the greater emissions reductions achieved in the 'Coordinated action scenario' allow Australia to improve its competitiveness in a decarbonising world and expand its production.

FIGURE 3.01: Assumed relative production changes in Australia under the 'Coordinated action scenario' (Australian Industry ETI analysis based on (BloombergNEF 2021b; Department of Industry, Science, Energy and Resources 2021c)[26]



3.2 Technology deployment timeline

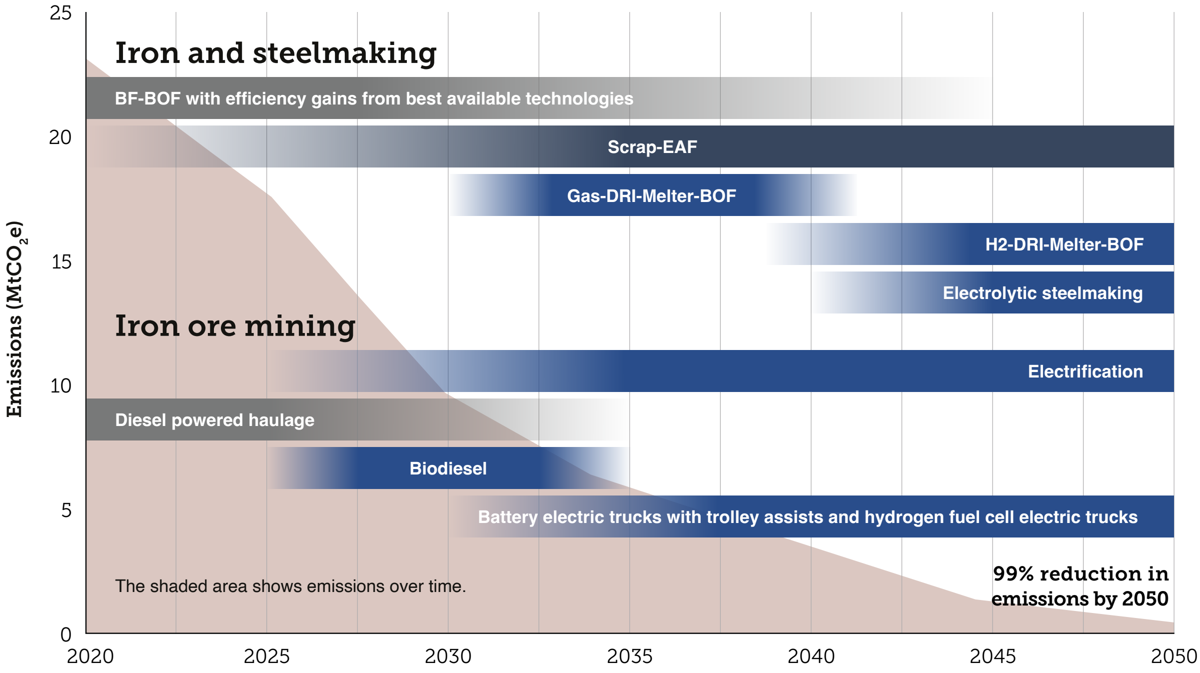
The 'Coordinated action scenario' shows what could be done to grow or maintain the iron and steel supply chain, in line with a 1.5°C carbon budget for the whole Australian economy, by developing and deploying a range of technology solutions as shown in Figure 3.02. This chart shows the timeline of implementation that the model finds to be the least-cost pathway, based on technology assumptions and other changes across the Australian economy.[27] The Australian steelmaking industry is dominated by two large integrated plants in Port Kembla (NSW) and Whyalla (SA). Given the size of these facilities, the transition will not be gradual and linear but will rather require several large investment decisions around retrofit, replacement and potential additional capacity of a large-scale plant.

25 Production inputs draw on BloombergNEF NEO 2021 projections for global metals demand and additional assumptions regarding Australia's share of the global market. Input assumptions are described in the companion technical report.

26 Production assumptions for other scenarios modelled by the Australian Industry ETI are included in the pathways technical report

27 Not all technology solutions that may play a role in decarbonising the supply chain are represented by the model. Technologies may be available before the model implements them. Assumptions regarding which technologies were included in the modelling are given in the companion technical report.

FIGURE 3.02: Technology deployment timeline for the decarbonisation of iron and steel in the 'Coordinated action scenario'[28]



2020–2030

Australian Industry ETI analysis finds that blast furnace-basic oxygen furnace (BF-BOF – see Figure 3.03) steel production, secondary steel production using the electric arc furnace (EAF), and the mining of iron ore resulted in the release of 24MtCO_2e in 2020.

The 'Coordinated action scenario' shows that an increase in electrification of iron ore mining and processing coupled with the use of biodiesel could see emissions begin to fall in the first half of the 2020s. The ongoing optimisation of BF-BOF production, leading to energy efficiency gains, and increases in steel recycling (scrap-EAF), could help to further reduce emissions. By 2030, up to A$2.9 billion could be required for technology investments to achieve this emission reduction.

2030–2040

The start of the next decade could see the deployment of battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (FCEV), displacing diesel trucks by 2035 in the 'Coordinated action scenario'.

To remain within a 1.5ºC carbon budget, the 'Coordinated action scenario' shows low-emissions steel production using direct reduced iron-melter-basic oxygen furnace (DRI-Melter-BOF) technology starts in 2030.[29] By 2040, DRI-Melter-BOF production could see a 60 per cent reduction in emissions-intensive BF-BOF steel production in this scenario. This, combined with emissions reductions from BEV's and FCEV's and increases in steel recycling, helps to reduce emissions in the supply chain by 81 per cent by the end of the decade.

2040–2050

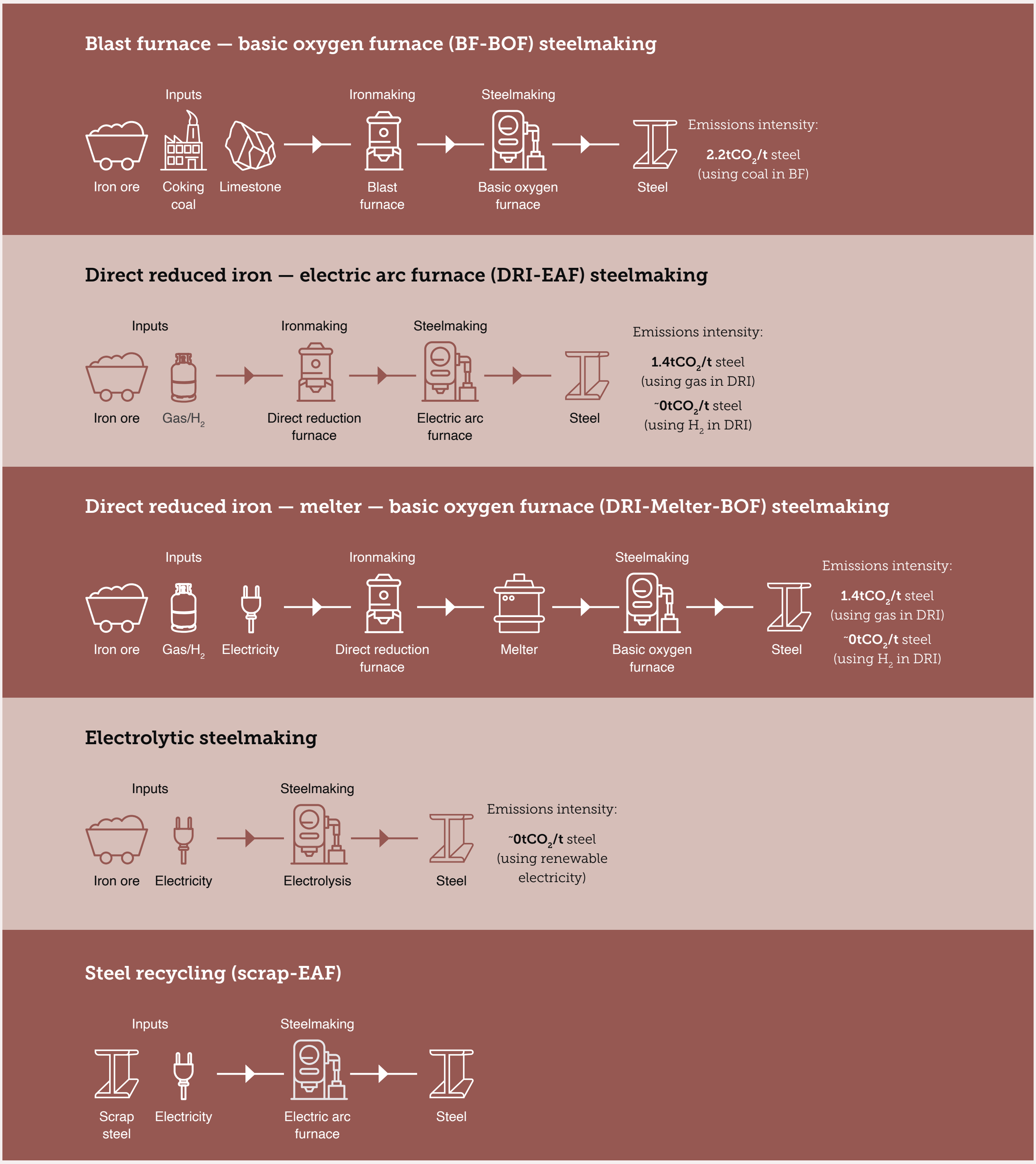
Further reductions in the costs of hydrogen in the 2040s favour a transition from gas to hydrogen technology for DRI-Melter-BOF production routes in 2045. The current context of extended periods of high gas prices could mean that a switch to hydrogen occurs sooner, as discussed in Information Box 3.01. By 2045, the 'Coordinated action scenario' sees the deployment of electrolytic steelmaking technologies and by 2050 coal-based emissions-intensive BF-BOF steel production could be wholly replaced with low-emissions alternatives.

28 The model findings are in five-year increments. For example, technologies introduced in 2028 can only appear in the modelling results from 2030 onwards.

29 Assuming DRI-melter-BOF is available by this date. All modelling inputs and assumptions can be found in the companion technical report. H2-DRI-EAF is an alternative steelmaking option using magnetite ores being investigated for deployment in Australia. While not preferred by the model, this pathway has been demonstrated in other jurisdictions and should be considered as part of a range of technology solutions.

The 'Coordinated action scenario' shows that low-emissions steel production (including secondary steel production), the replacement of diesel-powered haulage with BEVs and FCEVs, and the electrification of iron ore mining could allow the iron and steel supply chain to reduce its emissions by 99 per cent by 2050 if necessary action across the economy is taken. Across the supply chain, the cumulative investment for technology investments through to 2050 could be up to A$19.5 billion.

FIGURE 3.03: Steel production routes[30]



30 All technologies that use electricity as an energy source will vary in emissions intensity depending on the source of electricity used (i.e. coal-fired generation versus renewable energy)

INFORMATION BOX 3.01

Sensitivity study: the effect of gas prices on low-emissions steelmaking technology deployment

In 2022, Australia faced an extended period of higher than anticipated domestic gas prices, the result of international pressures and demand for Australian liquified natural gas (LNG). Coupled with shortfalls in domestic supply, this has driven much higher gas prices on the east coast, where steelmaking operations are based. Average wholesale gas prices on the east coast increased more than threefold between Q2 2021 and Q2 2022 (AEMO 2022b). Large industrial gas users are usually insulated from high wholesale prices as they have long-term contracts with suppliers, but there have also been spikes in contract prices leading to concern from commercial and industrial customers (ACCC 2022).

Lowering emissions in the iron and steel supply chain relies on the deployment of a range of technologies that depend on gas, including gas-DRI-Melter-BOF. The deployment and operation of these technologies will likely be affected by the continuation of high gas prices currently being experienced along the east coast of Australia. This may act to slow down the deployment of low-emissions technologies that rely on gas, as high gas prices will severely affect the cost-competitiveness of steelmakers who have committed to decarbonising their operations. In the absence of alternative cost competitive clean fuels, such as green hydrogen, steelmakers may be constrained in their ability to transition to low-emissions technologies.

To evaluate the effects of gas price on technology deployment, a sensitivity study was conducted for the ‘Coordinated action scenario’ in which elevated gas prices were assumed (see companion technical report). In general, as the model needs to deploy low-emissions technologies to remain with a 1.5°C carbon budget, higher gas prices led to slower or less uptake of gas powered DRI-Melter-BOF, and more rapid and increased uptake of hydrogen DRI-Melter-BOF or electrolytic steelmaking. These results emphasise the importance of the rapid development of a low cost hydrogen supply for green steelmaking, if the supply chain is to achieve emissions reductions in line with limiting warming to 1.5ºC while remaining cost-competitive.

3.3 Iron and steel supply chain decarbonisation

The ‘Coordinated action scenario’ shows that decarbonising the iron and steel supply chain in line with a 1.5°C carbon budget requires the development and deployment of low-emissions technologies alongside an unprecedented energy system transformation, presenting significant challenges and uncertainties (Figure 3.04).

FIGURE 3.04: Challenges for iron and steel decarbonisation in Australia

Developing emerging technologies and securing suitable ore types for future steelmaking	**Deploying technologies** into existing plant and operations, and building out steel recycling	**Integrating** renewable electricity and hydrogen capacity at scale	**Achieving scale** while remaining cost-competitive

Actions can be taken to overcome these challenges. This section discusses key enablers of the transition for the iron and steel supply chain, with a set of recommended actions at the end of the chapter.

Developing emerging green iron and steel technologies

While some decarbonisation technologies are mature and commercially available, many within the iron and steel supply chain are emerging technologies that are not yet commercially proven (Table 3.01). There are financial risks associated with investing significantly in commercially unproven technologies. For iron ore haulage, battery electric trucks and hydrogen fuel cell electric vehicles are at the demonstration phase of development; however, smaller underground BEVs are already commercially available. Most green steelmaking technologies are underdeveloped and are currently in the research and development or demonstration phase. More information about these technologies and their commercial readiness can be found in the *Australian Industry ETI Phase 1 Technical Report* (ETI 2021a).

TABLE 3.01: Commercial readiness of selected iron ore haulage and green steelmaking technologies

Process	Technology	Current stage of development[31]
Iron ore haulage	Biodiesel	deployment
	Trolley assists	deployment
	Battery electric vehicles	demonstration
	Hydrogen fuel cell electric vehicles	demonstration
Iron making	gas DRI[32]	deployment (pellet-based)
	H_2 DRI	demonstration
Steelmaking	EAF	deployment (scrap-based)
	gas DRI-EAF	deployment
	H_2 DRI-EAF	demonstration
	gas DRI-Melter-BOF	research and development
	H_2 DRI-Melter-BOF	research and development
	Electrolytic steelmaking	research and development

Rapid deployment of low-emissions iron and steel technologies will be needed to ensure the supply chain can reduce its emissions in line with a 1.5°C pathway. Action is needed urgently to ensure technologies are developed to the point where they can be deployed in commercial settings.

Collaboration for pilot and demonstration plants

Pilot and demonstration plants can support learning and help create confidence in new technologies. Early deployment of proven technology can also lower the cost curve, making scaling more feasible. Collaboration between government, research agencies, universities and industry is necessary, not only to enhance research and development (R&D), but also to work on the multifaceted requirements of transition including: developing new regulations and standards, new supply chain relationships and new business models. For this new collaboration, mechanisms are needed to bring private and public actors together as well as to manage shared risk, competitive tensions and intellectual property.

Capital allocation for R&D

Favourable finance for R&D and pilot plants can help reduce the financial risk to industry when developing and demonstrating emerging technologies. An acceptance of increased risk and an acknowledgement of first-mover disadvantage by financiers will enable greater access to capital for new green iron and steel projects. Effective financing could include government grants and venture capital. Tax incentives for R&D could also help enable and incentivise the development of emerging green iron and steel technologies.

Securing iron ore for future steelmaking technologies

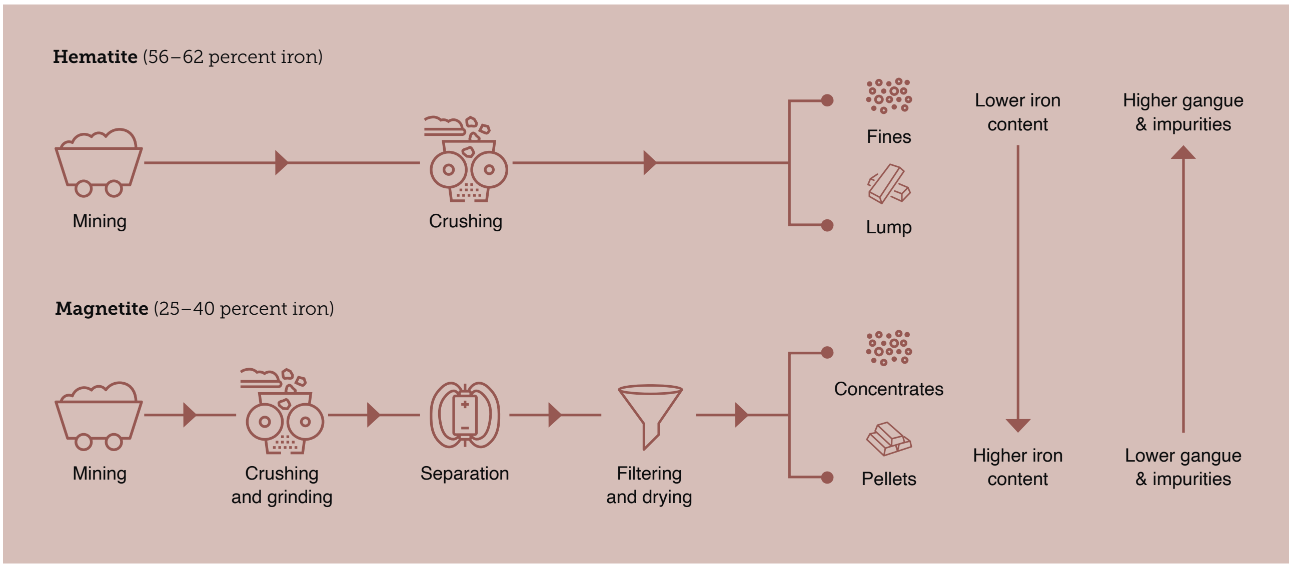
Australia will face additional challenges during the transition to green steel production. The bulk of Australia's iron ore currently mined is not compatible with DRI-EAF steelmaking technologies. While this technology was not deployed in the 'Coordinated action scenario', DRI-EAF could become a prominent production route for future global primary steel production, and potentially reducing demand for Australia's current iron ore exports (Mission Possible Partnership 2021a).

31 While some technologies are in the deployment stage of development, this may be influenced by regional or site specific factors impeding their commercial deployment in these settings.

32 Based on the IEA Iron and Steel Technology Roadmap TRL classification (IEA 2020).

Australia has two primary iron ore types; hematite-goethite and magnetite. Hematite-goethite ore is a naturally higher-grade ore, with iron content typically between 56 and 62 per cent. It requires little processing before it is shipped as lump and fines for use in blast furnaces and constitutes 96 per cent of Australia's current iron ore exports. Magnetite is naturally a lower grade ore (25–40 per cent iron), but can be processed to raise the iron content, then be subsequently agglomerated and indurated into pellets suitable for use in steelmaking. Magnetite constitutes only 4 per cent of Australia's current iron ore exports. Despite the lower grade of magnetite ore, the additional processing steps result in a final product with higher iron content, fewer impurities and less gangue[33] than hematite-goethite (Figure 3.05).

FIGURE 3.05: Hematite-goethite and magnetite processing[34]



The additional processing required for magnetite ore – called beneficiation – can make magnetite (or low-gangue ore) suitable for use in DRI-EAF technologies. This is because, unlike incumbent BF-BOF production, iron ore does not melt during DRI production, making separating any gangue difficult. The subsequent step – EAF – can only manage finite quantities of contaminants, therefore requiring the iron ore used during DRI to be of high grade and purity.

Beneficiating hematite-goethite to allow its use in DRI-EAF steelmaking is not an easy solution, as separating the impurities and gangue that render it unsuitable for DRI-EAF is very difficult. While magnetite is, as its name suggests, magnetic, hematite-goethite is not (Geoscience Australia 2019). This makes magnetite well suited to producing concentrates, which can be understood by an 'iron filings in sand' analogy: separating iron filings from sand using a magnet efficiently produces a pure iron product, but without a magnet, separating the iron filings and sand is a significant challenge (Eames 2021).

Securing sufficient quantities of iron ore suitable for future green steelmaking technologies will be critical to achieving the decarbonisation of the global steel supply chain as well as for maintaining Australia's current iron ore export market. Different strategies for meeting ore requirements for green steelmaking will depend on regional and cost factors, such as labour costs, access to low-cost renewable energy and hydrogen, and ore type and availability. A technology strategy is needed now to guide research, development and demonstration into ore compatibility, ore beneficiation and alternate steelmaking routes.

Partnerships and collaboration for R&D efforts

Partnerships between iron ore miners and iron and steel makers can enhance R&D efforts through the co-development of technology solutions. Co-investment between miners and steelmakers can also help spread the financial risk of R&D, but additional financial support will also be needed. As discussed previously, this could include government grants, tax incentives, and venture capital.

33 Gangue is the waste rock and impurities in ore deposits

34 Figure adapted from (BloombergNEF 2021a)

Research and development for hematite-goethite processing

Developing new methods of processing hematite-goethite for its use in green steelmaking (especially DRI-EAF) could allow continued use of existing mines and infrastructure and preserve Australia's current iron ore markets. The processing of hematite-goethite for use in DRI-EAF technologies is poorly understood and will require R&D to enable commercially viable methods. Furthermore, yield losses during beneficiation will need to be addressed so as to not decrease the economic viability of this route.

Expand magnetite mining

Australia could expand its current magnetite output, with magnetite representing 38 per cent of Australia's EDR (economic demonstrated resources) of iron ore (Geoscience Australia 2020). Deposits are distributed across Australia, with successful magnetite mining operations in South Australia, Tasmania and Western Australia (Karara Mining n.d.; Tasmania Mines n.d.). More than 90 per cent of South Australia's iron ore is magnetite, and the South Australian government is aiming to become a global leading supplier of magnetite ore, producing 50 million tonnes per year by 2030 (Department for Energy and Mining n.d.). 81 per cent of Australia's magnetite EDR occurs in Western Australia, but currently only 3 per cent of Western Australia's iron ore production is magnetite (Geoscience Australia 2020; Department of Jobs, Tourism, Science and Innovation 2022).

Mining and processing magnetite ore is capital and energy-intensive (Engeco 2021). Additional infrastructure is also needed, specifically, access to low-cost, firmed renewable electricity, water (as a processing medium) and tailings dams. In its favour, however, is the fact that the resulting higher quality end-product usually attracts a price premium, which may be amplified by increases in global demand from DRI-EAF steelmaking.

Expanding current magnetite mining in Australia must include measures to limit emissions and broader environmental impacts from new mine facilities. This includes using renewable energy to power mining and processing equipment, low-emissions haulage, sustainable water management and strong sustainability benchmarks included in the planning and approval process. There are a range of low-risk technology investment options which can be made in the short term to accelerate decarbonisation of mining operations (Clean Energy Finance Corporation [CEFC] & Minerals Research Institute of Western Australia [MRIWA] 2022b). In Australia, zero carbon or net zero mining is becoming the expected goal as the business case continues to improve, even for assets with complex decarbonisation challenges.

Transitioning existing plant and operations

Existing iron and steelmaking infrastructure cannot be ignored. Iron ore miners and steel manufacturers may be constrained in their ability to transition to new plants and equipment due to existing commitments to incumbent technology, affecting investment returns from sunk and planned investments. The transition to decarbonised steelmaking may require the early retirement of existing blast furnaces, while iron ore mines will need to adapt to new fuels – such as hydrogen and electrification – requiring significant infrastructure modifications, investments in new equipment and the establishment of robust hydrogen supply chains. Understanding asset lifecycles and intervening at key decision points to transition to lower-carbon steelmaking technologies will be important to minimise further long-term lock-in or stranded assets. Furthermore, with a number of opportunities for new technologies to decarbonise the supply chain, it will be important to have the necessary support in place to prepare operations and workers for the transition.

Financial and regulatory mechanisms to promote plant retrofits

To enable the transition of existing facilities, where possible, equipment with retrofit pathways should be prioritised to preserve existing infrastructure. Separate finance instruments for retrofitting existing plants can help, including tax incentives for new technology investments or government funding. Government can also support the transition of existing facilities through streamlined development and planning approval processes.

Optimise mine sites for renewable energy and hydrogen use

Mine sites will need to be optimised for alternative fuel use by building recharging or refuelling stations or overhead lines for trolleys.

Substantial changes to current haulage practices may be needed as switching to BEVs may reduce availability while haulage trucks are recharged. Different charging strategies may overcome this challenge, such as battery-swap stations, increasing the number of haulage trucks to ensure constant availability, or switching to trolley-based systems.

A switch to FCEVs will require the build-out of hydrogen infrastructure including production, transport, and storage. Depending on mine location, onsite hydrogen production could be favoured over transporting hydrogen from larger production sites and will depend on the difference between hydrogen transport and production costs. For onsite production, low-cost renewable electricity and efficient electrolysers will be needed to promote the competitiveness of FCEVs. A more detailed discussion of challenges and enablers for decarbonising mining is given chapter five, 'Focus on other metals'.

Development and retraining programs for current workforces

Transitioning to new technologies has risks and opportunities for labour forces working in existing operations. Transitioning operations and equipment requires skilled technicians, engineers, trade workers, and machinery operators. While these skills are not dissimilar to those iron and steel employees currently possess, retraining will undoubtedly be required when new technologies are deployed (Grattan Institute 2020). Workers in coal mining communities will be especially at risk when steelmaking transitions away from the use of coal to other fuels such as renewable electricity and green hydrogen. Government support and regulation for retraining current workforces in carbon-intensive iron and steelmaking industries will be needed to ensure a just transition for existing communities.

Building out Australia's steel recycling industry

The Australian Industry ETI modelling assumes that the future growth of steel recycling is capped at 35 per cent of domestic steel production, to represent Australia's current recycling schemes and limited scrap availability.

However, steel scrap will play an important role in decarbonising the iron and steel supply chain by not only reducing the demand for ore-based production, but also as an input that can lower the emissions intensity of primary production (Mission Possible Partnership 2021a). Changes in Australia's current scrap recovery and recycling schemes will be needed to achieve this.

Prioritise steel scrap for domestic use and promote onshore recycling

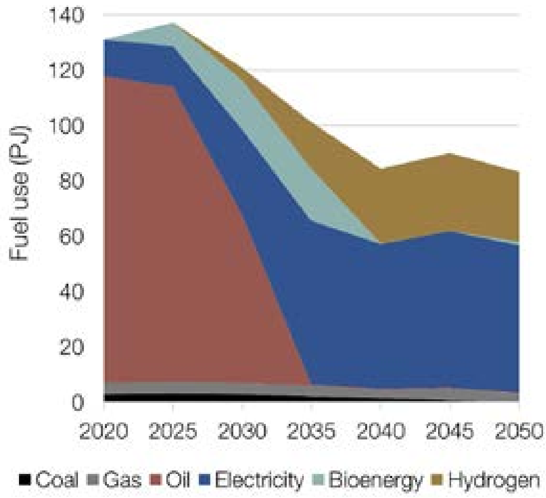
Limited domestic manufacturing currently means there is little prime steel scrap in Australia. Furthermore, most steel scrap is exported (approximately 2 million tonnes) from Australia, leaving little for domestic steel recycling. Prioritising steel scrap for domestic use can help ensure sufficient supply during the transition.

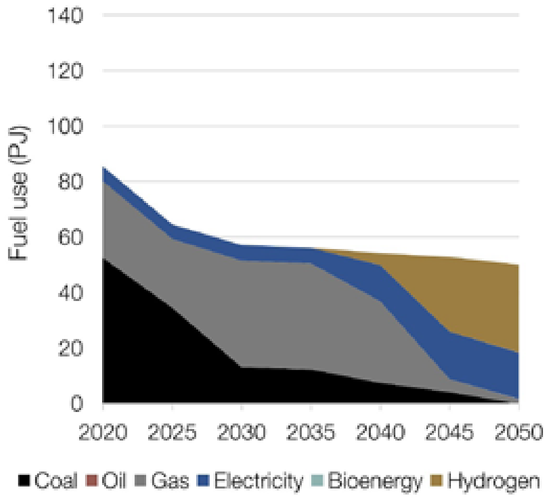
Mandates on minimum recycled content in steel products can also promote scrap recovery and recycling. These should however be in line with technical viability and differentiated by process routes. Value chain partnerships and collaboration between local communities and scrap collectors can promote greater collection recovery, and recycling of steel. This can be enabled by better distribution of returns along the steel value chain. Risk is currently weighted to steel producers while the reward is weighted to scrap material suppliers. The build-out of additional scrap collection and processing facilities may also be needed. A key aspect of scrap use is ensuring it is not contaminated (e.g. copper contaminants) to ensure high grade steel can be produced through recycling. The development of improved scrap management could be an important part of building Australia's steel recycling capabilities.

Integrating renewable electricity and hydrogen

The 'Coordinated action scenario' shows that a shift to decarbonised iron ore mining and steelmaking will include switches in fuel types (Figure 3.06). By 2035, diesel use in iron ore mining is replaced by bioenergy, hydrogen and electricity – with electricity use more than doubling by 2030. For steelmaking, the model finds an initial gas use increase as gas DRI-Melter-BOF increases in the medium term. However, after 2040, the use of hydrogen quickly becomes significant, increasing from only 8 per cent of total energy use to 63 per cent in just ten years. As discussed in chapter two, 'Pathway for heavy industry decarbonisation', by 2050, almost all hydrogen is produced via electrolysis in the 'Coordinated action scenario'. Similarly, the increase in electrified steelmaking technologies sees an approximate three-fold increase in electricity use by 2050.

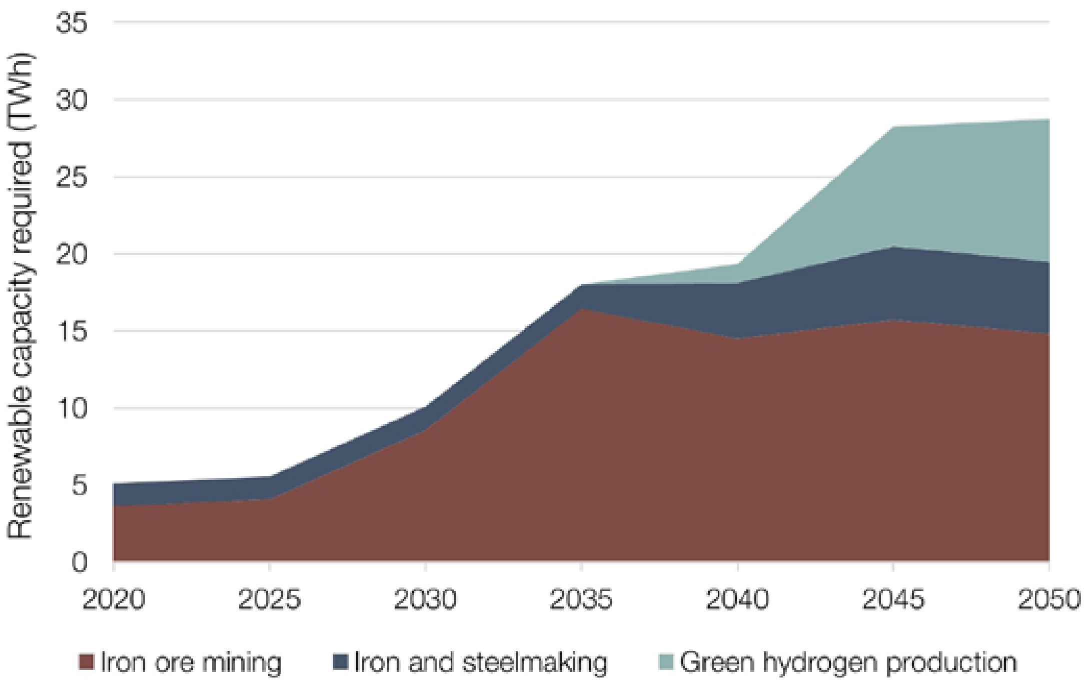
FIGURE 3.06: Changes in fuel use for iron ore mining (left) and iron and steelmaking (right) in the 'Coordinated action scenario'





Given the uptake of electrification technologies in the 'Coordinated action scenario', a parallel and rapid increase in renewable energy capacity is a critical driver of iron and steel decarbonisation by minimising electricity use emissions. By 2050, 20TWh of renewable energy will be required each year for the electrification of iron ore mining operations and steelmaking technologies (Figure 3.07). With most hydrogen produced via electrolysis by 2035 in the 'Coordinated action scenario', an additional 9TWh of firmed renewable energy will be needed to meet the demand for hydrogen in iron ore mining and steelmaking each year. This will need to occur alongside the build-out of hydrogen infrastructure including production, transport and storage infrastructure.

FIGURE 3.07: Electricity generation required for the decarbonisation of the iron and steel supply chain in the 'Coordinated action scenario'



Combined, the 29TWh/year of renewable energy needed to decarbonise the iron and steel supply chain alone is equivalent to doubling the current renewable energy generation of New South Wales, needing considerable areas of land to build-out the scale of renewable energy required (DISER 2022c). Achieving this scale of build-out as well as the necessary hydrogen infrastructure in the next decade, including production, storage and transport, will be critical for decarbonising iron and steel.

Clear, long-term development roadmaps

Clear, long-term roadmaps for energy and infrastructure developments are needed to provide certainty and investment confidence for iron ore miners and steelmakers. This should include coordination across levels of government to align the regulatory and policy mechanisms needed to support implementation of a robust and resilient transition roadmap.

Collaboration for shared infrastructure developments

Regional differences between iron ore miners and steelmakers pose unique challenges and opportunities for the integration of renewable energy and hydrogen into their operations.

Little collaboration and a lack of integrated grid and transmission infrastructure in the Pilbara region means that onsite power generation is often required at iron ore mines. A coordinated approach to renewable energy infrastructure developments can enable a more effective energy system transition and reduce energy costs. Coordinated investments can also help reduce risk and financial burdens to individual iron ore mines during the transition.

Optimisation of new plant location

Historically, proximity to coal has been important in determining the optimal location for steelmaking in Australia. The development of green ironmaking technologies could therefore favour new locations for plants as the use of coal is replaced with hydrogen and renewable electricity. Access to low-cost, firmed renewable energy and hydrogen could become a factor in deciding where new plants are located. Clustering renewable energy and hydrogen supply with end-users can help minimise the investment needed by reducing transmission and transport infrastructure needs. Access to large quantities of suitable iron ore, labour costs and access to existing downstream infrastructure (e.g. deep water ports) could also be important factors in determining where new plants are located.

Streamlined development approval processes

Legislation for land access and streamlined planning and development approval processes can ensure a timely transition to green mining and steelmaking facilities. These processes should include engagement with Traditional Owners for support of large-scale energy infrastructure projects, especially in the Pilbara region.

INFORMATION BOX 3.02

Sensitivity study: Establishing green iron exports

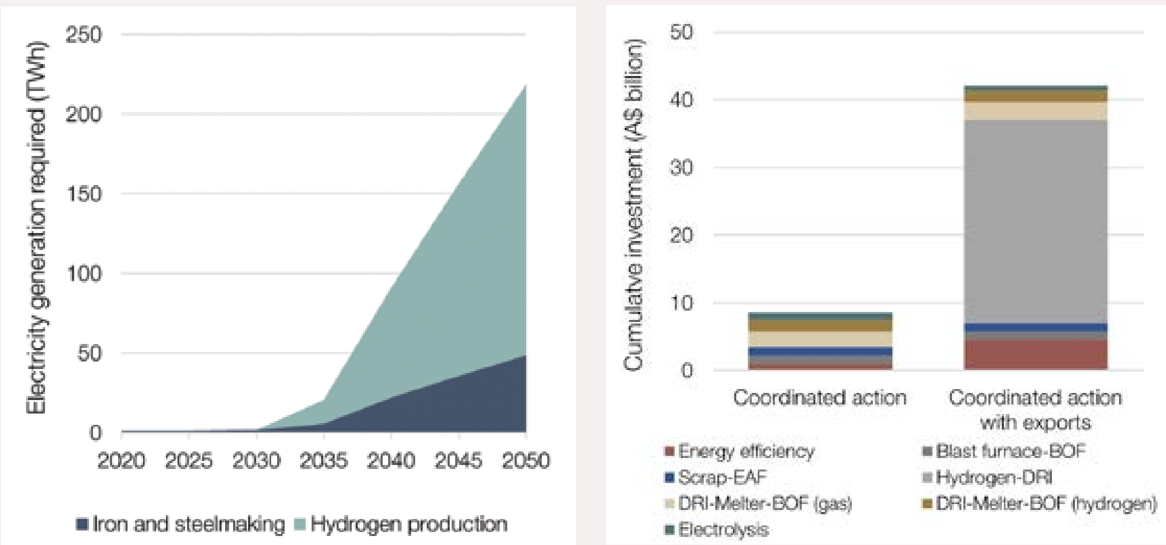
To investigate a potential new green iron industry, Australian Industry ETI modelled the implications of dramatically scaling green iron production for export. Green iron produced using H2-DRI (called 'sponge iron' or 'hot briquetted iron' (HBI)) could be exported in large quantities to take advantage of Australia's competitive opportunities.

This was based on AEMO's 2022 ISP (AEMO 2022a) which includes a 'Hydrogen superpower' scenario in which Australia produces around 50Mt of green steel by 2050 (in addition to considerable green hydrogen for export) (AEMO 2021). Although the ISP scenario shows the impact of this industry growth in the National Electricity Market (on the east coast), Australian Industry ETI modelling assumed that all green iron production would take place in Western Australia (in line with current iron ore industry narratives).

50Mt of green steel requires roughly 58.5Mt of sponge iron and approximately 99Mt of compatible iron ore[35]. To meet supply chain demands for green iron, roughly 4.2Mt of green hydrogen per year is produced by 2050. The energy system impacts of this would be considerable, requiring rapid scaling of renewable energy and hydrogen production (see chapter 2 'Pathway for heavy industry decarbonisation'). For this reason, the modelling of a green iron industry was included in a sensitivity study called 'Coordinated action with exports' in which technology development and energy system upgrades begin early.

Establishing a green iron export industry in Australia could require additional green iron technology investments of up to A$30 billion by 2050 and 234TWh/year of electricity generation on top of that required to transform domestic ironmaking and steelmaking. This new industry could require Australia to nearly double its current total electricity generation just to meet this demand (DISER 2022c) (Figure 3.08). The investment needed to develop the supporting energy infrastructure would be substantial as discussed in the 'Pathway for heavy industry decarbonisation' chapter.

FIGURE 3.08: Electricity (left) and cumulative investment (2020-2050) (right) needed to unlock Australia's green iron export opportunity (excludes iron ore electricity use and investment)



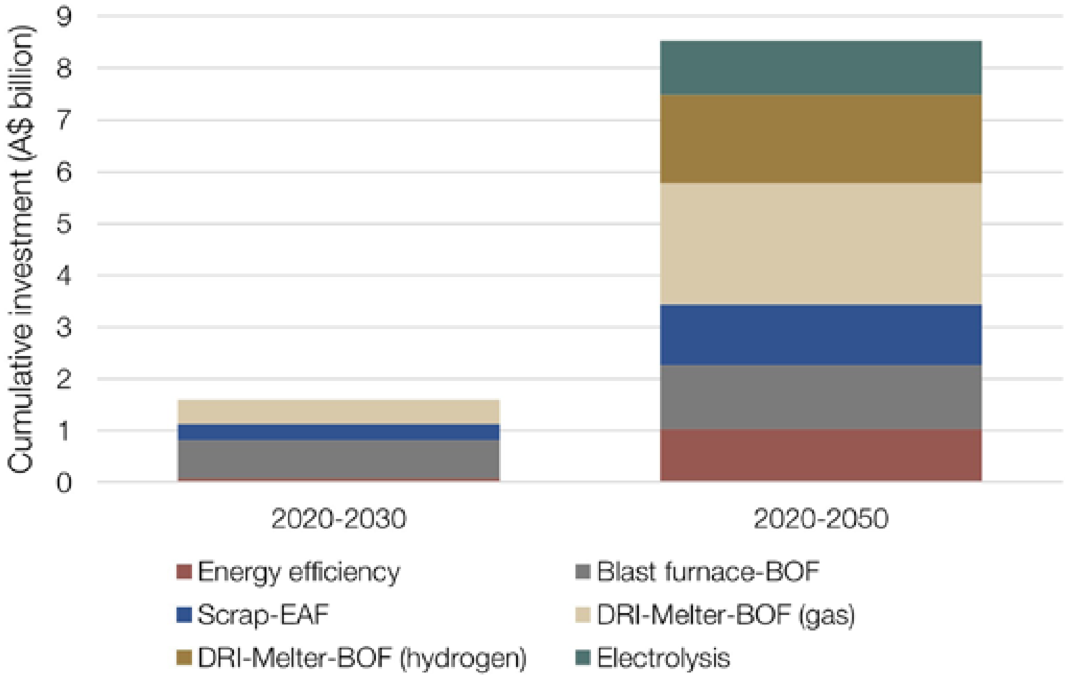
Achieving scale while remaining cost-competitive

The iron and steel supply chain operates in a globally competitive market, with market players trading steel in a global market (IEA 2020; World Steel Association 2022). Therefore, increases in production costs that cannot be passed on pose a risk to the global competitiveness of steel producers, making it unattractive for individual players to bear the upfront investment needed for decarbonisation.

35 Based on the assumption that each tonne of sponge iron requires 1.7 tonnes of iron ore (Dasarath Reddy 2013).

In Australia, decarbonising steelmaking could require technology investments of up to A$1.6 billion by 2030, increasing to A$8.5 billion by 2050 as seen in the 'Coordinated action scenario' (Figure 3.09).[36] With most green steelmaking technologies relying on low-cost, firmed renewable energy and hydrogen, the build-out of enabling energy infrastructure will significantly increase (potentially tripling or quadrupling) investment requirements. Australia's domestic steel industry competes with imports from countries that currently have less ambitious emissions reduction targets, which poses challenges for Australian steelmakers' competitiveness when bearing these investment costs.

FIGURE 3.09: Cumulative investment in steelmaking technologies in the 'Coordinated action scenario'



Large capital investments in technology replacement and the cost of renewable energy and hydrogen will lead to a price premium (known as a green premium) to make low-emissions steel economically feasible for steelmakers. Even with learning curve effects and decreases in renewable energy costs, the cost of green steelmaking could be between 15 and 30 per cent more in 2050 compared to today's carbon-intensive processes (Mission Possible Partnership 2022; Rocky Mountain Institute [RMI] 2019b).

The increased cost of green steel is however projected to have minimal effects on the price of most end-use products. For example, making green steel with hydrogen costs of US$2 per kilogram would likely increase the price of a car by only 0.3 per cent in 2050, as steel costs are only a small portion of the total cost of the car (Energy Transitions Commission 2019b; Grattan Institute 2020).[37] However, manufacturers of intermediate steel products – such as steel parts for car manufacturing – will be greatly affected by the 15–30 per cent cost increase of green steel. In the absence of incentives to procure green steel for manufacturing, the price premium for green steel would significantly affect the cost competitiveness of steel producers and manufacturers who have committed to decarbonising their operations.

To achieve the scale of the transition needed, the cost and financial risk of transitioning to green technologies as well as the cost premium for green steel will need to be addressed.

Clear demand signals for green steel

In the absence of clear demand signals for green steel, the financial risk of transitioning to green technologies limits investment confidence for steel producers. Clear demand signals for primary green steel, through mandates or local content requirements in government projects, can help facilitate market creation.

36 Excluding investments in iron ore mining (Cumulative investment between 2020 and 2030: A$1.25 billion. Cumulative investment between 2020 and 2050: A$10.95 billion) as well as energy and infrastructure

37 As the cost of green steel is in part dependent on hydrogen costs, a decrease in hydrogen prices would lead to further cost reductions. However, even if hydrogen prices were to decrease to US$0.6/kg by 2050, the levelised cost of steel produced via DRI-EAF could still be up to 17 per cent more than emissions intensive BF-BOF production (Mission Possible Partnership 2022).

Finance mechanisms to bridge the cost gap of green steel and support technology investment

Bespoke financial instruments will be needed to support the scale of investment in technology replacements needed and to help bridge the cost gap of green steel. These mechanisms could include offtake agreements, viability gap funding, contracts for difference, support from export credit agencies and government grants and subsidies.

Robust certification standards for green steel

The establishment of robust certification standards for green steel claims will be vital to create confidence and ensure transparency and accountability of emissions reductions within the market. Australia can leverage existing international standards. Aligning these standards with already existing international frameworks (such as the ResponsibleSteel Standards (ResponsibleSteel n.d.) would make it easier for domestic producers to find buyers outside Australia.

Promote customer willingness to pay for green premiums

Communities can also play a role in facilitating market creation through a willingness to pay for green premiums where possible. Collaboration between industry and government to raise public awareness of the scale of the transition needed may help increase customer willingness to pay the price premium. Certified green steel products (consumer goods) should be clearly labelled to help empower the public to choose green steel products over carbon-intensive alternatives. This will be dependent on robust certification standards discussed above.

INFORMATION BOX 3.03

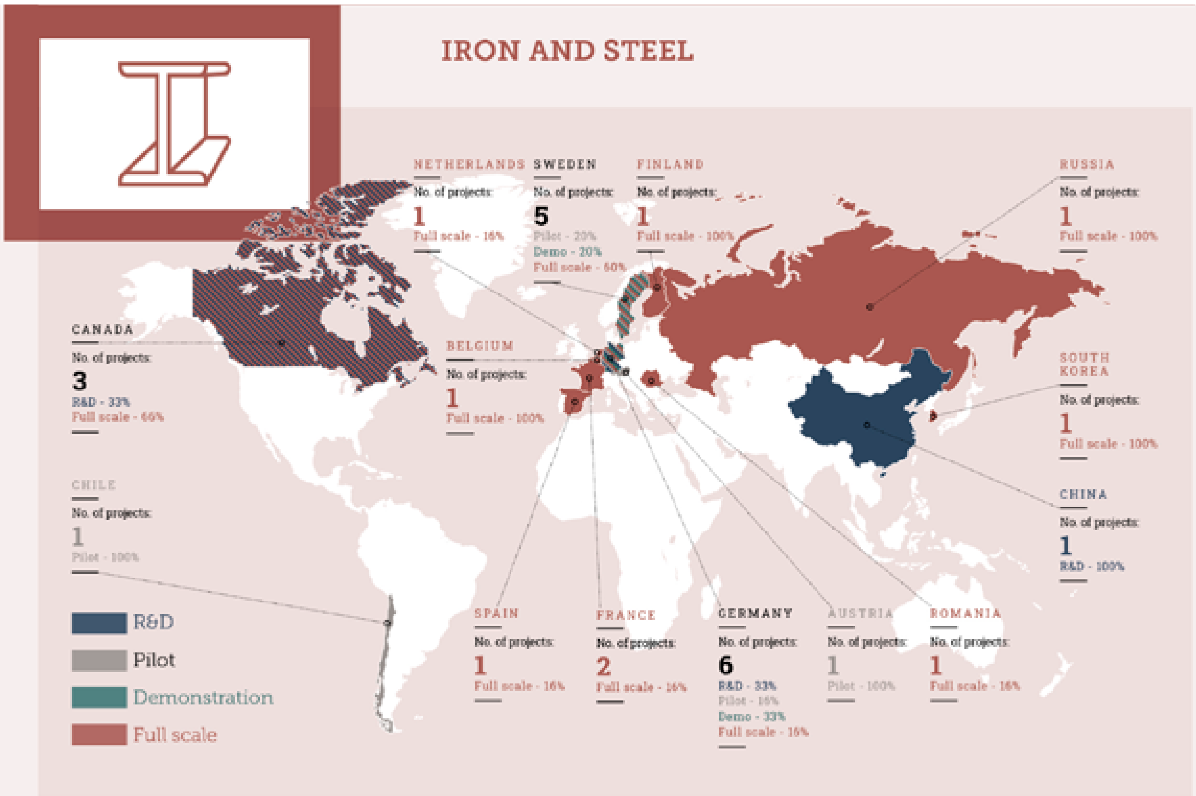
Australia's competitive advantage in renewable energy provides green iron and steel export opportunities

Australia's high labour costs and the cost of shipping steel mean it's currently more cost effective to export coal and iron ore from Australia to countries with cheaper labour costs and to locations where steel can be made close to end-use markets. A global shift to decarbonised steelmaking could significantly change the iron and steel supply chain and its economics.

Australia's globally competitive renewable energy resources (discussed in the 'Pathway for heavy industry decarbonisation' chapter) position it well to meet increased global demand for hydrogen to produce green iron and steel. The higher costs of shipping hydrogen – compared to coal – could, however, favour the establishment of green iron and steel industries in Australia (Grattan Institute 2020).

While Australia's globally competitive renewable energy resources mean it's well placed to capture the opportunities of green iron or steel industries, the activity of other renewable-rich countries – such as the United States, Canada, Brazil, northern Africa, the Middle East and China – will create fierce competition. Action is needed now to ensure Australia positions itself well in these emerging markets.

3.4 Momentum is building across the Australian and global iron and steel industry



Green iron and steel in Australia

Fortescue Metals Group has committed to fully decarbonise their operations including plans to produce coal-free steel.

BHP and Rio Tinto are investigating the performance of their ores in DRI and EAF steel production as well as novel beneficiation technologies.

BlueScope and Rio Tinto are collaborating on research into low emissions processes and technologies across the iron and steelmaking value chain including iron ore processing and iron and steelmaking.

Iron ore miners are investing in renewable energy and low emissions haulage.

Fortescue Metals Group has partnered with Liebherr to replace about 46 per cent of its current haulage fleet with low emissions haul trucks, with the first units expected to be operational by 2025.

Rio Tinto has opened their Gudai-Darri iron ore mine featuring a 34MW solar farm—expected to supply approximately 65 per cent of the mine's average electricity demand.

Efforts to produce iron ore suitable for green steelmaking are expanding

The Hawsons Iron project in NSW is scheduled for completion in December 2022 and could see the production of 20 million tonnes of high-grade iron product (70 per cent iron content) each year.

The South Australian government aims to secure A$10 billion in investments to expand the state's annual production of magnetite to 50 million tonnes by 2030.

Collaborations across the iron and steel supply chain

BHP has extended its partnership with the University of Newcastle for continued research into the decarbonisation of steelmaking through the Centre for Ironmaking Materials Research (CIMR).

Rio Tinto and Salzgitter have signed an MoU to investigate ways of using various ore types for hydrogen direct reduction steelmaking. The potential for greenhouse gas certification across the steel value chain is also being explored under the MoU.

The India-Australia Green Steel Partnership aims to support the commercialisation of new technology for improved steel production and export diversification. The partnership will connect Indian partners with CSIRO's Towards Net Zero Mission.

3.5 Enabling the transition

The 'Coordinated action scenario' shows that a transition aligned with 1.5°C in the Australian iron and steel supply chain is challenging, and requires strong, effective and coordinated action across the economy. While commitments from industry to a long-term transition have been a step forward, further action is now urgently needed from industry, government, and investors. This will be critical in order to overcome the challenges discussed above and enable the transition to net zero in the iron and steel supply chain.

The Australian Industry ETI has identified the following objectives (Figure 3.10) to help create a prosperous, globally competitive, net zero industrial economy in Australia.

FIGURE 3.10: Objectives and recommended actions for iron and steel

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia's industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower

Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy

Develop **integrated regions, supply chains and energy network** solutions

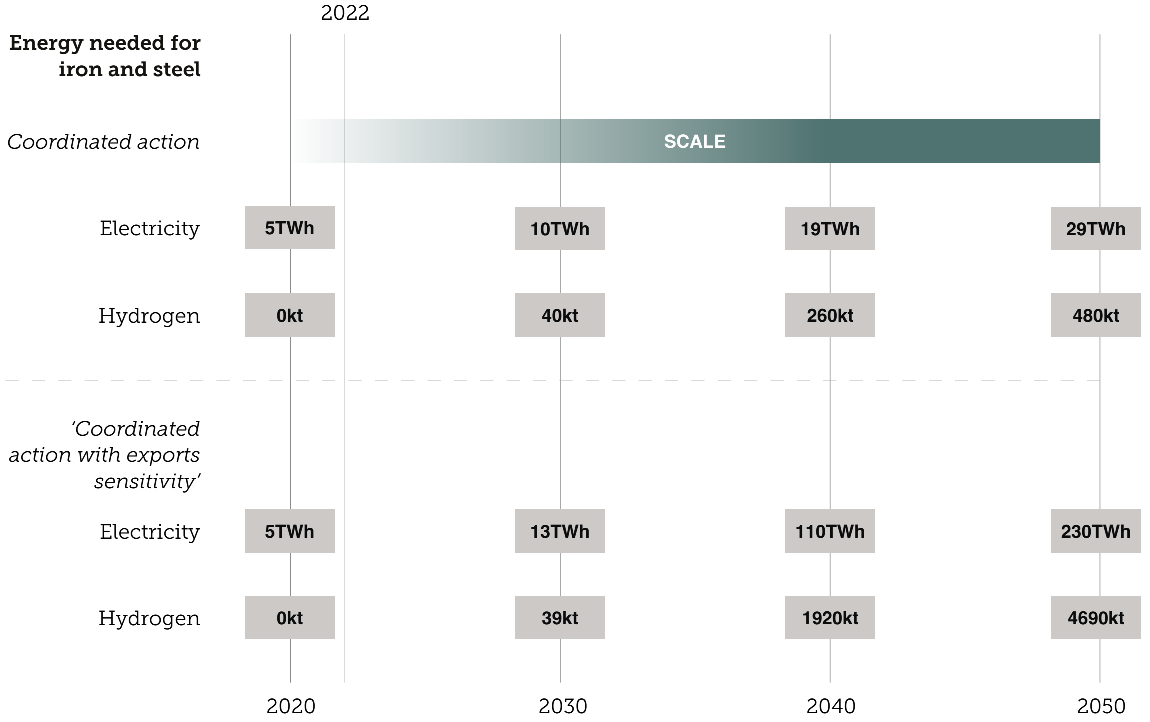
A STRONG, ENDURING FRAMEWORK

1. Develop iron and steel supply chain roadmaps for heavy industry
2. Develop a national strategy for the development of green iron export markets and future-proof iron ore production to enable green steel

LARGE-SCALE, COST-COMPETITIVE, RENEWABLE ENERGY SYSTEM OF THE FUTURE

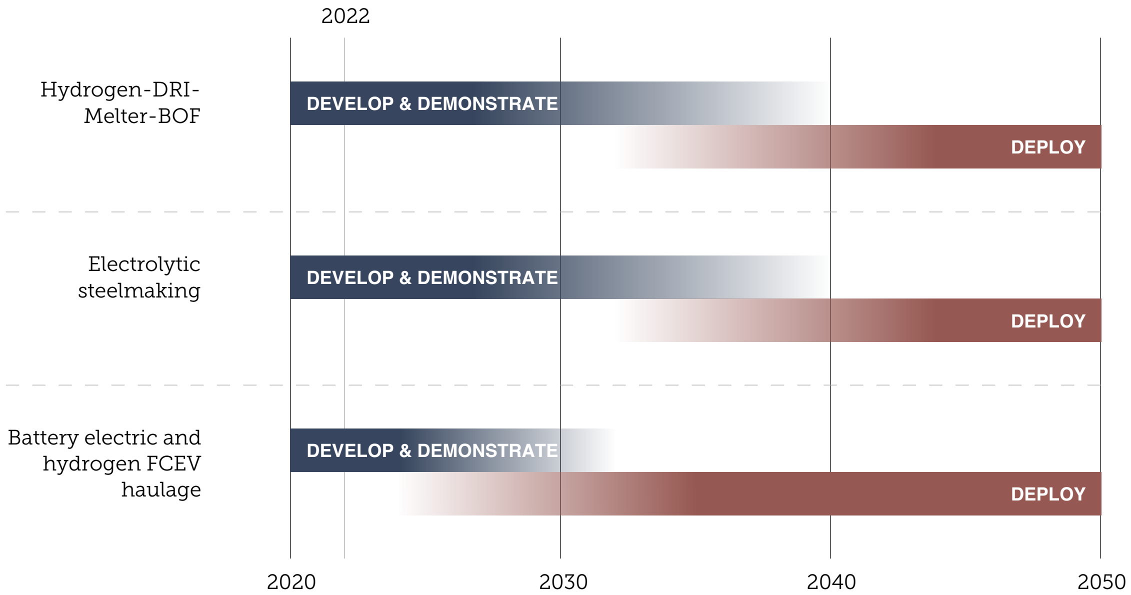
3. Set a series of short, medium and long-term goals for the development of the energy needed to decarbonise iron and steel
4. Set targets that drive the development of a large-scale, decarbonised hydrogen market

FIGURE 3.10: Objectives and recommended actions for iron and steel (continued)



ACCELERATED DEVELOPMENT AND DEMONSTRATION

5. Prioritise funding and support for pilots and demonstrations

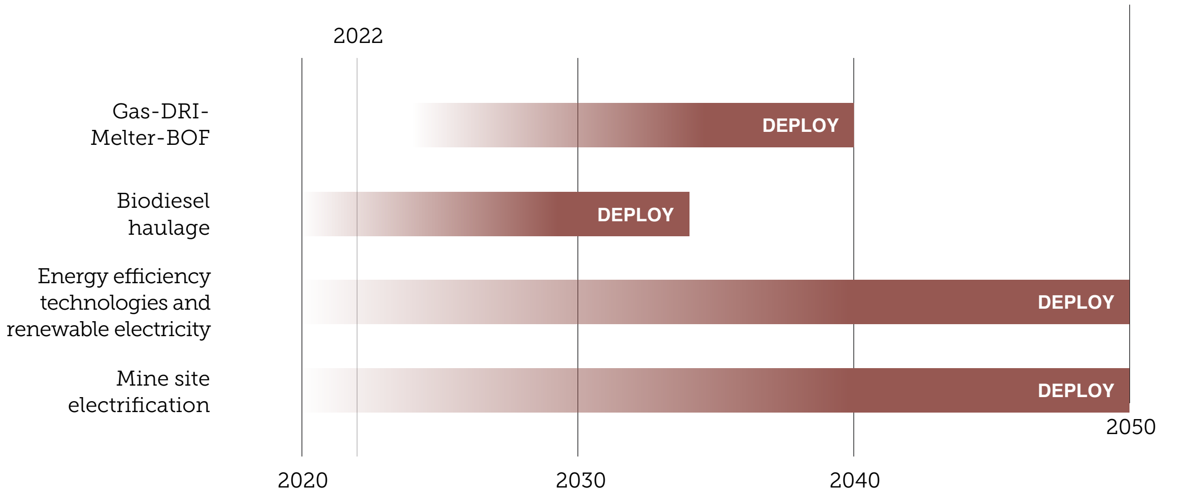


6. Investigate iron ore compatibility with green steelmaking technologies

DEPLOYMENT OF LOW CARBON SOLUTIONS

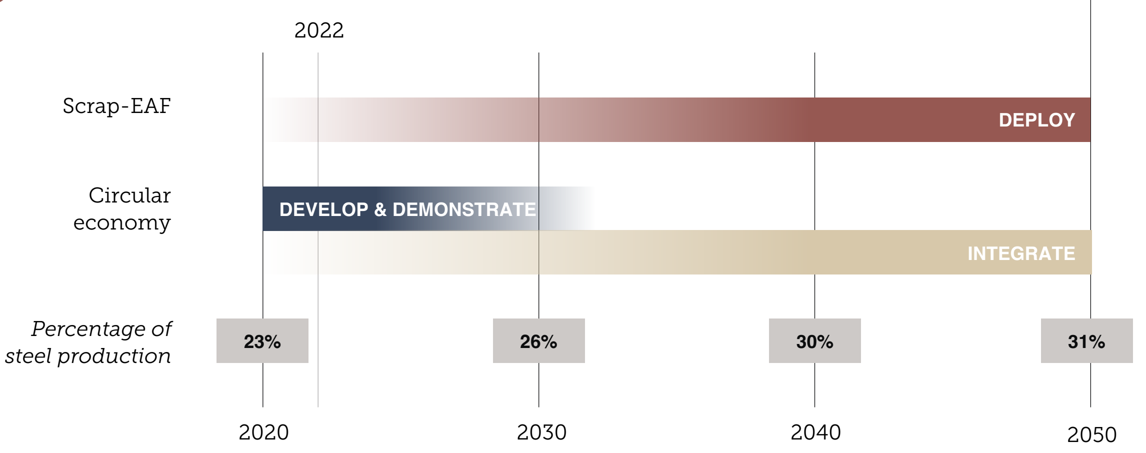
7. Develop firm commitments for offtake for green steel
8. Certification for emissions standards for steel production

FIGURE 3.10: Objectives and recommended actions for iron and steel (continued)



INTEGRATED NET ZERO REGIONS, SUPPLY CHAINS AND ENERGY NETWORK SOLUTIONS

9. Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions
10. Build the circular economy through extensive build-out of steel scrap collection, processing and recycling facilities



To ensure a timely and effective transition of the iron and steel supply chain, Table 3.02 shows a list of recommended actions. They are mapped against the four enabling themes that the Australian Industry ETI has identified as being important for driving decarbonisation in heavy industry, which are discussed in chapter eight 'Enabling the transition to heavy industry decarbonisation'. This mapping is represented by the coloured boxes. Chapter eight also contains key recommended actions to decarbonise all supply chains, which complement these recommended actions specific to iron and steel.

TABLE 3.02: Recommended actions to achieve the decarbonisation of the iron and steel supply chain

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Develop iron and steel supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation.				
	2	Develop a national strategy for the development of green iron export markets and future-proof iron ore production to enable green steel as part of a broad strategy of new export opportunities in a decarbonising global economy.				
Transition to the large-scale, cost-competitive, renewable energy system of the future	3	Set a series of short, medium and long-term goals for the development of the energy needed to decarbonise iron and steel. This is potentially at the scale of 29TWh/year of firmed renewable electricity by 2050 to enable decarbonisation of existing industry and potentially 234TWh/year to supply new green iron production.				
	4	Set targets that drive the development of a large-scale, decarbonised hydrogen market and undertake a planned approach to develop and update regulation for rapid and safe development of hydrogen production, transport and storage. This could possibly be at the scale of 0.47Mt of green hydrogen per year by 2050 to decarbonise existing operations in the supply chain and potentially 4.2Mt per year to establish new green iron production.				

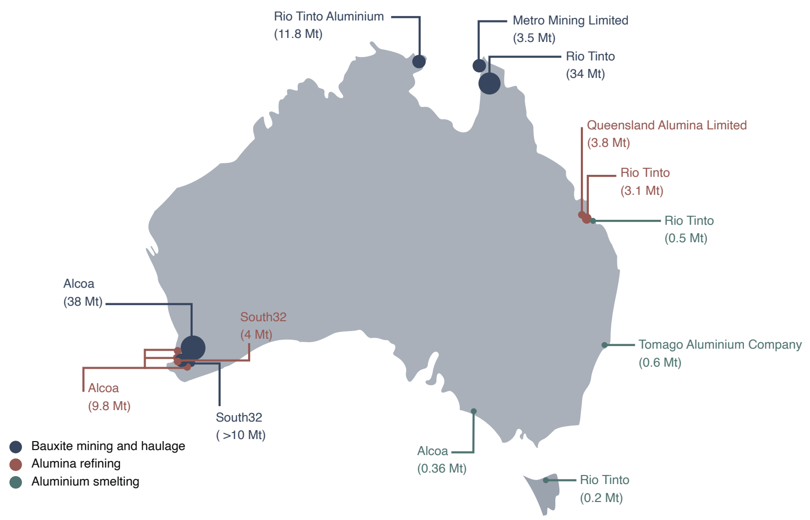
Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration to ensure Australia is at the forefront of emerging low carbon industrial technologies	5	Prioritise funding and support for pilots and demonstrations that build capability and expertise to enable Australia to maintain and grow market share in emerging green iron and steel industries.				
	6	Investigate iron ore compatibility with green steelmaking. This should prioritise efforts and collaborations to develop methods of processing hematite-goethite ore or expanding current magnetite output.				
Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition in a decarbonising global economy	7	Develop firm commitments for offtake for green steel. Government should set annual targets for major building and construction projects starting in 2030 and increasing through to 2040. This should come initially through state level targets for infrastructure and construction projects and should include certification schemes for low-emissions green iron and steel.				
	8	Certification for emissions standards for steel production. Robust certification for embodied carbon should be established to ensure accountability and transparency for low-emissions steel claims.				
Develop integrated net zero regions, supply chains and energy network solutions	9	Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions. Government support and regulation for retraining current workforces in carbon-intensive iron and steelmaking industries will be needed to ensure a just transition for existing communities.				
	10	Build the circular economy through extensive build-out of steel scrap collection, processing, and recycling facilities in Australia, designing products and services for circularity, and business model changes such as data-driven 'Product-as-a-service' models.				

4. Focus on aluminium

Aluminium production consists of three component processes, namely, bauxite mining, alumina refining and aluminium smelting. Aluminium smelting has the highest emissions intensity, releasing an average of 16 tonnes of CO_2e per tonne of aluminium produced, with the majority of emissions resulting from electricity use during the smelting process (International Aluminium Institute 2021).[38] With the global aluminium supply chain responsible for around 1 billion tonnes of greenhouse gas emissions annually and global demand for aluminium expected to increase by up to 50 per cent by 2050, solving the challenges of decarbonising the supply chain will be vital to limiting global warming to 1.5°C (World Economic Forum 2020b).

38 16 tonnes of CO_2e per tonne of aluminium is based on a global average and will vary depending on the type of electricity used (i.e. coal fire generated vs. renewable electricity)

Aluminium in Australia

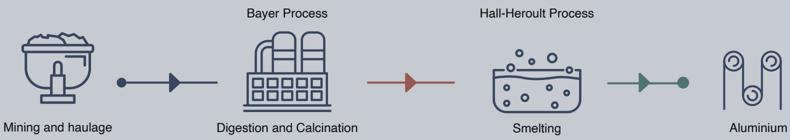


14,371 jobs across the supply chain

103Mt of bauxite, **21Mt** of alumina, and **1.6Mt** of aluminium produced annually, generating **A$13 b** in exports

approximately **35MtCO2e** emitted each year

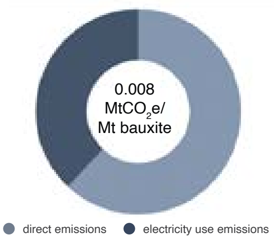
Aluminium is produced via bauxite mining, alumina refining, and aluminium smelting



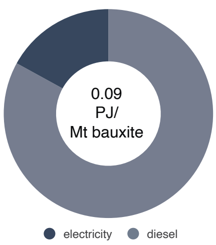
● **Bauxite mining** ● **Alumina production** ● **Aluminium production**

Bauxite

Emissions

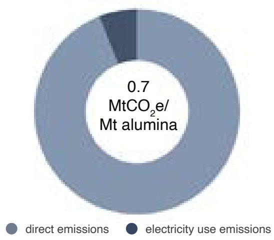


Energy Use

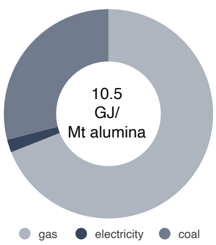


Alumina

Emissions

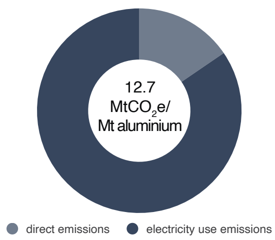


Energy Use

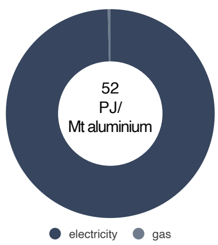


Aluminium

Emissions



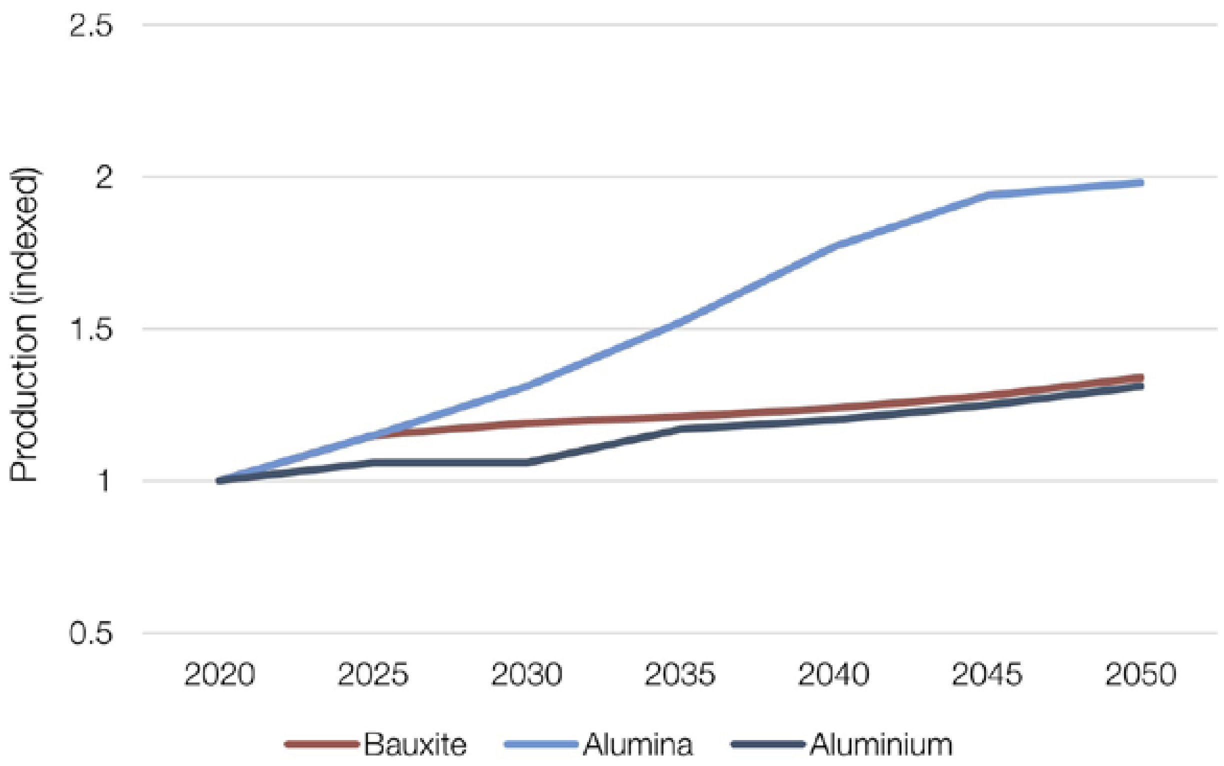
Energy Use



4.1 Aluminium supply chain production assumptions

The Australian Industry ETI modelling explores different production outlooks for bauxite, alumina and aluminium. In line with scenario narratives, the greater emissions reductions achieved in the 'Coordinated action scenario' allows Australia to improve its competitiveness in a decarbonising world and expand its production. In the 'Coordinated action scenario', the production of bauxite increases with Australia maintaining its current market shares. Alumina production in Australia increases in line with higher aluminium production in Australia's main alumina export markets (e.g. India and South Africa).[39] Similarly, aluminium production grows in line with Australia's share of projected global aluminium growth (Figure 4.01).

FIGURE 4.01: Assumed relative production changes in Australia under the 'Coordinated action scenario' (Australian Industry ETI analysis based on (DISER 2021c; IEA 2021c and BloombergNEF)



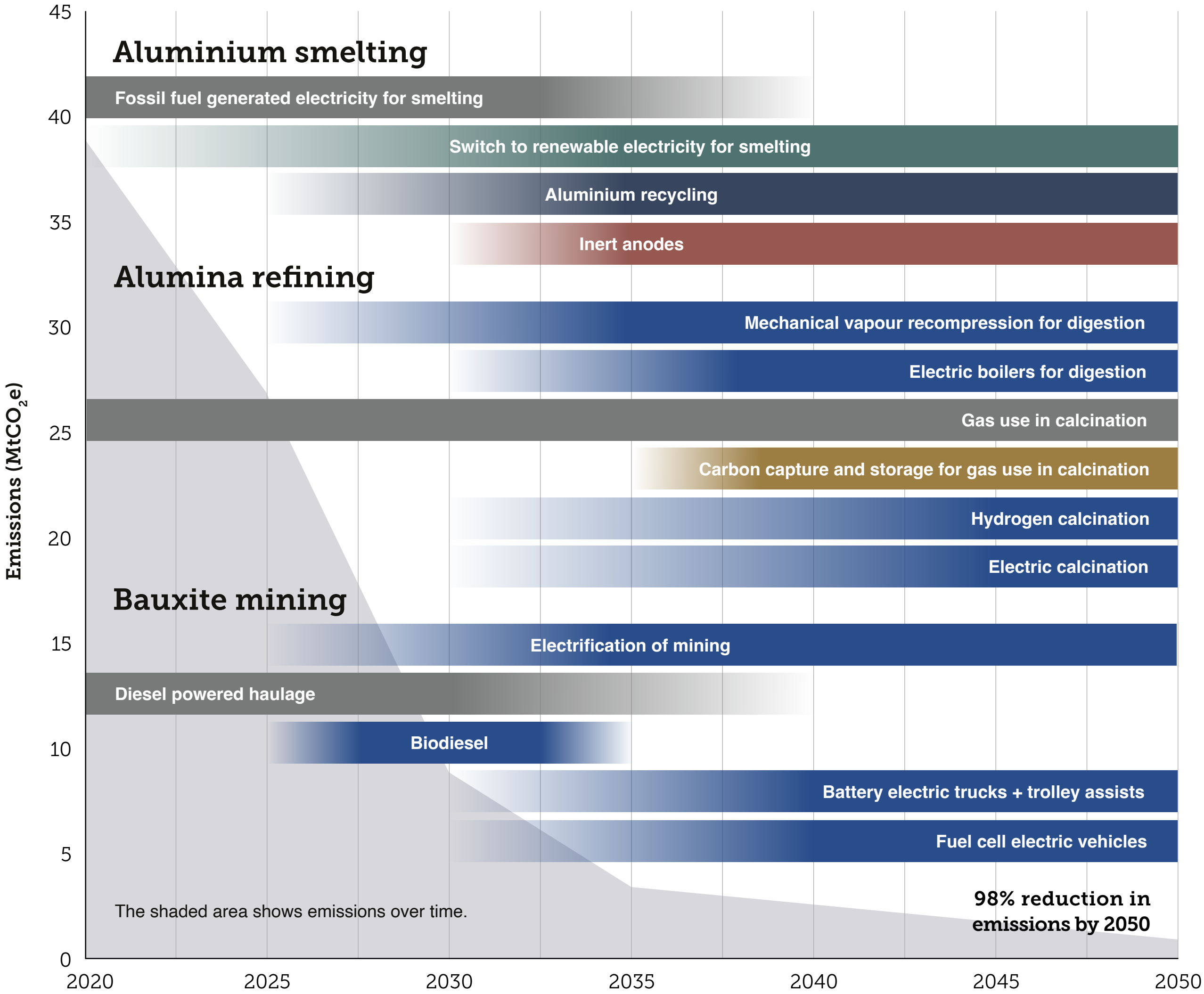
4.2 Technology deployment timeline

The 'Coordinated action scenario' shows what could be done to grow or maintain the aluminium supply chain while remaining within a 1.5°C carbon budget for the whole Australian economy, by deploying a range of technology solutions as shown in Figure 4.02. This chart shows the timeline of implementation that the model finds to be the least-cost pathway, based on technology assumptions and other changes across the Australian economy.[40]

39 Production inputs draw on BloombergNEF NEO 2021 projections and other sources for global metals demand and additional assumptions regarding Australia's share of the global market. Input assumptions are described in the companion technical report. Secondary aluminium demand uses recycled aluminium rather than alumina, so only primary production demand is considered when determining alumina demand assumptions. Alumina production is assumed to be supplied by onshoring on the supply chain. Both primary and secondary production are considered for aluminium production.

40 Not all technology solutions that may play a role in decarbonising the supply chain are represented by the model. In particular, several technologies to decarbonise alumina calcination are not displayed in the technology deployment timeline but may play an important role in the transition. Assumptions regarding which technologies were included in the modelling are given in the companion technical report.

FIGURE 4.02: Technology deployment timeline for the decarbonisation of the aluminium supply chain in the 'Coordinated action scenario'[41]



2020–2030

Australian Industry ETI analysis finds that total emissions from the aluminium supply chain in Australia were approximately 39$MtCO_2e$ as a result of bauxite mining (0.8$MtCO_2e$, 2 per cent), alumina refining (15$MtCO_2e$, 39 per cent) and aluminium smelting (22.8$MtCO_2e$, 59 per cent) in 2020.

To achieve emissions reductions in line with a 1.5°C trajectory, the 'Coordinated action scenario' shows that the electrification of bauxite mining and fuel switches to biodiesel for heavy haulage is required from 2025.

The main opportunities for decarbonising alumina refining are technologies to abate emissions from high process heat. Mechanical vapour recompression could begin to be implemented by 2030, abating emissions from the first step of alumina refining – called digestion – which requires temperatures of around 200°C (see Information Box 4.01). The significantly higher temperatures (up to 1000°C) needed for the second step – called calcination - require different technologies to replace fossil fuel use. In the 'Coordinated action scenario', abatement technology options are not yet cost-competitive with incumbent gas-powered calcination, which remains the dominant technology in this decade.

With most emissions for aluminium smelting resulting from electricity use, the scale of renewable energy deployed in the 'Coordinated action scenario' could see emissions from aluminium start to decline, complemented by increased aluminium recycling.

41 The model findings are in 5-year increments. For example, technologies introduced in 2028 can only appear in the modelling results from 2030 onwards.

2030–2040

In 2030, battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) could start to replace diesel powered haulage for bauxite mining as these vehicles become more available and costs of renewable electricity and hydrogen decrease.

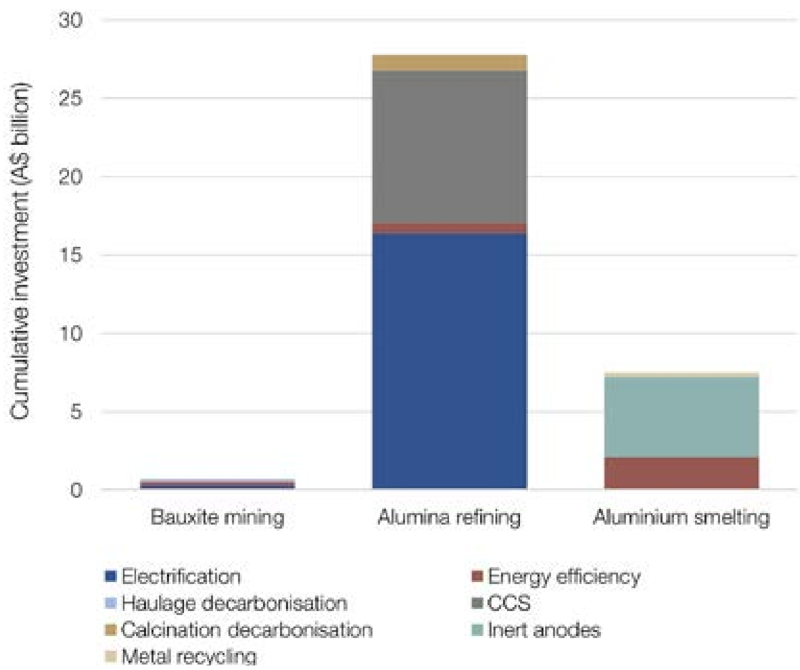
The use of hydrogen calcination and electric calcination increases in this decade, and both of these technologies are being investigated by industry in Australia. However, the modelling also shows continued gas use for calcination, with carbon capture and storage (CCS) deployed in 2035 to abate emissions in the 'Coordinated action scenario'. There is significant uncertainty in the costs and practicalities of implementing abatement technologies for alumina production. These include costs and reservoir availability for CCS, the capital investment required for electric calcination and costs of hydrogen for use as fuel in calcination. The focus of industry is on developing electric or hydrogen calcination to decarbonise alumina production over the next decade. Furthermore, the high natural gas prices could further favour electric or hydrogen-calcination over CCS. This is discussed in Information Box 4.02.

Non-energy emissions in aluminium smelting, resulting from the use of carbon anodes, can be abated by switching to inert anodes. Although inert anodes require high capital investment, they may result in long-term operating cost savings and uptake could occur as soon as these become commercially available in 2030.

2040–2050

The scale of technology deployment and grid decarbonisation in the 'Coordinated action scenario' could see emissions reductions of 98 per cent across the aluminium supply chain by 2050. This is enabled by significant investment in low-emissions technologies. By 2050, as much as A$28.5 billion could be required for technology investments for bauxite mining (A$692 million) and alumina refining (A$27.8 billion)[42] and a further estimated A$5.4 billion to deploy inert anodes[43] for aluminium smelting and to increase aluminium recycling (Figure 4.03). The investment needed to decarbonise the energy grid and ensure a reliable, firmed supply of electricity for aluminium smelters will add substantial additional costs to this figure.

FIGURE 4.03: Cumulative investment in low-emissions technologies in the 'Coordinated action scenario'.

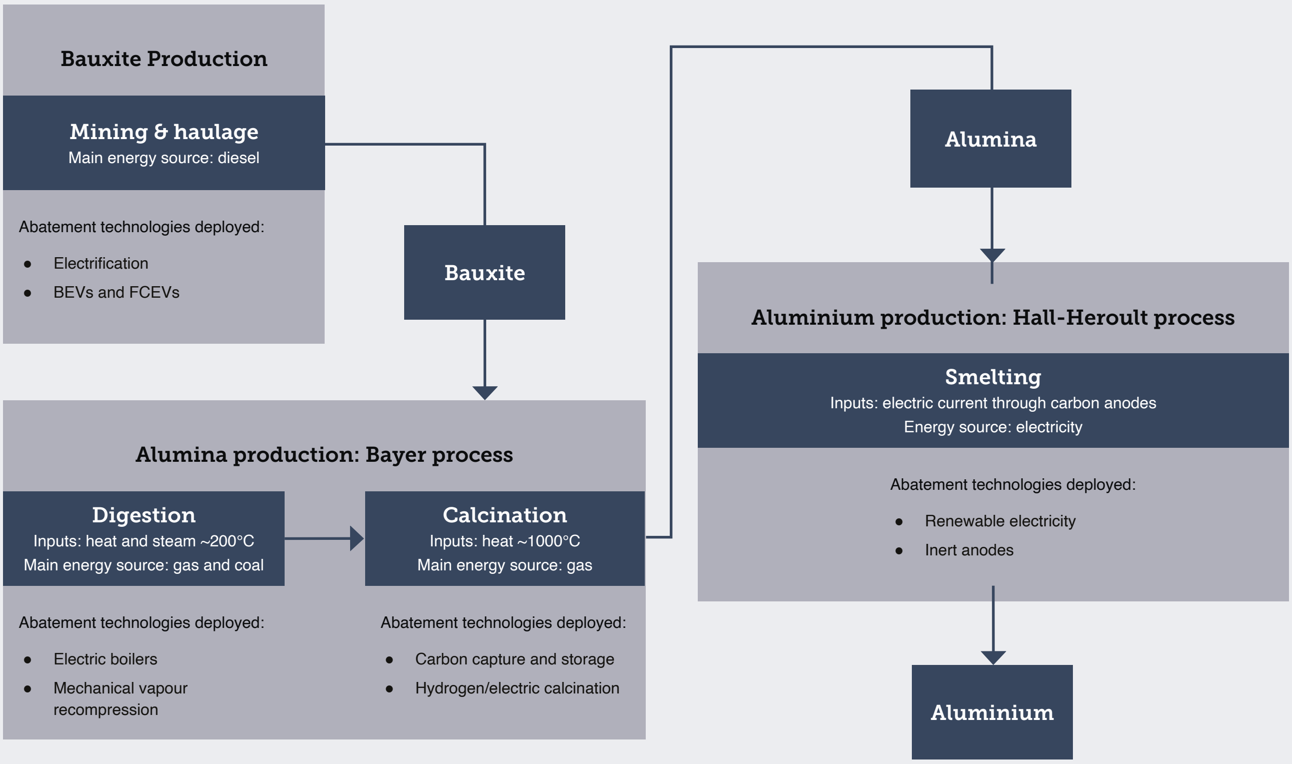


42 Recent publications such as the Alumina Roadmap (ARENA 2022) and MVR Retrofit and Commercialisation Report (Chatfield 2022) also investigate options for the decarbonisation of alumina refining. Some of the conclusions from these reports vary from what is presented here, as differing methodologies and assumptions have been used for each. These differences highlight the uncertainty in the future technology pathway for this sector, and make it clear that further pilots and demonstrations are vital to understand the optimum pathway to decarbonisation. The cumulative technology investment under the 'Coordinated action scenario' is based on growth assumptions shown in Figure 4.01, which sees Alumina production doubling between 2020 and 2050.

43 Investment estimates based on research by BloombergNEF. Estimates of the investment required may not accurately reflect the future cost of inert anodes as this technology is still under development.

INFORMATION BOX 4.01

FIGURE 4.04: Selection of technology options to decarbonise the aluminium supply chain



INFORMATION BOX 4.02

Sensitivity study: the effect of gas prices on alumina decarbonisation.

Alumina refining currently relies on gas to achieve the high temperatures needed for calcination. There are a range of options to decarbonise alumina refining including electric calcination, hydrogen calcination and gas calcination with CCS. There is uncertainty in the preferred technology mix moving forward, however the focus of industry in Australia is on developing electric or hydrogen calcination.

The continued use of gas (with or without CCS) in alumina refineries is partly enabled by low gas prices. While gas use with CCS continues in the ‘Coordinated action scenario’ under the modelled assumptions, the current context of extended periods of higher than anticipated gas prices along east coast Australia where some alumina refineries are located casts doubt on this option. To evaluate the effects of gas price on technology deployment, a sensitivity study was conducted for the ‘Coordinated action scenario’ in which elevated gas prices were assumed (see companion technical report). In general, long-term gas prices of A$14/GJ and higher resulted in electric calcination replacing gas powered calcination as early as 2030 in the sensitivity study.

4.3 Aluminium supply chain decarbonisation

The 'Coordinated action scenario' shows that decarbonising the aluminium supply chain in line with a 1.5°C carbon budget requires the development and deployment of low-emissions technologies, alongside an unprecedented energy system transformation, presenting challenges for achieving decarbonisation (Figure 4.05).

FIGURE 4.05: Challenges for aluminium decarbonisation in Australia

Developing emerging technologies to decarbonise the aluminum supply chain	**Deploying techologies** and transitioning existing plant and operations.	**Integrating** hydrogen capacity at scale and expanding aluminium recycling	**Achieving the scale** of cost-competitive, reliable renewable electricity

Actions can be taken to overcome these challenges. This section discusses key enablers of the transition for the aluminium supply chain, with a set of recommended actions at the end of the chapter.

Developing emerging technologies

Many technology solutions to decarbonise the aluminium supply chain are not yet commercially proven, increasing both the financial and implementation risks of these solutions.

As discussed in chapter five, 'Focus on other metals', (BEVs) and (FCEVs) are in the demonstration phase of development. Several barriers currently limit their further development including:

- Lack of clear demand signals for BEVs or FCEVs preventing investment in research and development
- Battery energy density cannot currently compete with diesel on range or refuelling time
- Lack of hydrogen infrastructure and hydrogen costs preventing development and deployment of FCEVs

The key opportunity for decarbonising alumina refining is replacing the fossil fuels (gas and coal) currently used for heat for digestion and calcination. Low-emissions technologies to achieve the lower temperatures (around 200 – 300ºC) needed for digestion are further along in their development than those needed for calcination. Mechanical vapour recompression is a mature technology already used in other sectors such as distillation plants (Mission Possible Partnership 2021b). The use of mechanical vapour recompression for alumina refining is still in its early stages, with no known operational alumina plants using the technology. Electric boilers may be required to achieve the higher digestion temperatures (around 300ºC) required in some refineries. Developing low-emissions technologies capable of achieving the higher temperatures needed for calcination (~1000ºC) is more challenging. Several emerging technology solutions are being investigated including electric calcination and hydrogen calcination.

For aluminium smelting, the key to decarbonisation is switching to renewable electricity (discussed later in this chapter in, 'Achieving the scale of cost-competitive, firmed renewable electricity') and abating non-energy emissions that result from carbon anodes. The strong uptake in modelling results for the 'Coordinated action scenario' shows that the development and deployment of inert anodes is advantageous, owing to their relatively low operating cost and ability to significantly reduce non-energy emissions in aluminium smelting. Inert anodes are currently in development and are not yet commercially available.

The rapid deployment of low-emissions technologies will be needed to ensure the aluminium supply chain can reduce its emissions in line with a 1.5 °C pathway. Key actions are needed now to ensure they are developed to the point where they can be deployed in commercial settings. Key enablers include:

Promoting the rollout of low-emissions haulage through collaboration

Partnerships between miners and manufacturers of low-emissions haulage trucks can provide clear demand signals, ensuring investment confidence for the further development of BEVs and FCEVs. Co-investment between miners and manufacturers can also facilitate R&D by distributing financial risks and rewards across the value chain. See chapter five, 'Focus on other metals', for a larger discussion of low-emissions haulage.

Investigating technologies for process heat abatement

Further research and development is needed for electric and hydrogen calcination technologies and their deployment into existing plants. An additional challenge for decarbonising alumina refining in Australia is the difference between bauxite ore deposits, especially between the east and west coast, potentially requiring different strategies and technology solutions. Pilot and demonstration projects will be needed to determine which technologies are best suited for differences in bauxite ore types. Pilot and feasibility studies are currently underway for renewable-energy-powered electric calciners in Western Australia (ARENA 2022a) and hydrogen calcination in Queensland, both of which are supported by ARENA (ARENA 2021).

Support R&D for inert anodes

The development of inert anodes has been a focus of the aluminium sector for decades, with most research currently focused on developing anode materials (Mission Possible Partnership 2021b). Alcoa and Rio Tinto have developed ELYSIS, a low-carbon aluminium produced using inert anodes. ELYSIS is being scaled from a pilot study in Canada to demonstrate commercial-size production in 2023 (ELYSIS 2021). Continued support for the commercial scale deployment of inert anodes in Australia will have significant benefits for aluminium decarbonisation. With several companies investigating inert anode technology, partnerships and collaborations can help fast-track R&D and distribute financial risks.

Transitioning existing plants and operations

Transitioning assets presents challenges for existing operations. For example, while technologies such as hydrogen calcination for alumina refining could be retrofitted into existing assets, others such as electric boilers and electric calcination, inert anodes or battery electric vehicles will require the full or partial replacement of existing assets. The high capital investment required for integrating new fuels and technologies coupled with production losses during downtime will further increase financial risks.

A strong engineering focus will be needed to optimise the rollout and integration of new technologies and supporting infrastructure. This may require new teams and labourers with necessary skill sets and technical expertise, presenting both risks and opportunities for existing workforces in the aluminium supply chain.

With a number of risks and challenges for transitioning existing facilities, it is important to have the necessary support in place to prepare operations and workers for the transition.

Transition plans for existing plants and mine sites

Careful scheduling and strategic decisions will be needed to identify transition plans that balance financial risks and the benefits from emissions savings. Transition plans for existing plants and mine sites should carefully balance current asset life times with emissions reductions potential to ensure the sector is on track to stay within a 1.5°C carbon budget. This could consider existing contracts and commercial obligations.

Support for transitioning plants

Support will be needed to help mitigate risks as existing plants transition. Plant downtime during the transition will add additional costs (in addition to significant technology and equipment investments) due to production losses during construction. This is likely to occur to differing extents within the supply chain. For example, it is possible to work on individual pots for aluminium smelting, reducing production losses compared to alumina refineries which may require an entire plant shutdown during construction.

The transition of existing plants will need to occur alongside an extensive build-out of renewable energy infrastructure. Clear long-term development roadmaps can help provide investment confidence for players in the aluminium supply chain. Finance instruments for transitioning plants will be needed, including, for example, tax incentives for new technology investments or government funding. Government can also support the transition of existing facilities through streamlined development and planning approval processes.

Development and training programs for workforces

Skilled engineers, technicians, trade workers, and machinery operators will be needed to ensure the transition to new low-emissions technologies occurs effectively and safely. This includes renewable energy engineers developing renewable energy generation on a large enough scale to power new technologies in the supply chain (Ker 2022).

Current workforces will need to be retrained to use the new machinery and fuels (such as hydrogen) once the transition has taken place. To ensure an effective and just transition, government support and regulation for developing and training current workforces must be in place.

Integrating hydrogen capacity at scale

Hydrogen may play an important role in decarbonising the aluminium supply chain, especially for applications where electrification is more challenging. Although the 'Coordinated action scenario' does not deploy substantial amounts of hydrogen calcination, consultation with Australian Industry ETI research partners suggests that this may play a significant role in decarbonising alumina refining as the technology offers key advantages. It can be retrofitted to existing gas-powered calciners and can help produce the steam necessary for digestion, thereby helping to lower the energy requirements and emissions for this step. Hydrogen also plays a role in decarbonising bauxite mining through the deployment of FCEVs in the 'Coordinated action scenario'.

The current lack of hydrogen infrastructure will require a substantial build-out of production facilities, along with storage and distribution infrastructure. This will need to occur before alumina refineries or bauxite mines can use hydrogen for their operations.

Promoting the development of a clean hydrogen market

If hydrogen calcination is deployed, a robust hydrogen supply chain will be needed. Demonstrating demand for hydrogen use in mining and alumina refining can help create market signals for clean hydrogen producers. Partnerships between hydrogen suppliers and alumina refineries can facilitate offtake by creating clear supply-demand profiles.

Access to affordable clean hydrogen

With the Australian Industry ETI modelling showing a strong preference for green hydrogen, especially in the long term (see chapter two, 'Pathway for heavy industry decarbonisation'), hydrogen costs will be influenced in turn by the costs of renewable electricity, storage, transport and transmission.

Strategies to reduce costs may include co-locating hydrogen supply and demand through hydrogen hubs to lower hydrogen storage and transport costs and achieve cumulative demand signals. However, establishing hydrogen hubs will depend on the availability of land and suitable renewable energy resources. If these are not available near existing bauxite mines and alumina refineries, hydrogen could be transported to the site via pipeline, ship or truck in order to integrate hydrogen at scale.

Safety standards for hydrogen use

A shift to hydrogen use will mean significant changes in the operations of mine sites and alumina refineries. Appropriate and robust safety standards must be developed to ensure the transition and continued use of hydrogen occurs safely.

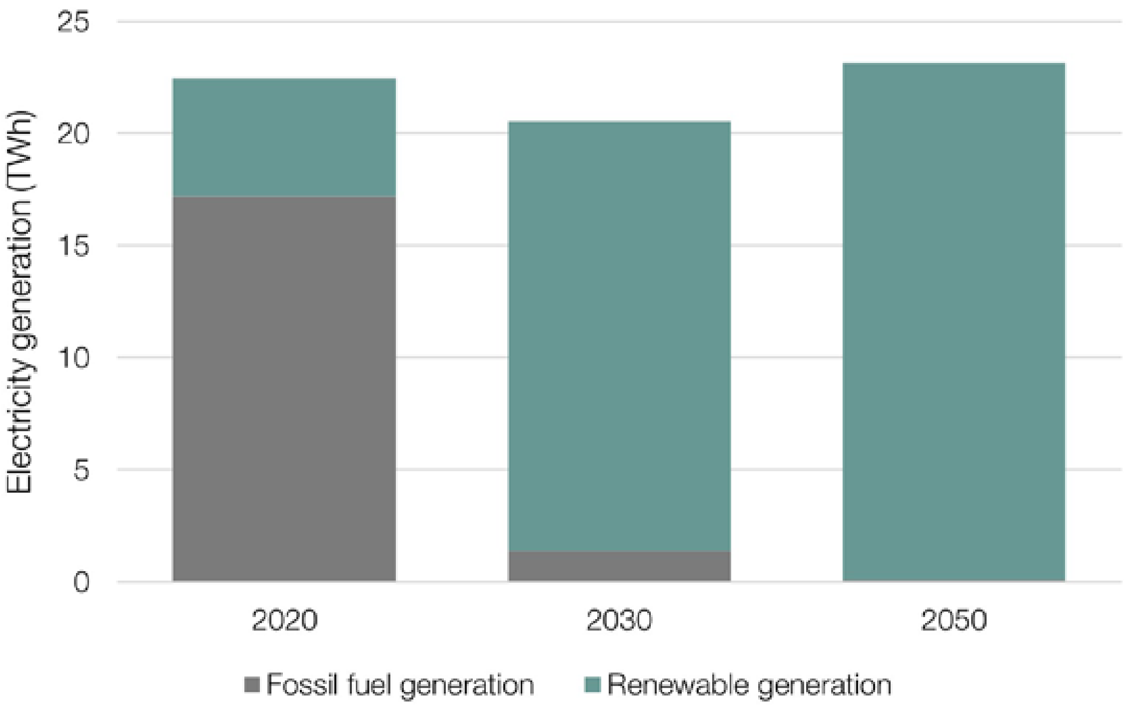
Achieving the scale of cost-competitive, firmed renewable electricity

Firmed, cost-competitive renewable energy is vital for bauxite mines, alumina refineries, and aluminium smelters.

Most emissions from aluminium smelting derive from electricity use. The sector's ability to decarbonise depends heavily on decarbonising the electricity grid. In the 'Coordinated action scenario', a strong shift to renewable electricity generation is seen between 2020 and 2030, with electricity supplied from renewables increasing almost four-fold (Figure 4.06). By 2050, 23TWh/year of renewable electricity generation will be needed to decarbonise aluminium smelting, requiring an extensive build-out of renewable energy capacity and associated energy system infrastructure.

The scale of renewable energy required to decarbonise aluminium smelting alone is equivalent to a third of the renewable generation currently produced throughout Australia (DISER 2022b). Clearly, this is a significant shift in scale for the energy system, which will require coordination and planning between electricity providers, government, the aluminium sector and investors. Vital to this transition will be ensuring that renewable energy is firmed through storage options to deliver constant, reliable electricity supply.

FIGURE 4.06: Electricity generated from fossil fuel and renewable sources for aluminium smelting



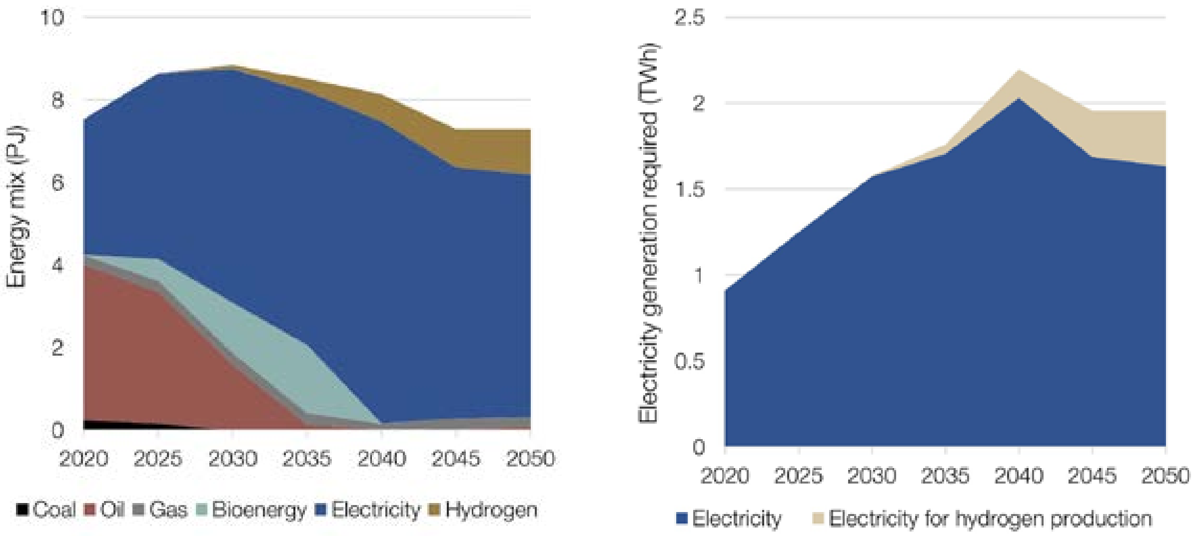
The scale of electricity needed for aluminium smelting means that electricity accounts for around 30 to 40 per cent of an aluminium smelter cost base. The aluminium industry has a number of critical electricity supply requirements: electricity costs must be globally competitive, supply must be consistent and uninterrupted, and supply is secured under long-term contracts (Australian Aluminium Council 2020).

Aluminium smelters currently contract with large, baseload electricity suppliers such as coal power plants for low-cost uninterrupted electricity supply. Reliable electricity supply is critical, because interruptions of greater than a few hours can result in severe damage to plants, leading to long-term production losses. A shift to variable, renewable generation – as coal power plants retire – could present significant risks to aluminium smelters if not managed effectively to ensure the scale of generation and firming mechanisms can deliver low-cost electricity (Wong et al. 2020).

Bauxite mines and alumina refineries could also face significant challenges during the transition to renewable generation. In the ambitious 1.5°C aligned 'Coordinated action scenario', gas use decreases as electric boilers and mechanical vapour recompression begin to be implemented by 2030. Between 2020 and 2050, our model shows a significant role for gas with CCS, however we note low interest from industry in this technology pathway at this time. Based on the model assumptions, electricity use increases 11-fold, from 1.6TWh/year in 2020 to 18TWh/year in 2050. Significant industry interest in electric calcination suggests substantially more electricity may be needed if there is greater adoption of electric calcination technology compared to the relatively small uptake seen in the 'Coordinated action scenario'. Similarly, although hydrogen calcination is deployed to a small extent in the 'Coordinated action scenario', the production of hydrogen via electrolysis in a larger shift to hydrogen calcination could increase electricity demand substantially.

In the ‘Coordinated action scenario’, a switch to low-emissions haulage and increasing electrification could increase electricity use in bauxite mines by 76 per cent by 2050, increasing from 0.9TWh in 2020 to 1.6TWh in 2050 (Figure 4.07). With the Australian Industry ETI modelling showing a strong preference for hydrogen produced via electrolysis in the long term (see chapter two, ‘Pathway for heavy industry decarbonisation’), the production of hydrogen to fuel FCEVs will add an additional 0.3TWh/year of generation demand.

FIGURE 4.07: Changes in fuel use for bauxite mining (left) with the corresponding rise in electricity generation requirements (right) in the ‘Coordinated action scenario’.



While the scale of electricity required for bauxite mines is comparatively much lower than the scale needed to decarbonise aluminium smelters and alumina refineries, many bauxite mines are not connected to the grid. This creates unique challenges for securing renewable generation and integrating renewable electricity into existing facilities.

An unprecedented transformation of the energy system is required to decarbonise aluminium smelters and alumina refineries. Action is needed now to ensure low-cost, firmed renewable electricity can be delivered, including to off-grid bauxite mines.

Storage solutions to deliver low-cost, firmed renewable electricity

With electricity contributing 30 to 40 per cent of an aluminium smelter's cost base, access to low-cost, firmed renewable electricity will be critical to achieving decarbonisation. However, with increasing penetration of renewables, required storage capacity and storage duration increases, leading to increases in electricity costs. Smelters currently contract directly with coal-fired power plants for around A$40-50/MWh. Aluminium smelters requiring firmed electricity will need to contract a bundle of renewables and storage through power purchase agreements. This could cost around A$73/MWh from 2030.

Developing effective generation and storage solutions – including options such as customer-owned storage, thermal storage, and large-scale batteries – should be optimised to ensure reliable and affordable electricity is available for aluminium smelters and alumina refineries.

System planning to maximise load balancing

Effective demand management can reduce renewable electricity costs by reducing the need for storage. Aluminium smelters and alumina refineries can play a unique role in this. For example, smelters could modulate their electricity load over short periods of time when electricity supply is low (Butler 2020). Load balancing can only be provided for short periods of time (up to 3 hours), as longer shutdown periods can cause smelter potlines to freeze, leading to fatal damage to plant equipment and significant long-term production losses (Judd 2016). Technologies to extend load balancing periods are currently being investigated. The use of thermal storage, for example, can enable alumina refineries to act like a battery; by drawing heat from thermal storage during periods of low variable electricity supply and 're-charging' the thermal storage during periods of high variable electricity supply (Alcoa 2021).

Collaborations between energy providers and alumina refineries/aluminium smelters will be needed to maximise the benefits of load balancing, with appropriate market mechanisms to decrease risk for providing these services; especially for aluminium smelters.

Co-locating renewable electricity generation and end-use

The AEMO 2022 ISP models proposed renewable energy zones, some of which are proximate to aluminium smelters. Co-locating renewable energy infrastructure and aluminium operations can facilitate cost reductions by minimising transmission needs. Partnerships can facilitate this though off-take agreements or through mechanisms such as market requests for proposals (RFP) to create clear demand signals for renewable electricity generators.

Optimising mine sites for renewable energy use

While a discussion of enablers for effectively integrating renewable energy at off-grid mine sites is given chapter five, 'Focus on other metals', priority enablers that are also relevant to bauxite mining include:

- Contracts for off-grid renewable energy integration: to reduce the impact of variability, a bundle of renewables, storage and peaking plants (with gas or diesel for rare extended periods without sunshine or wind) will need to be built or contracted. This infrastructure will also carry a remote construction cost premium, and mines will require strong incentives to offset some of these capital investments.
- Adopting new haulage practices: transitioning to low-emissions haulage may require substantial changes to current haulage practices. Switching to BEVs, for example, may increase downtime while haulage trucks are recharged. Different charging strategies could overcome this challenge, such as battery-swap stations, increasing the number of haulage trucks to ensure constant availability, or switching to smaller, trolley-based systems.
- Policy and financial support for renewable energy projects: effective policy measures will play a vital role in achieving the necessary scale of the transition. Renewable energy targets, coupled with strong sustainability benchmarks for mining, can help drive the uptake of renewable energy. Bespoke financial instruments that acknowledge the risks associated with onsite renewable generation can ensure sufficient capital is available to fund the transition.

INFORMATION BOX 4.03

Decarbonising aluminium smelters and alumina refineries can facilitate a broader, system-wide energy transition.

The scale of renewable energy needed to decarbonise aluminium smelters and alumina refineries is a significant barrier to the decarbonisation of the supply chain; however, it also provides opportunities to facilitate a broader, system-wide energy transition. The massive build-out of electrification infrastructure, including generation and transmission, needed to decarbonise the aluminium sector provides a large asset base that can also be utilised by other sectors and industries in the region.

With aluminium smelters likely to be one of the hardest sectors to transition to renewable generation owing to the sheer scale of firmed renewable energy needed, learnings from this transition can provide a strong basis to facilitate transition for other industries. Effective mechanisms for sharing knowledge will be needed and should manage shared risks and intellectual property across sectors.

Expanding aluminium recycling

Aluminium can be recycled endlessly without losses in value or metallurgical properties. Because of this, approximately 75 per cent of all aluminium made is still in use today. Aluminium recycling provides significant emissions savings as recycling requires 95 per cent less energy compared to primary aluminium production (The Australian Aluminium Council 2020). Aluminium recycling therefore provides an opportunity to maximise aluminium production without exceeding carbon budget constraints for a 1.5°C pathway.

There are two types of aluminium scrap: new and old scrap. New scrap results from off-cuttings during the manufacture and fabrication of aluminium products. This can be collected and recycled by aluminium smelters. Old scrap results from discarded consumer goods such as beverage cans or old car parts. This type of scrap is usually contaminated and is therefore dealt with by specialist recyclers, as the contaminants pose risks to aluminium smelters (The Australian Aluminium Council 2020).

Australia's domestic aluminium recycling is low compared to other countries, with 95 per cent of aluminium scrap recovered in Australia exported, primarily to South Korea and Indonesia (Australian Aluminium Council 2021). If Australia increased its domestic scrap recycling in line with global averages, approximately 30 per cent of current primary production could be achieved through recycling, while avoiding around 25 per cent of Australia's emissions from aluminium smelting.[44]

The Australian Industry ETI modelling assumes that future growth of aluminium recycling in Australia is capped at the current ratio of exported scrap to Australian aluminium production. With aluminium recycling likely to play a role in achieving significant emissions reductions from the aluminium sector, a substantial build-out of aluminium recycling facilities and practices is needed.

Build-out Australia's aluminium remelting capabilities

Aluminium recycling in Australia is currently limited by low remelting capabilities, due to safety and process risks from contaminated aluminium scrap. Expanding aluminium recycling will require the build-out of remelting facilities coupled with improvements in scrap recovery and separating practices.

Improve scrap recovery and separation techniques

Aluminium producers' ability to increase their recycling capacity depends on the availability and quality of scrap. Improvements in scrap collection and sorting will be needed for Australia to expand its recycling. Partnerships across the supply chain can promote recovery through circular business models that promote closed-loop recycling. This can be complemented by collaboration between scrap collectors and product end-users to reduce the amount of scrap lost to landfill. Educational programs and clear product labelling can help promote the responsible disposal of aluminium products.

44 Simplified calculations based on Australian consumption of approximately 0.64Mt aluminium in 2018-19 as proxy for annual aluminium waste. Given the long-lived nature of aluminium products (generally >40 years), actual waste may be less than this. Global average aluminium scrap recovery is around 73 per cent (van Heusden et al. 2021).

4.4 Momentum is building across the Australian and global aluminium industry

ALUMINIUM

Companies are committing to the Research and development of new low emissions technologies

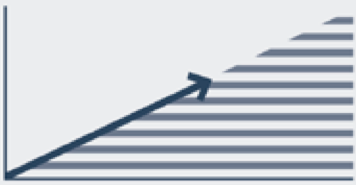
Alcoa and Rio Tinto led the formation of ELYSIS, a Canadian company developing carbon free aluminium smelting. The project has also received funding from Apple, the Canadian Government, and the Quebec Government.

Alcoa is trialling the technical and commercial feasibility of mechanical vapour recompression and electric calciners powered by renewable energy to decarbonise their alumina refining operations. These studies are supported by ARENA.

Rio Tinto is investigating the feasibility of substituting natural gas with renewable hydrogen for calcination, to partially decarbonise their alumina refining operations. The project also includes a demonstration project at Rio Tinto's Yarwun refinery. The study is partly funded by ARENA.

Renewable electricity is being used to power aluminium smelting

South32 and Alcoa Corp will spend approximately $175 million to restart operations at the Brazilian aluminium smelter – Brazil Aluminium – which has been under maintenance since 2015. The reopening will see the use of 100 per cent renewable energy to power the aluminium smelter.



Demand for green aluminium is increasing, with companies committing to purchase low emissions aluminium for their products

Apple has invested $4.7 billion to help the development of low-emissions manufacturing and recycling. Part of this involves the direct purchase of zero-carbon aluminium, which Apple will incorporate into its iPhone SE.

Rio Tinto and beer brewer Corona Canada have launched Canada's first low-carbon beverage can, released in select stores. The cans come with a QR code to inspire customers to find out more about the low carbon footprint of the can.

Ford is committing that 10 per cent of its aluminium purchases will be near-zero carbon aluminium by 2030, as part of the First Movers Coalition which aims to help commercialise zero-carbon technologies.

Leading lenders are developing climate-aligned financial frameworks to help decarbonise the aluminium sector

The Aluminium Climate-Aligned Finance Working Group – a partnership between the top 3 lenders for the aluminium sector and RMI's Centre for Climate-Aligned Finance – will create a financial framework that defines how lenders can support the decarbonisation of the aluminium sector. Lenders will include an assessment of how well the emissions of the aluminium portfolio are aligned with 1.5 degree climate targets in accordance with the guidelines of the UN convened Net Zero Banking Alliance.

4.5 Enabling the transition

The ‘Coordinated action scenario’ shows that a transition aligned with 1.5°C in the Australian aluminium supply chain is challenging, and requires strong, effective and coordinated action from industry, government and investors.

The Australian Industry ETI has identified the following objectives (Figure 4.08) to help create a prosperous, globally competitive, net zero aluminium supply chain in Australia.

FIGURE 4.08: Objectives and recommended actions for aluminium

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia’s industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower

Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy

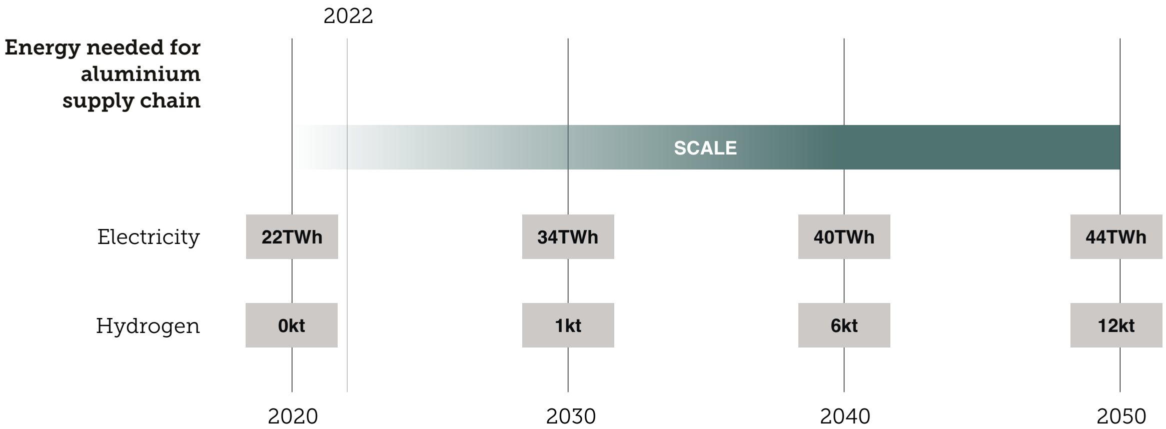
Develop **integrated regions, supply chains and energy network** solutions

A STRONG, ENDURING FRAMEWORK

1. Develop aluminium supply chain roadmaps for heavy industry

LARGE-SCALE, COST-COMPETITIVE, RENEWABLE ENERGY SYSTEM OF THE FUTURE

2. Set a series of short, medium, and long term goals for the development of the energy needed to decarbonise the aluminium supply chain
3. Develop storage solutions to deliver low-cost firmed renewable electricity
4. Set targets that drive the development of a large-scale, decarbonised hydrogen market

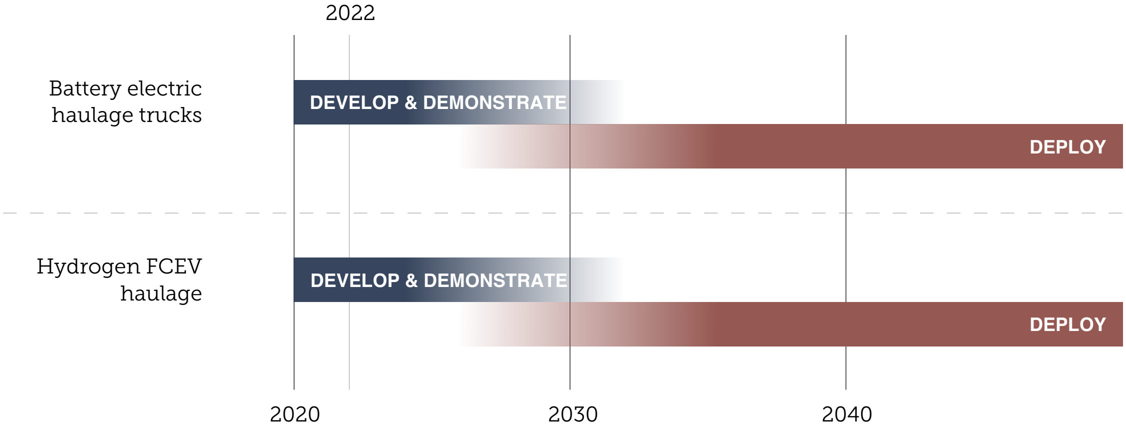


Note: Electricity and hydrogen use could be substantially higher if hydrogen and electric calcination technologies are taken up to a greater degree.

FIGURE 4.08: Objectives and recommended actions for aluminium (continued)

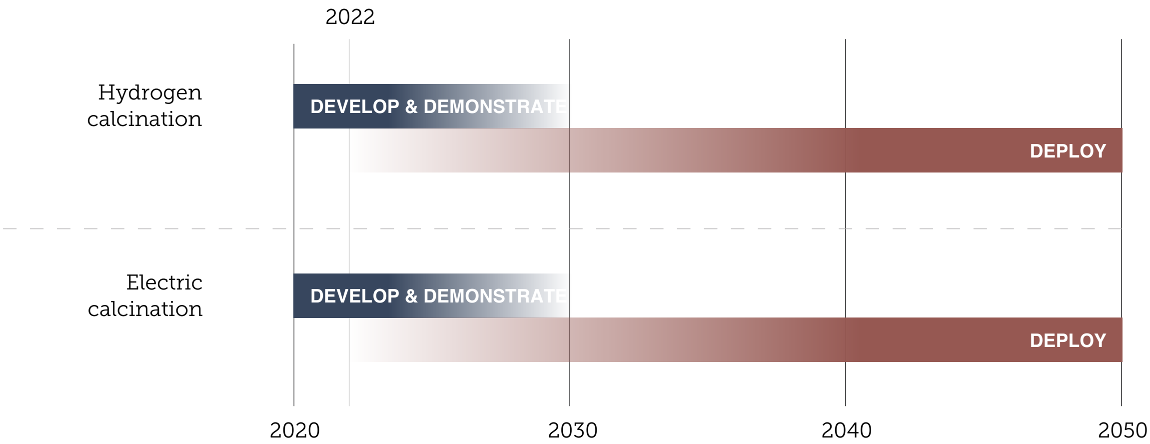
ACCELERATED DEVELOPMENT AND DEMONSTRATION

(5) Establish partnerships for development of net zero haulage between OEMs and miners



ACCELERATED DEVELOPMENT AND DEMONSTRATION

(6) Promote research and development of emerging technologies for process heat abatement



Note: Hydrogen calcination is not used extensively in the coordinated action scenario, but it is included here due to insights from industry participants.

(7) Promote research and development for inert anodes

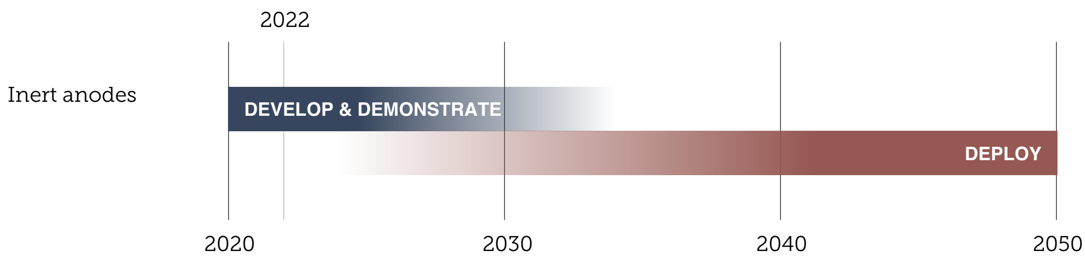
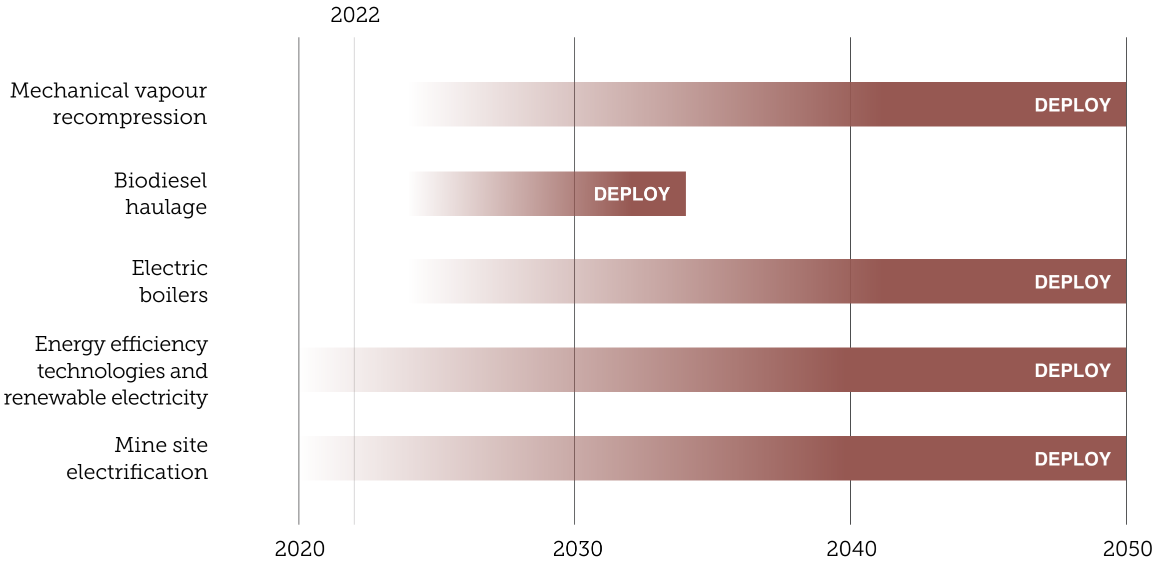


FIGURE 4.08: Objectives and recommended actions for aluminium (continued)

ACCELERATED DEVELOPMENT AND DEMONSTRATION

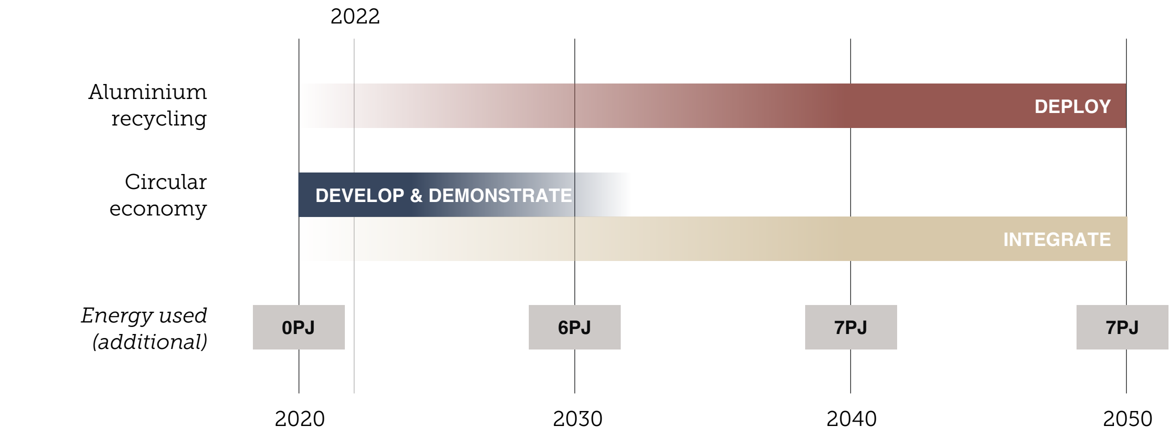
(8) Develop early supply, demand and enabling infrastructure to scale net zero solutions in the aluminium supply chain



INTEGRATED NET ZERO REGIONS, SUPPLY CHAINS AND ENERGY NETWORK SOLUTIONS

(9) Energy markets should prioritise enabling demand management

(10) Build the circular economy through extensive build-out of aluminium scrap collection, processing, and remelting facilities in Australia



To ensure a timely and effective transition of the aluminium supply chain, Table 4.01 shows a list of recommended actions. They are mapped against the four enabling themes that the Australian Industry ETI has identified as being important for driving decarbonisation in heavy industry, which are discussed in chapter eight 'Enabling the transition to heavy industry decarbonisation'. This mapping is represented by the coloured boxes. Chapter eight also contains key recommended actions to decarbonise all supply chains, which complement these recommended actions specific to aluminium.

TABLE 4.01: Recommended actions to achieve the decarbonisation of the aluminium supply chain.

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Develop aluminium supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation.		■		■
Transition to the large-scale, cost-competitive, renewable energy system of the future	2	Set a series of short, medium, and long term goals for the development of the energy needed to decarbonise the aluminium supply chain. This is potentially at the scale of 34TWh per year of renewable electricity by 2030 and 43TWh per year by 2050.	■			■
	3	Develop storage solutions to deliver low-cost firmed renewable electricity including options such as customer-owned storage, thermal storage, and large-scale batteries. Develop mechanisms to easily contract for these services to ensure the reliability and affordability of electricity at high penetrations of renewables. Partnerships can facilitate this though off-take agreements or through mechanisms such as market requests for proposals (RFPs) to create clear demand signals for renewable electricity generators and storage services.	■	■	■	■
	4	Set targets that drive the development of a large-scale, decarbonised hydrogen market and undertake a planned approach to develop and update regulation for rapid and safe development of hydrogen production, transport and storage.	■			■

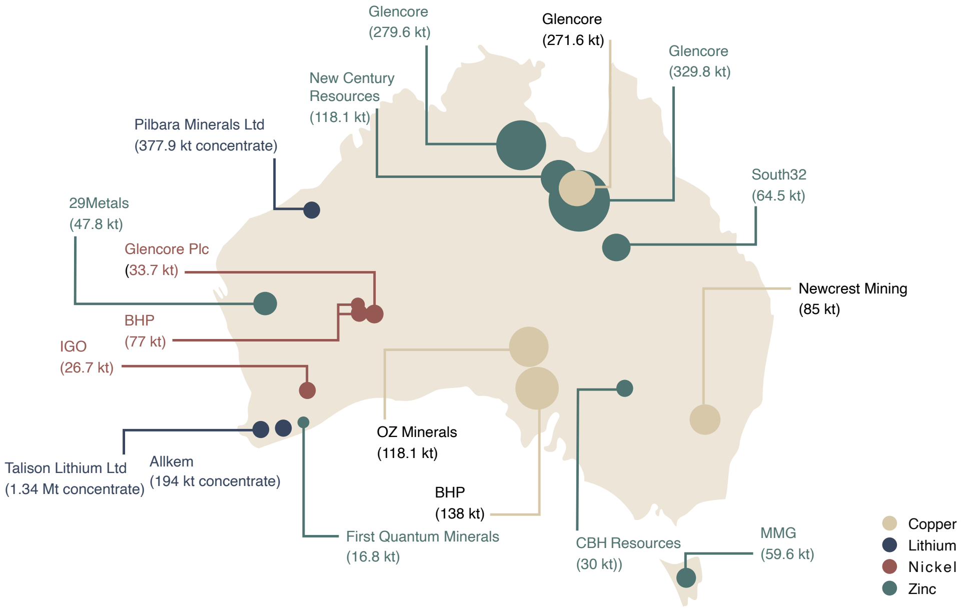
Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower	5	Establish partnerships for development of net zero haulage between OEMs and miners to aggregate demand and provide investment confidence for the further development of BEVs and FCEVs.	■	■		
	6	Promote research and development of emerging technologies for process heat abatement. Further research and development is needed for electric and hydrogen calcination technologies and their deployment into existing plants. R&D should consider the difference between bauxite ore deposits, especially between the east and west coast, potentially requiring different strategies and technology solutions.	■			
	7	Promote research and development for inert anodes. Continued support for the commercial scale deployment of inert anodes will have significant benefits for aluminium decarbonisation. Partnerships and collaborations can help fast-track R&D and distribute financial risks across the industry.	■	■		
Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	8	Develop early supply, demand and enabling infrastructure to scale net zero solutions in the aluminium supply chain. This should include levers such as offtake commitments, guaranteeing the purchase of green aluminium through government procurement, aggregation of industry demand, feed-in tariffs, voluntary pledges, mandates and certification schemes for low-emissions aluminium.	■	■	■	■
Develop integrated net zero regions, supply chains and energy network solutions	9	Energy markets should prioritise enabling demand management with appropriate market mechanisms for alumina refineries and aluminium smelters to facilitate lower cost firming of variable renewable energy for industrial processes.	■			■
	10	Build the circular economy through extensive build-out of aluminium scrap collection, processing, and remelting facilities in Australia, Partnerships across the supply chain should be established to promote recovery through circular business models that promote closed-loop recycling.	■	■	■	■

5. Focus on other metals

Other metals – nickel, lithium, copper and zinc – are essential inputs to low-carbon technologies such as batteries, wind turbines, hydrogen electrolysers and transmission infrastructure. These metals will therefore play a primary role in a global net zero transition. With global demand expected to rise substantially, the challenge will be to keep pace with this demand while meeting emissions and broader environmental requirements within the supply chain.

Australia is well placed to take advantage of the need for other metals, with relatively large global shares of reserves and production of nickel, lithium, copper and zinc. Solving the challenges of decarbonising this supply chain in Australia will be critical to ensuring a sustainable supply of these metals as the global energy transition gathers pace.

Other Metals in Australia

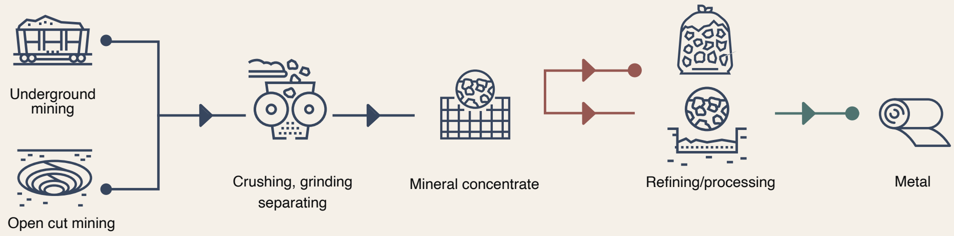


16,902 copper, nickel, lithium, zinc mining jobs

2.61Mt of copper, nickel, lithium, and zinc produced, generating **A$19.6 b** in exports each year.

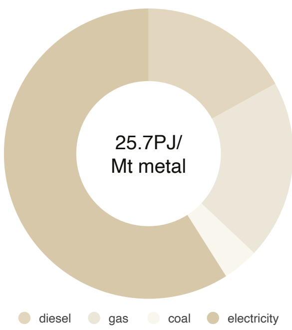
approximately **4.6MtCO_2e** emitted each year

Other metals mining and processing

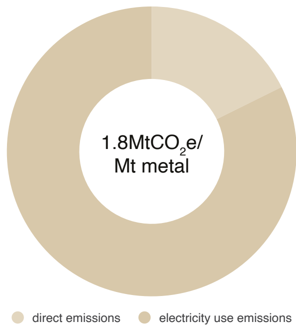


Other Metals Combined

Energy Use



Emissions



5.1 Other metals production assumptions

The decarbonisation of the global energy system will profoundly change demand for other metals. According to the IEA, efforts to achieve the goals of the Paris Agreement could require six times more mineral inputs in 2040 than today. The rise in demand for battery storage will see significant growth in global lithium demand, while an expansion of electricity networks and hydrogen electrolysers will see substantial growth in copper and nickel markets (IEA 2022d).

Australia is well placed to take advantage of an increase in demand for other metals owing to its shares of global reserves and production of other metals. Table 5.01 below provides a summary of key metals for different decarbonisation technologies and Australia's relative share of global reserves. Australia is ranked second for production of zinc and holds 32 per cent of global reserves, and ranks fifth for nickel production with 24 per cent of global reserves. Australia is ranked number one for lithium production and seventh for copper.

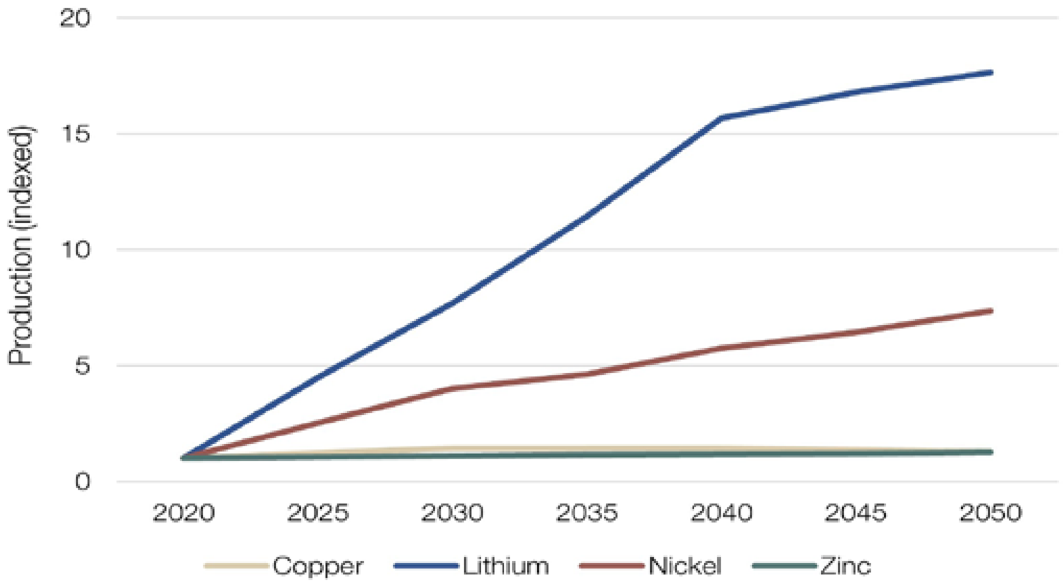
TABLE 5.01: Australian production of Other metals and their importance in low-emissions technologies

The relative importance of the mineral for each low carbon technology is indicated by shading. (filled) = high, (hatched) = moderate, (empty) = low

	Aus % share of global reserves	Aus global ranking for production	Wind	Solar PV	CCS	Electric vehicles	Energy storage
Nickel	24	5	moderate	low	high	high	moderate
Zinc	32	2	high	moderate	low	low	low
Copper	12	7	high	high	high	high	low
Lithium	11	1	low	low	low	high	high

The Australian Industry ETI modelling explores different production outlooks for other metals. The 'Coordinated action scenario', with a 1.5°C carbon budget, assumes that the demand for other metals from Australia grows in line with projected global demand growth between 2020 and 2050 (Figure 5.01).[45] In line with scenario narratives, the greater emissions reductions achieved in the 'Coordinated action scenario' allows Australia to improve its competitiveness in a decarbonising world.

FIGURE 5.01: Assumed relative production changes in Australia under the 'Coordinated action scenario' (Australian Industry ETI analysis based on (BloombergNEF 2021b; DISER 2021c; IEA 2021c).



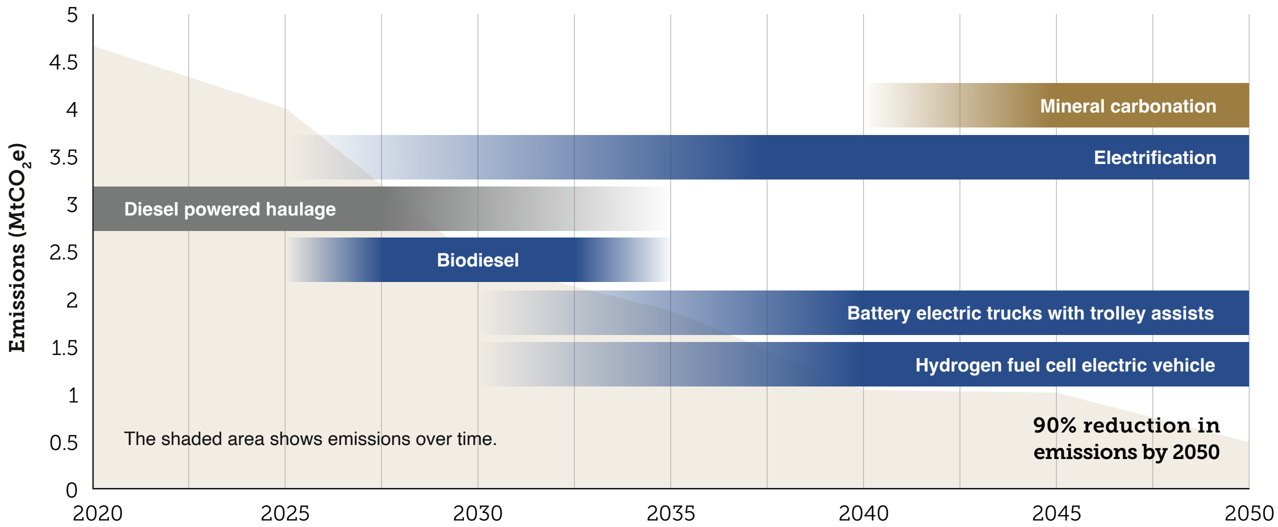
5.2 Technology deployment timeline

The 'Coordinated action scenario' shows what could be done to grow or maintain the other metals supply chain while remaining in line with a 1.5°C carbon budget for the whole Australian economy, by deploying a range of technology solutions, as shown in Figure 5.02. This chart shows the timeline of implementation that the model finds to be the least-cost pathway, based on technology assumptions and other changes across the Australian economy.[46]

45 Production inputs draw on BloombergNEF *NEO* 2021 projections for global metals demand and additional assumptions regarding Australia's share of the global market. Input assumptions are described in the companion technical report.

46 Not all technology solutions that may play a role in decarbonising the supply chain are represented by the model. Technologies may be available before the model implements them. Assumptions regarding which technologies were included in the modelling are given in the companion technical report.

FIGURE 5.02: Technology deployment timeline for the decarbonisation of other metals in the ‘Coordinated action scenario’.[47]



2020–2030

In 2020, the mining and processing of other metals results in the release of 4.6MtCO_2e. Process and equipment optimisation sees emissions begin to decline between 2020 and 2025 due to energy efficiency gains in the ‘Coordinated action scenario’. Low availability of cost-competitive, low-emissions haulage in this decade could result in biodiesel being used as a replacement fuel for heavy haulage. Electrification of mining and processing help to further reduce emissions in this decade.

2030–2050

By 2030, battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) could start to compete with diesel-powered haulage in the ‘Coordinated action scenario’. This is facilitated by reductions in the cost of renewable energy and hydrogen and could completely replace diesel trucks by 2035. Mineral carbonation could be deployed in 2040, helping to capture and reduce emissions. The continued electrification of mining and low-emissions haulage in the ‘Coordinated action scenario’ could allow a 90 per cent reduction in emissions by 2050.

5.3 Other metals supply chain decarbonisation

The ‘Coordinated action scenario’ shows that decarbonising the other metals supply chain in line with a 1.5°C carbon budget requires Australia to address, significant challenges and uncertainties. Meeting growing demand with sustainable production will require further development of green mining technology; additionally, renewable energy and hydrogen infrastructure will need to be effectively integrated with new and existing mines (Figure 5.03).

FIGURE 5.03: Challenges for other metals decarbonisation in Australia

Developing emerging green mining technologies	**Deploying techologies** and transitioning existing plant and operations.	**Integrating** renewable electricity and hydrogen at scale	**Meet growing demand** with sustainable production and building a circular economy of other metals

47 The model findings are in five-year increments. For example, technologies introduced in 2028 can only appear in the modelling results from 2030 onwards.

Actions can be taken to overcome these challenges. This section discusses key enablers of the transition for the other metals supply chain, with a set of recommended actions at the end of the chapter.

Developing emerging green mining technologies

The pathway to decarbonise other metals includes the deployment of some technologies that are not yet commercially viable. Battery electric and hydrogen fuel cell electric vehicles, for example, are in the demonstration phase of development. There are currently no large open-pit, battery-electric mine vehicles; however, smaller underground BEVs are already commercially available and offer benefits as the lack of exhaust gases removes the need for ventilation providing cost savings (RMI 2019a). The challenge for developing larger, heavy haul BEVs is in balancing battery size and capacity. As the BEV becomes larger, it requires a larger battery which adds additional weight to the BEV which in turn requires an even larger battery. Battery energy density cannot currently compete with diesel on range or refuelling time (RMI 2019a).

Mineral carbonation is another emerging technology that could feature in the decarbonisation of other metals mining. Mineral carbonation is a naturally occurring process, where CO_2 from the air reacts with mine waste rock (known as tailings) to form mineral carbonates – effectively capturing and permanently storing CO_2. Mineral carbonation occurs slowly in nature, but there are ways to expedite this using emerging technology solutions. Mineral carbonates with sequestered carbon can be used as value-added products for building and construction industries. Other mineral carbonation projects involve the carbonation of minerals in-situ, where the carbonated material is stored on mine sites such as the trials underway at the BHP Mount Keith tailings dam in Western Australia (BHP 2020).

To achieve the emissions reductions needed to keep the other metals supply chain within a 1.5°C carbon budget, emerging green mining technologies will need to be further developed to facilitate their commercial-scale deployment. Key enablers that can help unlock the development and deployment of emerging technologies include:

Partnerships for development of heavy haulage

The manufacture of heavy haul trucks is dominated by a small number of competitors, leading to incremental rather than transformational changes in technology development. Current original equipment manufacturers (OEMs) of diesel-powered haul trucks rely on maintenance and spare parts as a significant source of revenue. With electric engines requiring 90 per cent fewer parts, a shift to decarbonised haulage represents a substantial change in OEM revenue models. Without a clear demand signal for BEVs and FCEVs, investing heavily in R&D is a significant risk for OEMs – as the rewards are weighted towards equipment users (State of Play 2022).

Partnerships between OEMs and miners can boost investment confidence for the further development of BEVs and FCEVs. Partnerships of this nature are already underway at some mine sites internationally and within Australia (AUS HeavyQuip Journal Newsroom 2022; Jensen 2021). Co-investment between miners and OEMs can also facilitate R&D by distributing financial risks and rewards across the value chain. Finance instruments will be needed for pilot studies, with financiers acknowledging the first-mover disadvantage.

Incentives for mineral carbonation to sequester carbon

Incentives such as carbon credits could help make mineral carbonation a source of revenue for miners, turning what is currently a waste product into an asset. Robust and regulated measurement, verification and reporting methodologies will be needed to ensure transparency and accountability for mineral carbonation, especially if policy settings are in place to allow its use as an offset method. The Minerals Research Institute of Western Australia (MRIWA) is developing a mineral carbonation roadmap, including the development of economic models for various use cases and the necessary guidelines for offset credit validation and trading authorisations (MRIWA 2022).

Partnerships to enable mineral carbonation

Mineral carbonates with sequestered carbon can be used as value-added products for building and construction industries (MCi Carbon n.d.). Partnerships between miners and end-users of the carbonate products (e.g. the construction industry) can help promote R&D through clear offtake pathways. Collaboration between research agencies, universities and industry can spread the financial risk and enhance R&D efforts. Through partnerships with the Australian government, heavy industry and carbonate product customers, Mineral Carbonation International (MCi) is currently scaling their carbon capture technology and identifying ideal locations for the construction of its first carbon plant (MCi Carbon n.d.).

Transitioning existing plants and operations

Fuel switching from diesel and gas to electricity is a huge opportunity for decarbonisation. The electrification of mining processes, such as drilling and digging, is already commercially available but faces deployment challenges at both brownfield and greenfield sites. Most notably, switching to renewable energy and low-emissions technologies poses challenges to current operational practices. Development of high-voltage electricity cabling throughout the site must be done with care for safety reasons and appropriate, additional safety measures will need to be in place for electrical or battery combustion events (CEFC & MRIWA 2022b). At existing sites, replacing fossil-fuel-powered generators and trucks with low-emissions alternatives will also affect returns on previous investments.

Addressing the emissions from processes outside of mining will also present challenges. Once mined, metal ores undergo a process of beneficiation – removing gangue to produce ore concentrates which improves their economic value. In Australia, the majority of other metals are shipped as mineral concentrates – approximately 52 per cent of copper, 48 per cent of nickel, nearly 100 per cent of lithium and 65 per cent of zinc production are shipped as concentrates. The rest is further processed to prepare the metal for final use in product manufacturing. There are multiple processing operations, classified as pyrometallurgical (involving heating at high temperatures), hydrometallurgical (involving leaching, and solvent extraction processes, typically followed by electrowinning) or electrometallurgical (involving electrowinning which uses an electric current to deposit the metal). Variability across the metals considered in this supply chain leads to a wide range of processing techniques, which can differ even within a metal type.[48]

Variability in mine site characteristics and processing operations will affect the ease of transitioning to sustainable production. Appropriate strategies will need to be developed to prepare existing operations and workforces for the transition.

Demand management to take advantage of variable renewable energy

Currently, most mines operate continuously with little fluctuation in load profile, which is not aligned with the nature of solar or wind generation. In addition to the physical infrastructure required for renewable energy generation and storage, operational changes might be needed to allow sites to adapt to variable generation. Different strategies could be adopted such as load shifting to coordinate peak electricity demands with peak supply periods, load shedding to reduce demand when supply is low, or hybrid-power systems that allow switching between renewables and diesel or gas powered generation. The strategy implemented will depend on the operational needs and energy intensity of a mine site. Strategies that maximise mine productivity and emissions reductions should be prioritised.

New haulage practices

Transitioning to low-emissions haulage may require substantial changes to current haulage practices. Switching to BEVs, for example, may increase downtime while haulage trucks are recharged. Different charging strategies could overcome this challenge, such as battery-swap stations, increasing the number of haulage trucks to ensure constant availability or switching to trolley-based systems. The variability of mine site characteristics means that different mines will need to find the optimal strategy for their operation, creating uncertainty and increasing implementation risks. Partnerships with OEMs and miners can help mitigate these risks through the co-development of technology solutions (State of Play 2022).

Skills and capabilities in the workforce to prepare for the transition

Effective training and development programs must be in place to equip the workforce with skills needed to deploy the necessary technology solutions for the transition. Skilled renewable energy technicians, engineers and trade workers will be required.

Integrating renewable electricity and hydrogen

The 'Coordinated action scenario' shows that the key to decarbonising the other metals supply chain is the electrification of mining and processing and the rollout of low-emissions haulage, resulting in fuel switching from diesel to electricity.

In the 'Coordinated action scenario', increases in mining and processing and the transition to BEVs will see electricity use double by 2050 (Figure 5.04). The rollout of hydrogen fuel cell electric vehicles will increase electricity demand slightly, as electrolysis becomes the most cost-competitive hydrogen production route by 2050 (discussed previously in chapter two, 'Pathway for heavy industry decarbonisation').

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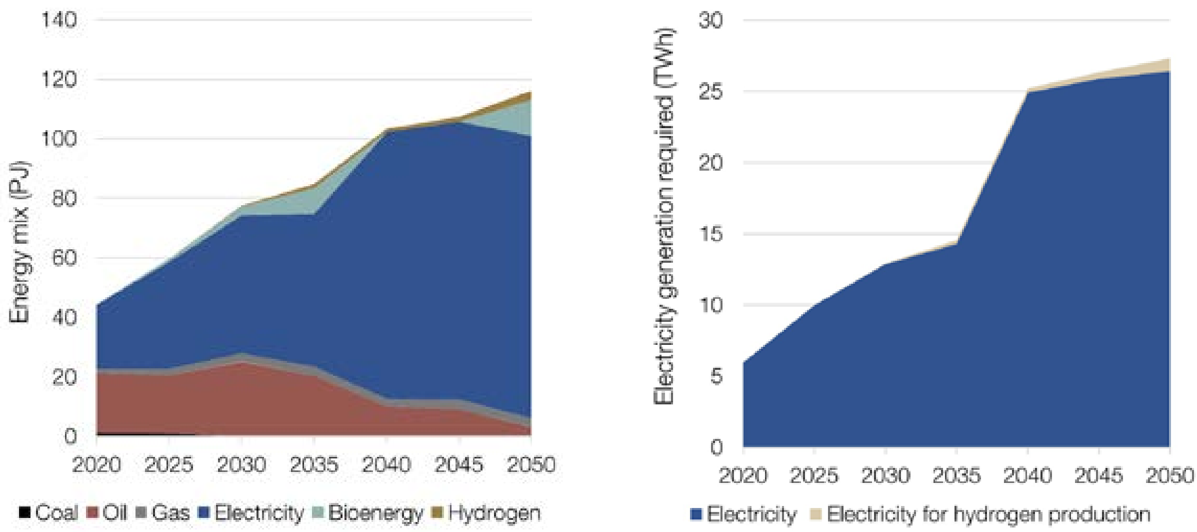
48 To individually model each metal considered within Other metals and capture this richness at multiple supply chain stages would be a major undertaking, and not within scope of the Australian Industry ETI research and analysis.

With electricity quickly dominating the energy mix for other metals, an extensive build-out and integration of renewable energy infrastructure will be needed to minimise electricity use emissions and ensure the supply chain remains within a 1.5°C carbon budget. The electrification of mining and the rollout of BEVs and FCEVs will require just over 26TWh/year of renewable energy by 2050, equivalent to roughly doubling the current renewable electricity generation of Queensland (DISER 2022c)(Figure 5.04).

FIGURE 5.04: Changes in fuel use for other metals mining and haulage with the corresponding rise in electricity generation requirements in the 'Coordinated action scenario'.



A critical challenge to achieving the scale of renewable energy required is the variability of mine site energy infrastructure, including off-grid and edge-of-grid challenges. Many remote mines rely on onsite power generation from diesel or gas-powered generators. Transitioning to renewable energy may be difficult due to land constraints, financial commitments to incumbent fossil fuel-powered generation, and the finite lifetime of mines. Mining operations also rely on relatively flat load profiles, so it is necessary to design for a tolerance of variable renewable supply in extraction and processing.

Contracts for off-grid renewable integration

The practicality of implementing renewable energy generation at a site is, in large part, determined by mine site geography. A grid-connected mine is shielded from the variability of solar and wind, because energy may be generated and transmitted from distant locations (for example, from locations where the sun is shining) and companies can contract for renewable energy without the need for generation and load matching due to the presence of electricity markets to take excess energy. But when operating off-grid, high-quality renewable resources (wind and solar) may not be readily available near the site. Under these conditions, companies may need to build (or contract) transmission from more distant locations or implement significant energy storage solutions.

To reduce the impact of variability, a bundle of renewables, storage and peaking plant (with gas or diesel for rare extended periods without sunshine or wind) will need to be built or contracted. This infrastructure will also carry a remote construction cost premium, and miners will require strong incentives to act to cover these capital investments.

Flexible renewable energy infrastructure

The finite lifespan of mines may discourage significant investments in onsite renewable energy and hydrogen infrastructure, especially for existing mines that are approaching their end of life. Methods of decoupling renewable energy infrastructure from the mine lifespan could help overcome this challenge. For example, the development of portable renewable energy infrastructure that can be relocated at the end of the mine's life could help improve returns on renewable energy infrastructure for mine sites.

Hydrogen infrastructure for FCEV haulage

The use of FCEVs is currently hindered by a lack of hydrogen infrastructure at mine sites. Depending on mine location, onsite hydrogen production could be favoured over transporting hydrogen from larger production sites and will depend on the difference between hydrogen transport and production costs. For onsite production, low-cost renewable electricity and efficient electrolysers will be needed to promote the competitiveness of FCEVs.

Policy support

Effective policy measures will play a vital role in achieving the necessary scale of the transition. Renewable energy targets, coupled with strong sustainability benchmarks for new mining and processing sites, can help drive the uptake of renewable energy. Government incentives for clean hydrogen production and use can facilitate the scaling of hydrogen infrastructure at mine sites.

Finance mechanisms that support transition

Bespoke financial instruments and financiers that acknowledge the risks associated with onsite renewable generation can ensure sufficient capital is available to fund the transition. The National Reconstruction Fund, the CEFC, and the Northern Australia Infrastructure Facility (NAIF) are examples of financiers that could provide capital for green mining projects.

Meeting growing demand with sustainable production

The metals and mining sector is increasingly exposed to concerns around emissions, water use, deforestation and impacts on local communities. This push for socially and environmentally conscious metals production is likely to increase under global decarbonisation amid a greater focus on supply chain transparency and product provenance. In particular, mining companies have been under recent shareholder and consumer pressure to address scope 3 emissions.

The challenge will be to keep pace with global demand while meeting emissions and broader environmental, social and governance (ESG) requirements to ensure the sustainable production of other metals. Failure to meet these requirements could result in consumer and shareholder backlash, affecting Australia's competitiveness in the global other metals supply chain. Action is needed to ensure Australia can expand its production of other metals while meeting global ESG standards.

Meeting sustainability goals

Australian other metals miners can protect social licence to operate and differentiate themselves with strong ESG credentials that align with global frameworks, such as the United Nations Sustainable Development Goals (SDGs). Some opportunities include:

- Increasing resource efficiency
- Respect for human rights and heritage of Traditional landowners
- Support for circularity and waste recovery
- Protection of land and water from impacts of extraction, including reducing tailings and tailings management
- Reduced water use
- Creation and strengthening of international partnerships to enhance ESG ratings of minerals.

Australia's strong regulatory environment can help companies meet international standards for critical minerals and maintain transparent supply chains.

Designing for sustainability

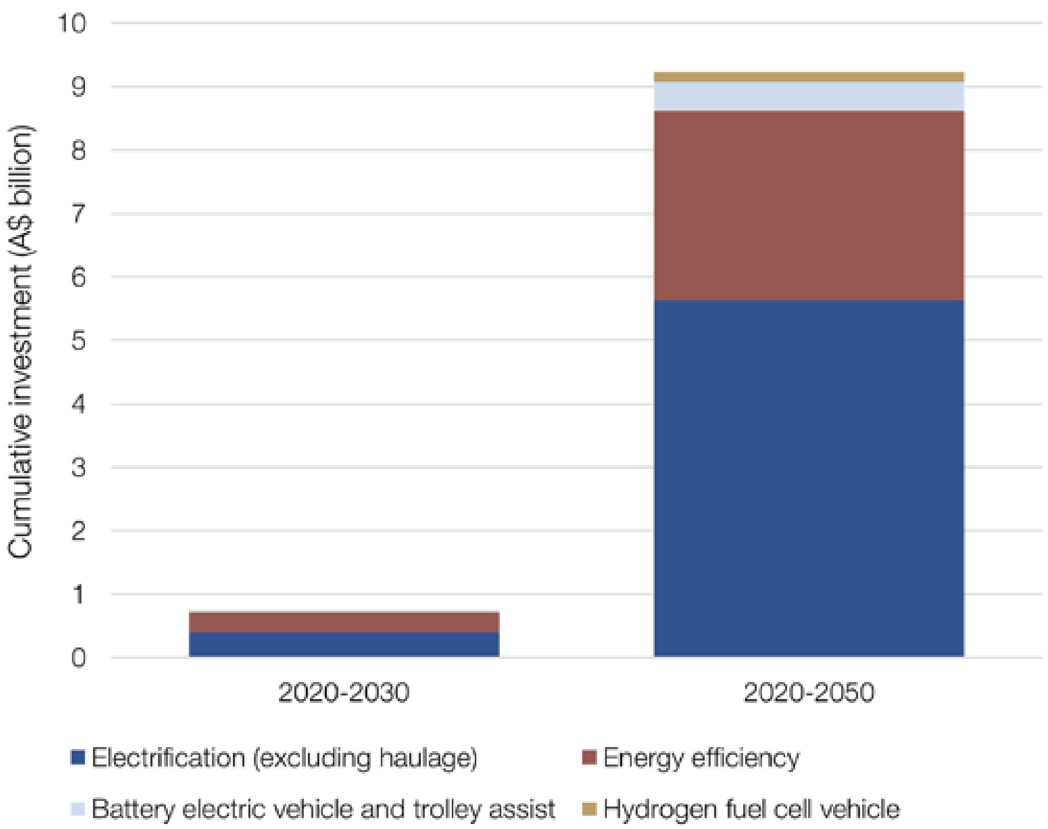
New and existing mine sites will need to be designed and adapted for net zero emissions production, with strong sustainability benchmarks included in the development approval process. The variability in mine site characteristics will make this challenging, as no single solution will fit all mines, requiring collaboration between miners and renewable energy engineers to find bespoke solutions. The CEFC and MRIWA have produced a practical guide to develop roadmaps to decarbonise mining operations, including a framework for creating a zero-carbon mine that takes into consideration mine site variability (CEFC & MRIWA 2022a).

Improved governance can help companies integrate sustainable mining deeply into corporate strategy and decision-making. In addition to designing sustainable mines, sustainability should be built into the operations of existing mines.

Finance for green technologies

Meeting growing demand with sustainable production will require substantial investment in green technologies. By 2050, A$9.2 billion could be required for the deployment of low-emissions haulage, electrification technologies and energy efficiency improvements (Figure 5.05). Effective finance mechanisms for green mining projects will be needed to help fund the transition. These mechanisms must operate with appropriate rigour and responsiveness, with capital allocation for a thorough carbon costing assessment. Examples of finance mechanisms include green bonds and loans and government grants (CEFC & MRIWA 2022b).

FIGURE 5.05: Cumulative investment in low-emissions technologies in the 'Coordinated action scenario'.



Foster onshore processing and manufacturing

By fostering onshore processes and manufacturing, Australian companies have the opportunity to influence global decarbonisation by decreasing their scope 3 emissions. The development of onshore processing and manufacturing industries should align to global ESG standards, building Australia's reputation as a sustainable supplier of other metals and their associated products.

To achieve this, onshore processing and manufacturing will need to be cost-competitive. The clustering of other metals mining with downstream processing and manufacturing can facilitate onshoring, with collaborations across the supply chain helping to reduce financial risk through shared infrastructure developments and co-investments. In this way, industry partners can collaborate on emissions targets, including scope 3 emissions. Furthermore, clustering mining and downstream manufacturing and processing can help guarantee long-term demand for renewable generation helping to address some of the challenges discussed previously in this chapter's 'Integrating renewable electricity and hydrogen' section.

Demand signals for other metals

Australian minerals will be critical for the clean energy revolution. However, miners need clear demand signals, to understand which materials will be required in the future and where they will be needed.

Greater certainty about Australia's future energy system, such as a firm commitment to a system plan aligned to a 1.5 degrees Celsius trajectory, could encourage the production of minerals for domestic use (AEMO). Aggregated information on materials needed to complete planned Australian energy system infrastructure projects will send clear demand signals for investment . International partners can also provide similar policy signals for the energy transition.

INFORMATION BOX 5.01

Although a major global producer of lithium, Australia could capture considerable economic value through increased presence in downstream processes.

Despite world-leading lithium resources, along with almost all of the elements required for lithium-ion battery storage, Australia captures just 0.5% of the global value chain (Australian Trade and Investment Commission 2018).

Estimates suggest the global market for lithium-ion batteries could grow to more than A$3 trillion by 2025 (up from around A$200 billion in 2017). Australia could benefit from its high lithium reserves and capture a larger share of the global battery manufacturing value chain.

To capture this opportunity, Australia could also leverage advantages such as existing mining expertise, efficient logistics, high-quality infrastructure and an attractive investment landscape.

Building a circular economy for other metals

The significant increase in demand for other metals means the supply chain could face challenges in ensuring a consistent, sustainable supply. Copper, for instance, faces declining ore quality in major global reserves, requiring increasingly greater energy inputs and emissions-intensive processing (IEA 2022d).

Copper, nickel and zinc are well suited to recycling, with little degradation of their value or metallurgical characteristics during recycling. Establishing circular economies of other metals could play an important role during the transition by reducing pressure on primary production. Recycling copper, nickel and zinc can also provide energy savings of 84, 90 and 75 per cent, respectively, leading to lower emissions compared to primary production (DISER 2021d).

A significant barrier to establishing circular economies of other metals is the large portion lost to landfill or tied up in products with long lifespans such as infrastructure developments (International Zinc Association 2022). For example, in 2013, only 2 per cent of lithium-ion batteries were recovered in Australia and sent for offshore recycling (King et al. 2018). According to CSIRO, the loss of spent lithium-ion batteries could equate to an economic loss of up to A$3 billion by 2036 (King et al. 2018). Establishing onshore recovery and recycling of not only lithium-ion batteries but also nickel, copper and zinc could allow Australia to capture additional economic opportunities in the other metals supply chain.

Promoting scrap recovery and recycling

An extensive build-out of scrap collection, processing, and recycling facilities will be needed to establish a circular economy of other metals. For other metals present in consumer goods (for example rechargeable batteries, wiring and other e-waste), coordination and collaboration between communities and waste collectors can help improve scrap recovery. Government support will be needed to achieve this through programs to improve public awareness of the importance and best practice of recycling other metals.

Value chain partnerships can also help build circular economies of other metals, especially when present in larger products such as transmissions cables, cars and electrical equipment. The development of traceability systems can help track other metals through the supply chain to promote efficient recycling practices.

Setting of targets for recycled content in products such as cars or batteries can help provide certainty that a market will exist for recycled other metals, giving confidence in investments in recycling infrastructure and logistics.

5.4 Momentum is building across Australian and global other metals industries

OTHER METALS

Mining companies are investing in renewable energy to power their operations.

BHP has secured renewable energy to power three of their major nickel operations in Western Australia. The PPA between BHP and Enel Green Power is expected to deliver renewable energy by 2024. BHP also has an existing PPA with Merredin Solar Farm for 50 per cent of their output and are currently constructing the Northern Goldfield Solar Project which will consist of 38MW of solar power and a 10MW battery energy storage system.

ARENA and Sandfire Resources partnered in the DeGrussa Solar Project which saw the development of a 10MW off-grid solar power plant, with storage, at the DeGrussa Copper mine, providing most of the mines daytime energy needs. The project was also financed by the CEFC.

Oz Minerals has finalised a pre-feasibility study into the use of 50MW off-grid renewable generation to power 80 per cent of energy needs for its greenfield West Musgrave copper and nickel mine in Western Australia.

Industry organisations are collaborating for responsible and sustainable mining

International Council on Mining and Metals brings together a third of global metals and mining industry to drive action and innovation to improve sustainable development performance.

The Australian minerals industry has adopted Towards Sustainable Mining – a framework which helps mining companies to evaluate, manage, and communicate their sustainability performance.

The Australian Centre for Sustainable Mining Practices based at the University of New South Wales is working with industry and government to find solutions to sustainability issues in mining.

Optimising waste can lead to lower emissions and products for the construction industry

Mineral Carbonation International (MCi) captures industrial CO2 emissions and reacts them with mine waste to produce products for the construction industry. The technology has been developed over 15 years, with investments from the Australian Government and industry organisations such as Orica.

BHP is also investigating mineral carbonation at their Mount Keith Nickel Operation. The tailings dam at the facility already stores an estimated 40,000 tonnes of CO2 but BHP aims to increase this through process and engineering solutions.

Low emissions haulage is being investigated and deployed

Aurizon – Australia's largest rail freight operator – and Anglo America have agreed to work on a feasibility study for the introduction of hydrogen-powered trains between the North West Minerals Province and Townsville Port.

The world's largest hydrogen-powered truck is being piloted in South Africa. The 2MW hydrogen-battery hybrid is fuelled by green hydrogen produced onsite from an electrolyser and solar array. The prototype is capable of hauling up to 300 tonnes – equivalent to the capability of current diesel-powered haulage trucks.

A project led by Ark Energy will see five hydrogen fuel cell trucks – supplied by Hyzon Motors – ferry zinc from Sun Metals' Townsville mine to the Port of Townsville in late 2022. The hydrogen will be produced onsite at the zinc refinery using a 1MW electrolyser. This project was financed by the CEFC.

5.5 Enabling the transition

The ‘Coordinated action scenario’ shows that a transition in the Australian other metals supply chain aligned with 1.5°C is challenging and requires strong, effective and coordinated action from industry, government and investors. Strong action now is critical to overcome the challenges discussed above and to enable the transition to net zero in the other metals supply chain.

As shown previously in this report, the Australian Industry ETI has identified objectives (Figure 5.06) to help create a globally competitive other metals supply chain aligned to a 1.5°C carbon budget.

FIGURE 5.06: Objectives and recommended actions for other metals

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia’s industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower

Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy

Develop **integrated regions, supply chains and energy network** solutions

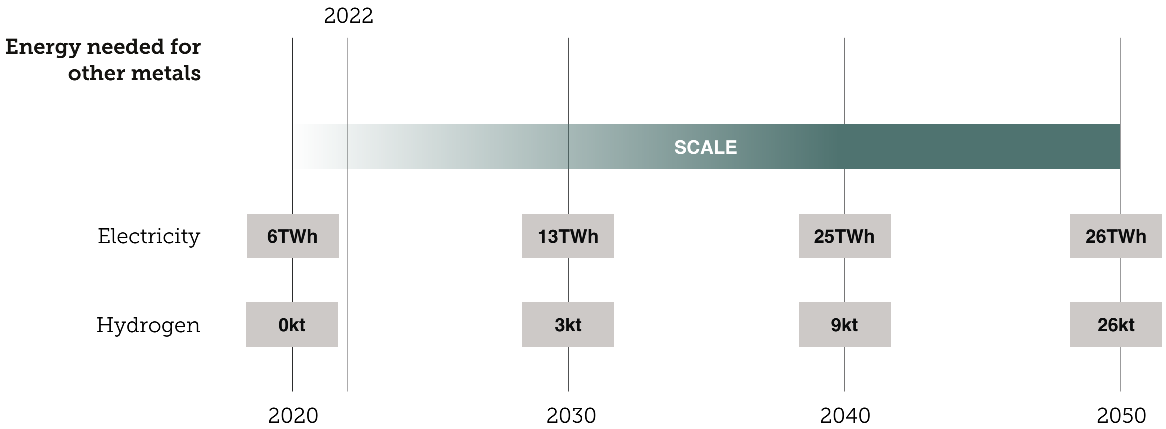
FIGURE 5.06: Objectives and recommended actions for other metals (continued)

A STRONG, ENDURING FRAMEWORK

1. Develop other metals supply chain roadmaps to build capabilities in sustainable production and processing
2. Design for sustainability
3. Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions

LARGE-SCALE, COST-COMPETITIVE, RENEWABLE ENERGY SYSTEM OF THE FUTURE

4. Support the development of remote energy systems for off-grid mining



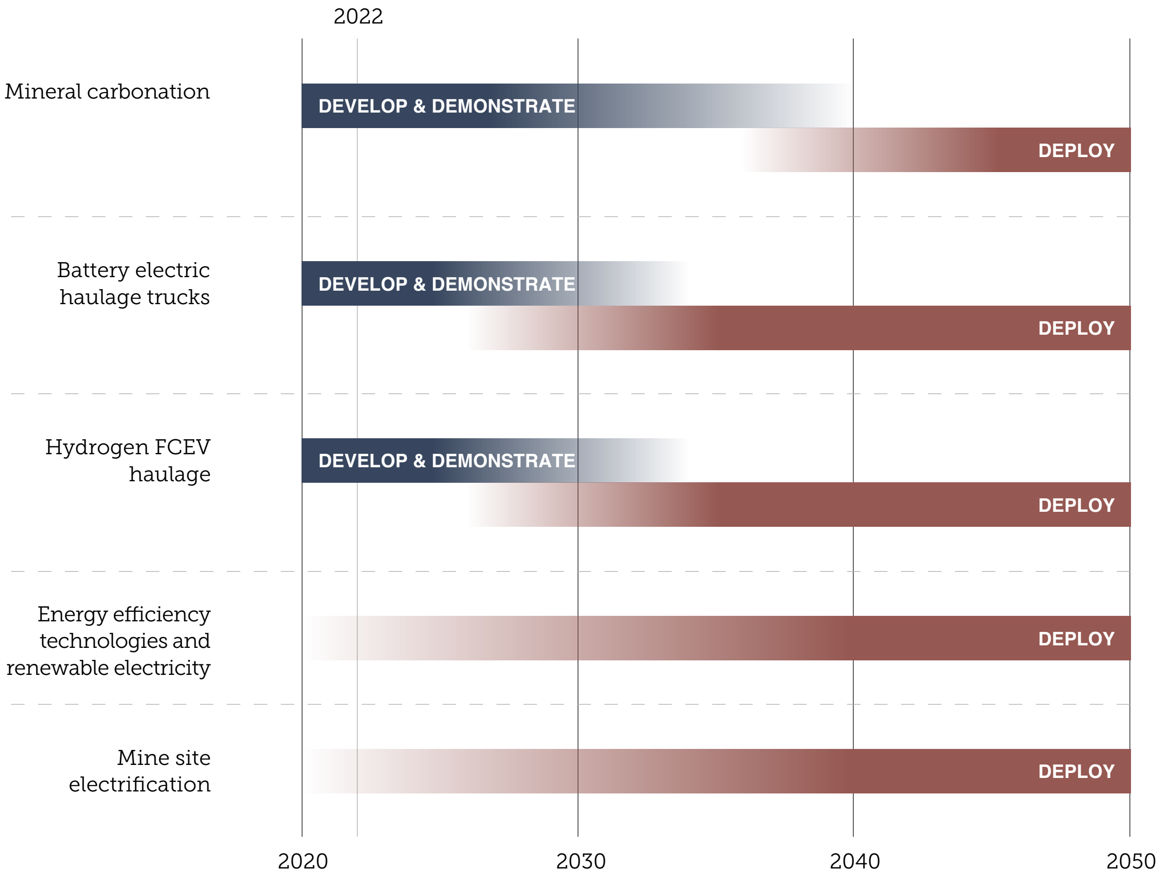
ACCELERATED DEVELOPMENT AND DEMONSTRATION

5. Research, development and commercialisation support for flexible renewable energy infrastructure
6. Support for partnerships to produce value-added products from mineral carbonation for use in the building and construction industries
7. Establish partnerships for development of net zero haulage between OEMs and miners

DEPLOYMENT OF LOW CARBON SOLUTIONS

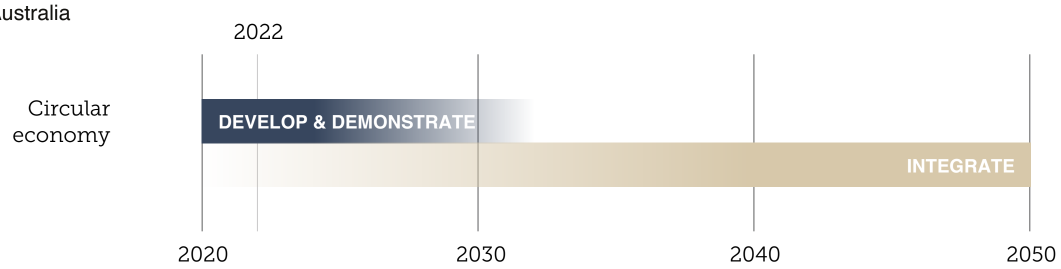
8. Development of an Emissions Reductions Fund methodology for mineral carbonation
9. Support for the build-out of low-emissions haulage infrastructure in remote operations

FIGURE 5.06: Objectives and recommended actions for other metals (continued)



INTEGRATED NET ZERO REGIONS, SUPPLY CHAINS AND ENERGY NETWORK SOLUTIONS

10 Build the circular economy through extensive build-out of other metals collection, processing, and recycling facilities in Australia



To ensure a timely and effective transition of the other metals supply chain, Table 5.02 shows a list of recommended actions. They are mapped against the four enabling themes that the Australian Industry ETI has identified as being important for driving decarbonisation in heavy industry, which are discussed in chapter eight `Enabling the transition to heavy industry decarbonisation'. This mapping is represented by the coloured boxes. Chapter eight also contains key recommended actions to decarbonise all supply chains, which complement these recommended actions specific to other metals.

TABLE 5.02: Recommended actions to achieve the decarbonisation of the other metals supply chain

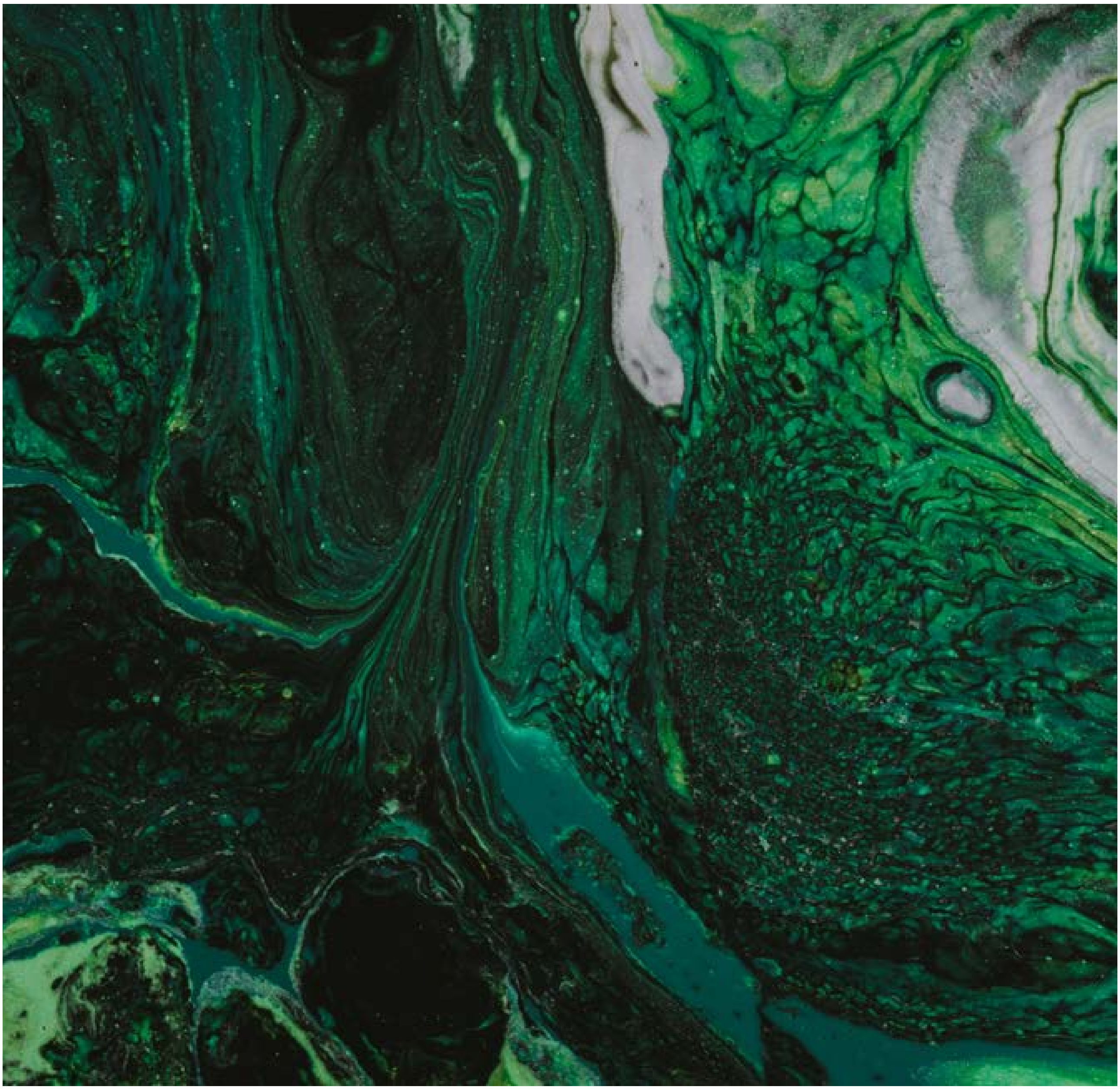
Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Development of other metals supply chain roadmaps focussing on the development of infrastructure, capabilities and markets needed to position Australian minerals for differentiated competitiveness in a net zero global transition and foster opportunities for increasing onshore processing and manufacturing of metals and metal products.				
	2	Design for sustainability. New mines should be planned for net zero production with strong sustainability benchmarks included in the development approval process. Existing mines should embed sustainability benchmarks into their operations. Benchmarks will need to consider variability in mine site characteristics and drive collaboration between miners and renewable energy engineers to find bespoke solutions.				
	3	Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions.				
Transition to the large-scale, cost-competitive, renewable energy system of the future	4	Support the development of remote energy systems for off-grid mining by setting renewable energy targets for remote systems as well as incentives for clean hydrogen use to facilitate the scaling of renewable energy and hydrogen infrastructure at mine sites. This is potentially at the scale of 13TWh/year by 2030 and 26TWh/year by 2050.				

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower	5	Research, development and commercialisation support for flexible renewable energy infrastructure that enables relocation of infrastructure at the end of the mine life and support the business case for shorter life operations.				
	6	Support for partnerships to produce value-added products from mineral carbonation for use in the building and construction industries. Requires commitment from offtakers for products, alongside commitments towards research and development and commercialisation with the goal of deploying technologies at scale.				
	7	Establish partnerships for development of net zero haulage between OEMs and miners to aggregate demand and provide investment confidence for the further development of BEVs and FCEVs.				
Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	8	Development of an Emissions Reductions Fund methodology for mineral carbonation to enable a source of revenue for miners to incentivise investment in mineral carbonation.				
	9	Support for the buildout of low-emissions haulage infrastructure in remote operations including hydrogen refuelling stations and battery charging stations.				
Develop integrated net zero regions, supply chains and energy network solutions	10	Build the circular economy through extensive build-out of other metals collection, processing, and recycling facilities in Australia. Development of inventories of other metals and accreditation of recycled content in products to improve circularity.				

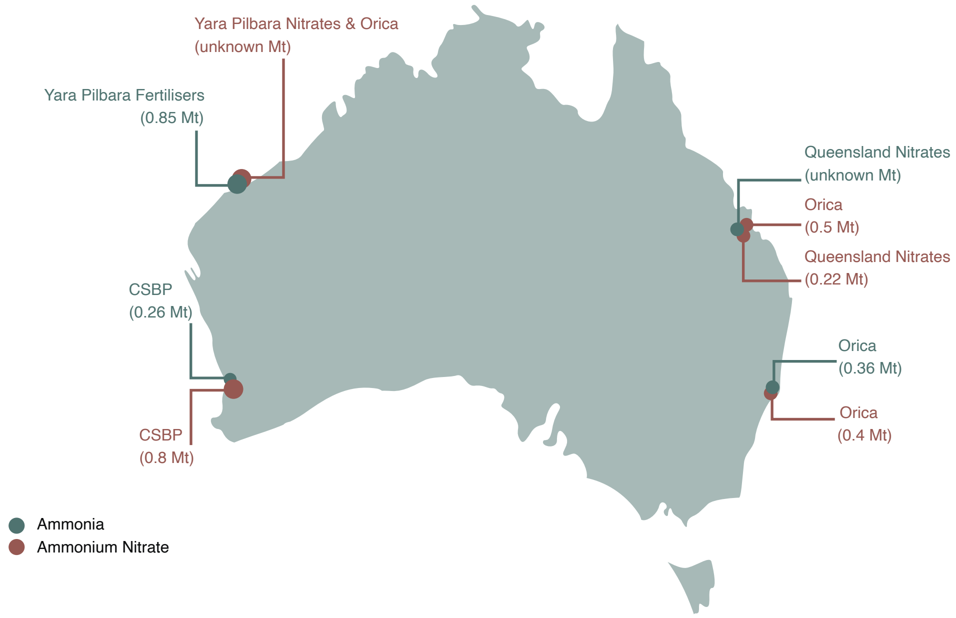
6. Focus on chemicals

The chemicals supply chain in the Australian Industry ETI covers the production of ammonia, fertilisers and commercial explosives. Ammonia is the largest of these industries, and its global production accounts for roughly 1.5 per cent of global CO_2 emissions (Chatterjee et al. 2021). Ammonia is a precursor for ammonium nitrate – which is used in commercial explosives and agricultural fertilisers – and urea, which is also used in agricultural fertilisers. Globally, 70 per cent of ammonia is used to produce fertilisers (IEA 2021a).

As the global population grows, demand for ammonia and fertilisers will rise to support increased food production (IEA 2021a), so investing in abatement technologies is essential. Miners, farmers and other customers can reduce their indirect emissions by purchasing lower-emissions chemicals. Ammonia production could also increase as the global energy transition gathers pace, as ammonia has the potential to act as a zero-emissions energy carrier. There are many opportunities to decarbonise the chemicals supply chain in Australia and to unlock the benefits of green ammonia in Australia's future energy system.



Chemicals in Australia

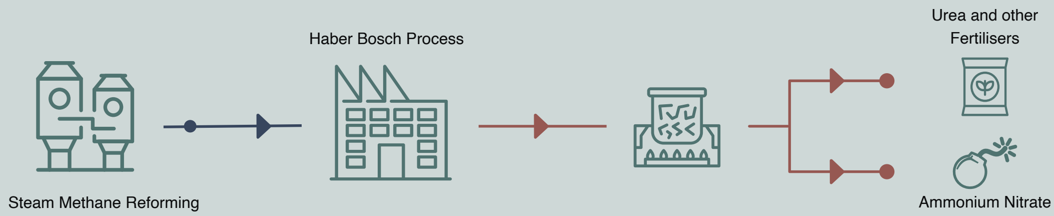


3,400
chemicals jobs

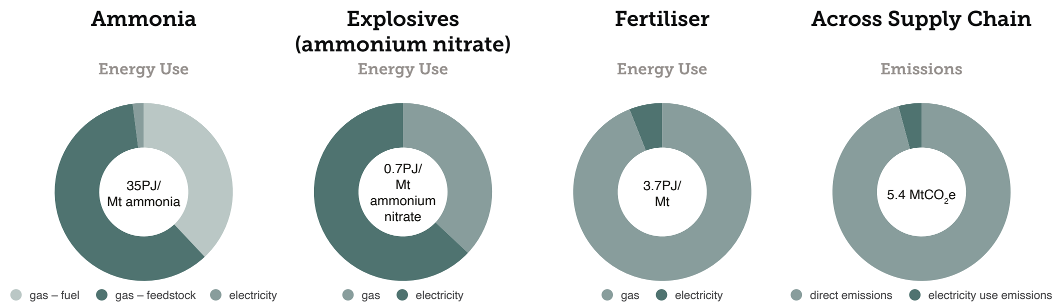
1.8Mt of ammonia,
1.9Mt of ammonium nitrate,
and **0.5Mt** of fertilisers produced

approximately
5.4MtCO_2e emitted
each year

Ammonia, ammonium nitrate, and fertilisers production



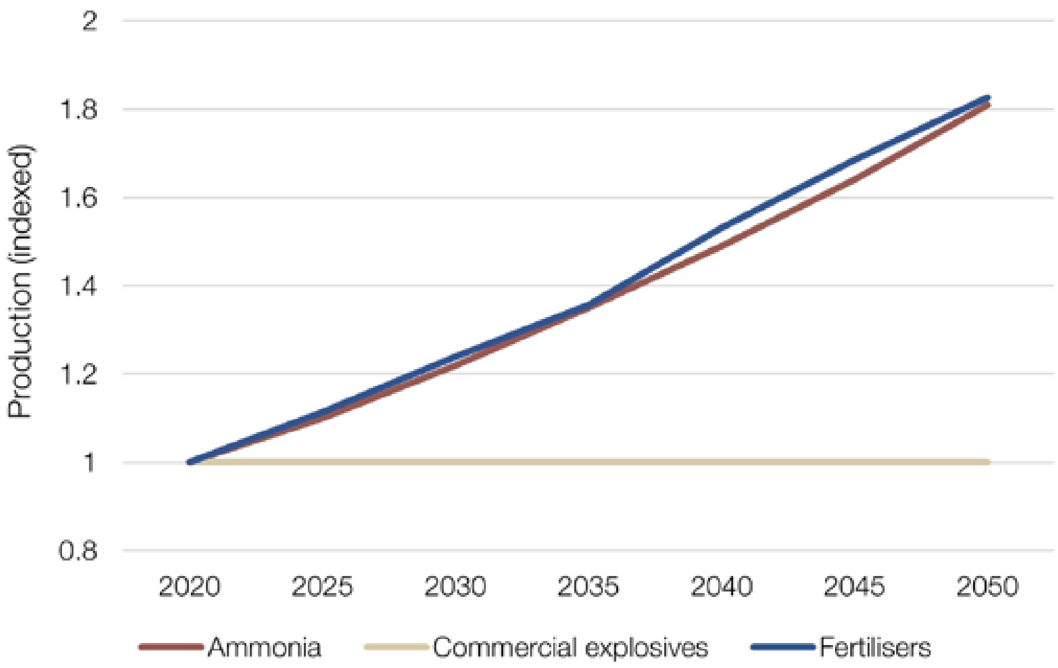
- **Ammonia production**
- **Ammonia nitrate and fertiliser production**



6.1 Chemicals production assumptions

The Australian Industry ETI modelling explores different production outlooks for chemicals. The 'Coordinated action scenario', with a 1.5°C carbon budget, assumes the demand for ammonia from Australia grows in line with projected global demand growth between 2020 and 2050 (Figure 6.01).[49] Ammonia is a precursor for both fertilisers and commercial explosives, so some increased ammonia production will be used in these product supply chains. Commercial explosives demand has been assumed to stay flat across all scenarios.[50] Fertilisers demand growth follows the growth of the other chemicals sector in Australian National Outlook modelling (BloombergNEF 2021b; Brinsmead et al. 2019). In line with scenario narratives, the greater emissions reductions achieved in the 'Coordinated action scenario' allow Australia to improve its competitiveness in a decarbonising world and expand its production.[51] New technologies and other economy-wide enablers are assumed to be available to support this decarbonisation and competitiveness.

FIGURE 6.01: Assumed relative production changes in Australia under the 'Coordinated action scenario' (Australian Industry ETI analysis, (Brinsmead et al. 2019))



49 Production inputs draw on BloombergNEF NEO 2021 projections for global metals demand and additional assumptions regarding Australia's share of the global market. Input assumptions are described in the companion technical report.

50 Commercial explosives production is assumed to remain flat due to a lack of data. Input assumptions are described in the companion technical report.

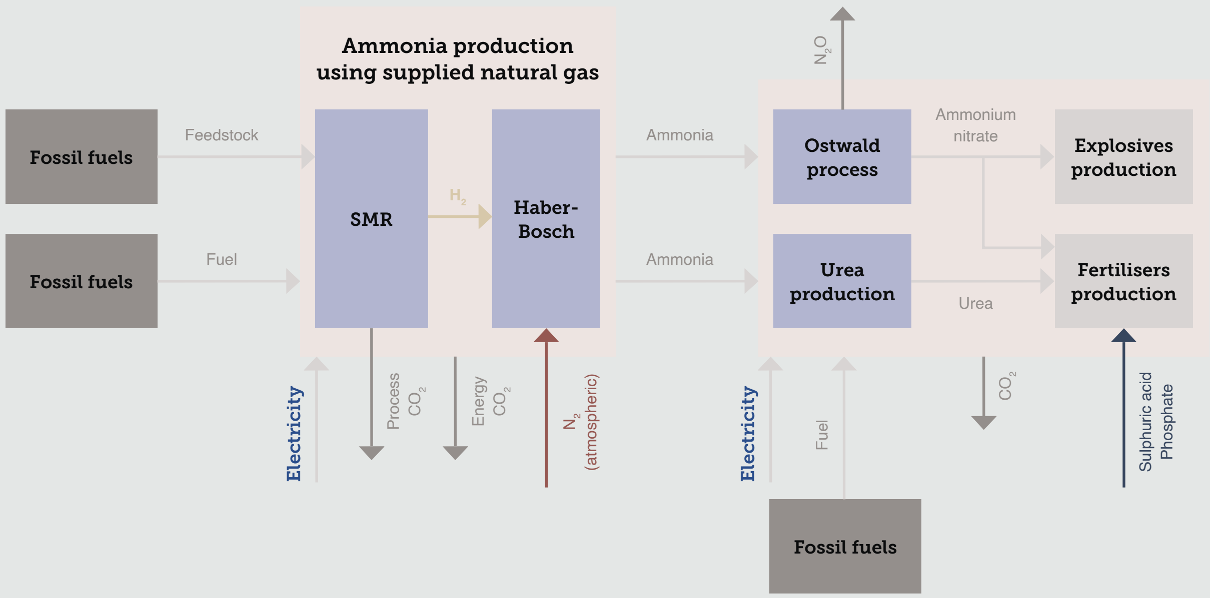
51 The assumed demand does not include potential export of ammonia as an energy carrier in a hydrogen export market.

INFORMATION BOX 6.01

Conventional ammonia production and possible abatement technologies

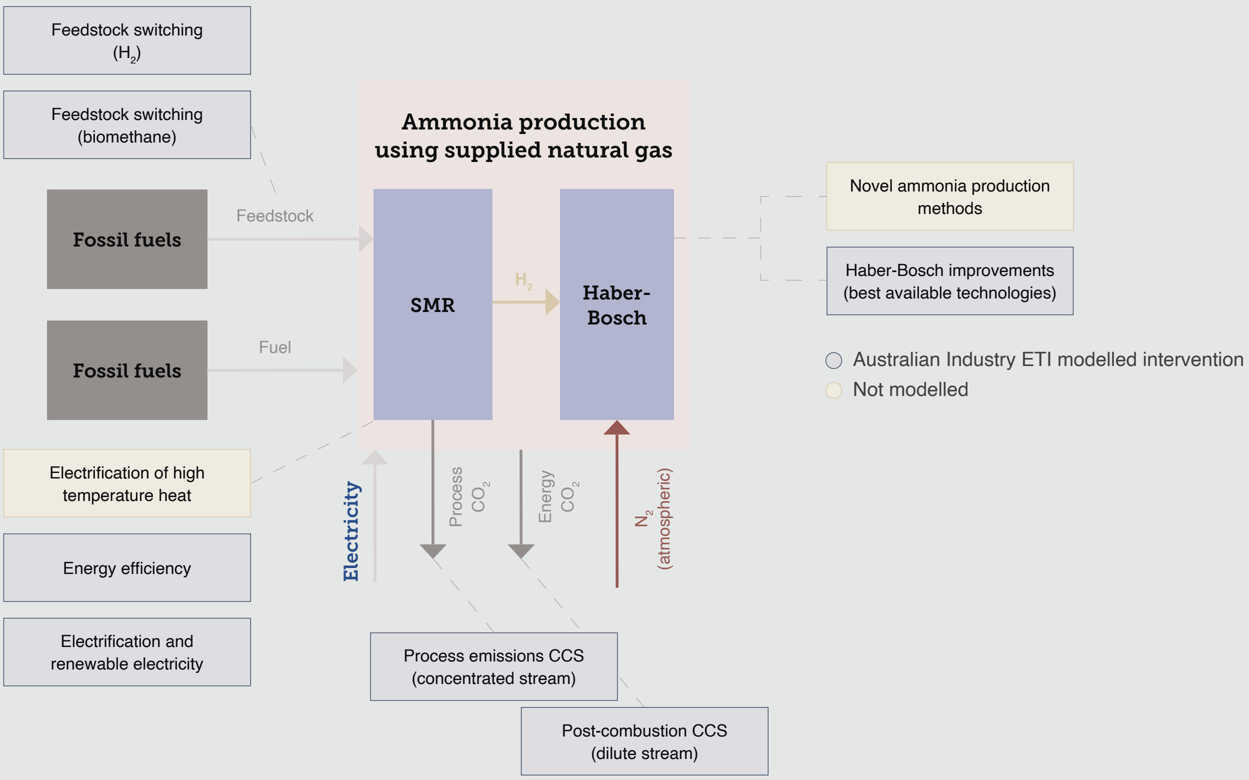
Gas feedstock and fuel in ammonia production results in high process and energy emissions. Conventionally, natural gas is the most commonly used feedstock for ammonia plants around the world. A steam methane reforming (SMR) process within the plant converts methane to hydrogen, which is then used in the Haber-Bosch process for ammonia production. Natural gas is also used as a fuel for the ammonia plant. Ammonia is then converted to ammonium nitrate through the Ostwald process. Ammonium nitrate is used in commercial explosives and fertiliser production (Figure 6.02).

FIGURE 6.02: Conventional nitrogenous chemicals production



There are many opportunities to reduce emissions from these processes. Most of the abatement technologies modelled by Australian Industry ETI are used in the production of ammonia, because it is the largest process in terms of emissions and output in the Australian chemicals supply chain. Feedstock and fuel switching, energy efficiency and best practices, as well as CCS and renewable energy were modelled for ammonia production (Figure 6.03).[52]

FIGURE 6.03: Potential ammonia emissions abatement technologies



INFORMATION BOX 6.02

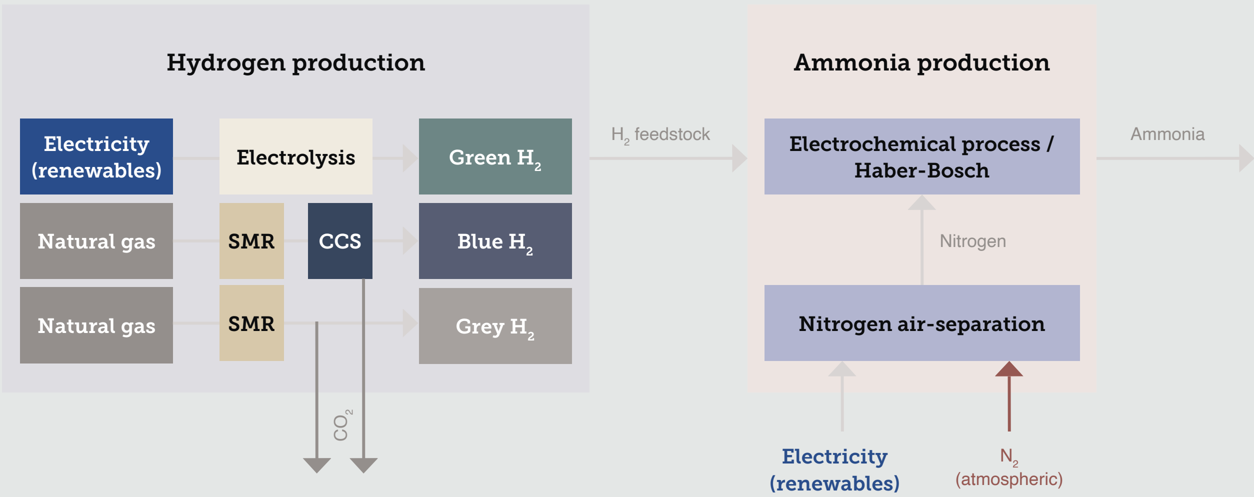
Hydrogen feedstock for ammonia

Switching to blue hydrogen (produced using gas with CCS) or green hydrogen (produced using renewable electricity) can lower carbon emissions from ammonia. Currently, gas feedstock is used for a steam methane reforming (SMR) process within ammonia plants, which produces grey hydrogen (produced using gas) for the Haber-Bosch process and is highly emissions-intensive. Feedstock switching to green hydrogen would involve retrofitting the plant to directly accept hydrogen rather than gas. Green hydrogen for ammonia requires large-scale renewable electricity deployment, as well as electrolysers. Once the plant is retrofitted to use hydrogen as a feedstock, it can use hydrogen sourced from different methods of production. CCS could also be used for the SMR process, which is the same method as the production of blue hydrogen, which may also be used to decarbonise other industrial supply chains. To use CCS, compression and liquefaction equipment could be added to an existing plant, and the captured carbon sequestered (or utilised). Natural gas feedstock can also be blended with hydrogen up to a certain percentage with minimal additional costs. However, exceeding approximately 20 per cent hydrogen blending involves significant changes to the process which require additional investment.The model chooses to retrofit ammonia plants early. Instead of applying CCS within the plant,

52 CCS is a modelled abatement technology. Carbon capture and utilisation (CCU) may also take place, but this is not modelled as the abatement potential within the chemicals supply chain is the same regardless of whether the emissions are sequestered or utilised.

it finds that the optimal path is to produce green, blue or grey hydrogen and to supply it to the ammonia plant, replacing gas feedstock to the plant as early as possible (Figure 6.04). This is because the model has perfect foresight and determines that retrofitting the plant to use supplied hydrogen is lower cost in the long-term. However, it is likely that ammonia producers will use CCS to reduce emissions from the current process, rather than purchase hydrogen from an external supplier.

FIGURE 6.04: Green ammonia production with hydrogen feedstock



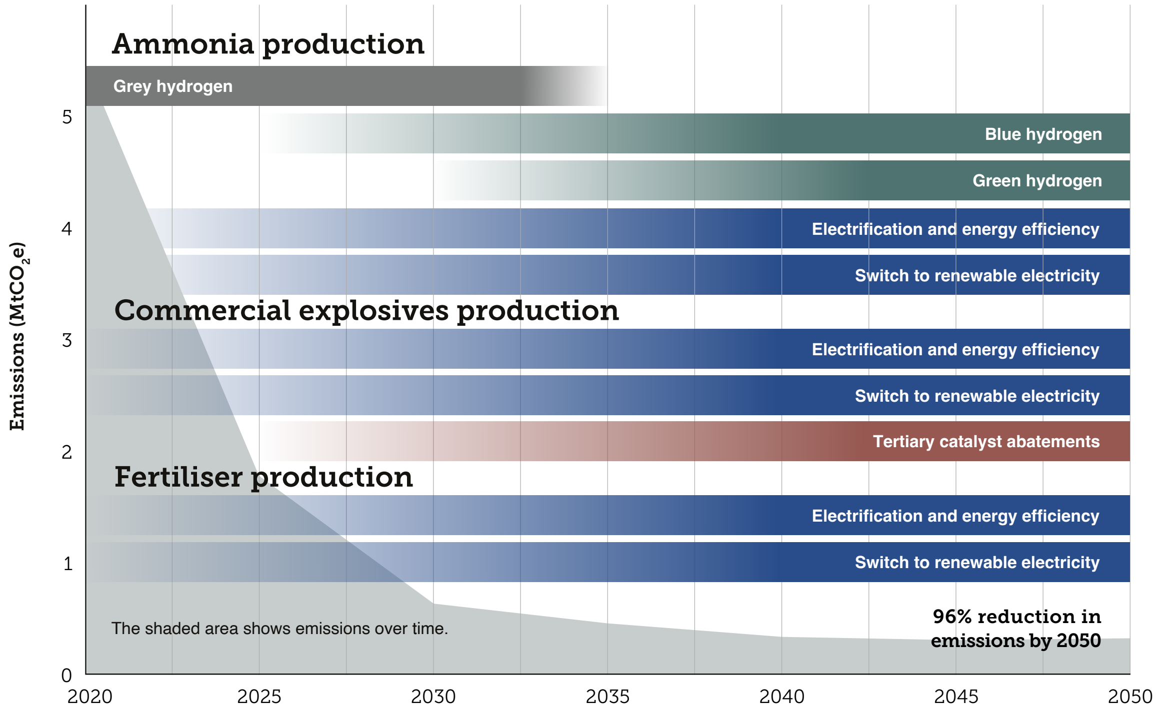
6.2 Technology deployment timeline

In 2020, the production of ammonia, commercial explosives and fertilisers resulted in the release of 5.4MtCO_2e/year.

The 'Coordinated action scenario' shows what could be done to grow or maintain the chemicals supply chain while remaining in line with a 1.5°C carbon budget for the whole Australian economy, by deploying a range of technology solutions as shown in Figure 6.05 on page 113. This chart shows the timeline of implementation that the model finds to be the least-cost pathway, based on technology assumptions and other changes across the Australian economy.[53]

53 Not all technology solutions that may play a role in decarbonising the supply chain are represented by the model. Technologies may be available before the model implements them. Assumptions regarding which technologies were included in the modelling are given in the companion technical report.

FIGURE 6.05: Technology deployment timeline for the decarbonisation of the chemicals supply chain in the 'Coordinated action scenario'[54]



2020—2030

Energy and electricity emissions in the chemicals supply chain could decrease by 89 per cent by 2030 under the 'Coordinated action scenario'. Favourable economy-wide conditions and accelerated technology deployment result in the retrofitting of brownfield plants and a very rapid scaling of the supply of different kinds of hydrogen for feedstock supply. In the 'Coordinated action scenario', 4 per cent of feedstock could be green hydrogen by 2030 with nearly 85 per cent of the remaining hydrogen making use of CCS technology (see Information Box 6.02). Some green hydrogen projects come online before 2030, but as the quantity produced may not be sufficient to completely replace natural gas, most hydrogen would be manufactured using natural gas, similar to the current ammonia production process.

Nitrous oxide (a potent greenhouse gas) process emissions could be significantly reduced during commercial explosives manufacturing through the addition of tertiary catalyst abatement technology. In the 'Coordinated action scenario', this solution sees rapid uptake.

Given the scale of renewable energy deployed in the 'Coordinated action scenario', Australia's electricity system decarbonises rapidly, and the switch to renewable energy means that electricity emissions across the chemicals subsectors reduce significantly. Electrification and energy efficiency processes are also implemented during this time, and continue to be implemented at a sustained rate until 2050 as assumed by the 'Coordinated action scenario'.

2030—2040

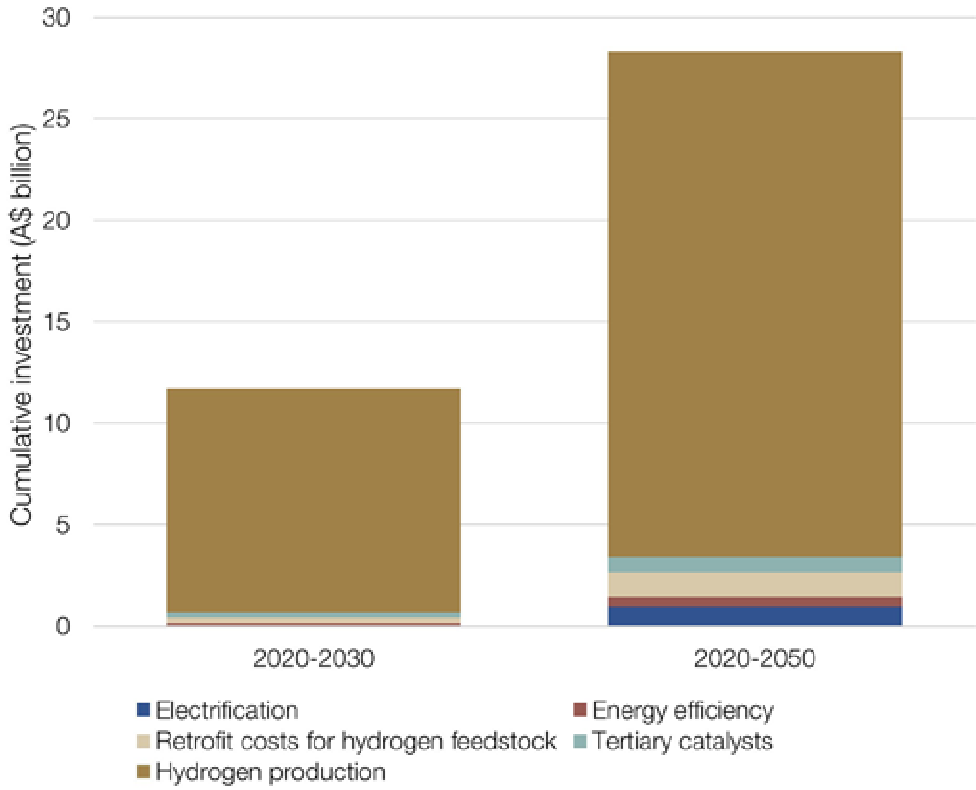
Blue hydrogen use for ammonia production in the 'Coordinated action scenario' could gradually decline, with green hydrogen being produced using both PEM and AE. In the model findings, some blue hydrogen is also carried forward, but it represents only 20 per cent of hydrogen usage by 2040, with the remainder being green. Despite increased electricity use in the fertiliser, commercial explosives and ammonia industries, the high penetration of renewables under the 'Coordinated action scenario' means electricity emissions are only 0.01MtCO_2e by 2040.

54 The model findings are in five-year increments. For example, technologies introduced in 2028 can only appear in the modelling results from 2030 onwards. Quantities of fuel used are not represented on this chart. Blue hydrogen is mainly a transition fuel, with only a small amount used past 2040. See Figure 6.08.

2040–2050

The scale and pace of change seen under the 'Coordinated action scenario' means emissions from the chemicals supply chain reduce by 96 per cent by 2050. One important enabler of this is the availability of capital expenditure for priority technologies (a cumulative A$3 billion) (Figure 6.06).

FIGURE 6.06: Cumulative expenditure on decarbonisation technologies and hydrogen for the chemicals supply chains in the 'Coordinated action scenario'



The additional investment required for technologies for hydrogen production would increase this figure further. In the 'Coordinated action scenario', in 2030, roughly 40 per cent of hydrogen in Australia is used in ammonia production. By 2050, while hydrogen use for ammonia increases, it only comprises around 9 per cent of total hydrogen use across the economy. The production of hydrogen in the ammonia sector leads to cumulative expenditure of A$11 billion from 2020 to 2030, and A$25 billion from 2020 to 2050. This would make the decarbonisation of hydrogen by far the biggest investment associated with the 'Coordinated action' pathway.

With the development of large-scale, low-cost hydrogen production throughout the economy and a strong supply chain, gas could be entirely replaced as feedstock for ammonia. In the 'Coordinated action scenario' more than 97 per cent of the hydrogen used is green hydrogen by 2050. Under these conditions, more than 99 per cent of emissions per unit of ammonia could be abated, supporting the economy-wide 1.5°C-aligned trajectory.

Due to the smaller size of the fertilisers and commercial explosives industries, fuel switching may not be prioritised. In the 'Coordinated action scenario', the model finds that gas use continues unabated in these industries, as lower cost abatement options are found elsewhere in the economy. However, lower emissions could still be achieved by using renewable electricity instead of fossil fuels for heat generation. This would be enabled by strong investment in energy efficiency and electrification across ammonia, fertilisers and commercial explosives (Figure 6.06).

6.3 Chemicals supply chain decarbonisation

The ‘Coordinated action scenario’ shows that decarbonising the chemicals supply chain in line with a 1.5°C carbon budget requires rapid technology deployment and supportive market, regulatory and policy environments (Figure 6.07).

FIGURE 6.07: Challenges for chemicals decarbonisation in Australia

Developing emerging technologies and preparing for large-scale production of green products	**Deploying mature technologies** early to boost clean feedstock and pursue quick wins	**Integrating** renewable energy at scale	**Achieving scale** to take advantage of new opportunities

Actions can be taken to overcome these challenges. This section discusses key enablers of the transition for the chemicals supply chain, with a set of recommended actions at the end of the chapter.

Developing emerging technologies

Many technologies with the highest abatement potential in the chemicals supply chain are mature, mainly facing deployment and commercial challenges. There are also technologies with the potential for significant impact that require further development.

CCS technologies have attracted attention in ammonia R&D. SMR abatement with CCS in ammonia plants is one of the most affordable forms of CCS, taking advantage of a highly concentrated process stream of CO_2.[55]

In the ‘Coordinated action scenario’, ammonia production makes use of CCS to abate emissions from the SMR hydrogen production process (see Information Box 6.02). CCS with SMR is used for the production of blue hydrogen, and if it has the high capture rates assumed in the Australian Industry ETI modelling, it could be used as a transition feedstock before green hydrogen is available at the quantities needed.[56] In the coordinated action scenario, approximately 83 per cent (93,000 tonnes) of hydrogen produced for ammonia in 2030 is blue hydrogen, but production declines to 13 per cent in 2040. It is important to note that while emissions from ammonia production can be reduced with CCS, upstream emissions from gas extraction would remain part of the company’s scope three emissions.[57]

A particular issue with CCS is the risk of leakage from underground storage, which would negate the emissions abatement achieved. Regulation of CCS activities would therefore also need to address this risk (Energy Transitions Commission 2022).

In addition to substituting fossil fuels with hydrogen, there are several other promising abatement technologies for zero emissions ammonia production (see below). These have not been modelled by the Australian Industry ETI due to a lack of data on new or untested technologies.

Research and development of ammonia technologies

Technology strategies for ammonia production processes with a low technology readiness level (TRL) will require greater clarity on the challenges and opportunities of these technologies, which include technologies that would replace the Haber-Bosch process (IEA 2021a). Continued research and development in this area could result in novel, low-emissions processes becoming commercial, such as electrified process heat (Rouwenhorst n.d.), electrochemical or solid state ammonia synthesis (Brown n.d.) (Batool & Wetzels 2019; Suryanto et al. 2021), use of plasma reactors (Sun et al. 2021), membrane reactors that use catalysts to form nitrogen and hydrogen at ambient pressure (Colorado school of mines 2011), and methane splitting to produce solid rather than gaseous carbon (Philibert n.d.).

55 Input assumptions are described in the companion technical report.

56 The input assumption for blue hydrogen is that CCS captures 90 per cent of emissions.

57 This is not quantified by Australian Industry ETI.

Collaboration and sharing best practices will be key enablers of CCS development for both early-stage demonstrations and deployment in major projects. International collaboration and partnerships with other industries will be important for CCS R&D.

Emissions reduction incentives or encouragement

Many technologies modelled by the Australian Industry ETI are not economically viable today. Proactive investment in R&D for technologies with high abatement potential should be supported by institutional initiatives or encouraged through regulatory or economic measures.

Fostering demand for green products

Costs associated with emissions reduction reduce the attractiveness of the short-term development and deployment of abatement technologies. It is important to consider how a customer might build a business case for purchasing green products if they are more expensive than others.

Demonstrated value of green products

In the short-term, green chemicals products will likely carry a premium, and many offtakers may find it difficult to justify the higher cost. Initiatives such as greater emissions transparency for end consumers or standardised green ammonia certification, could help companies make a stronger business case for procurement of green chemicals (Cocker n.d.).

One offtaker of green ammonia could be shipping companies, which may have a strong incentive to switch to ammonia vessels if customers are seeking reductions in their scope 3 emissions. Firm commitment from customers and a comprehensive, long-term value chain strategy would be needed. The Mission Possible Partnership puts the number of ships needed to be retrofitted or built to be between around 40,000 to 80,000, in addition to bunkering and storage terminals (Mission Possible Partnership n.d.).

Guarantee of origin and international standards for hydrogen

Ammonia demand could dramatically increase in the future as a carrier of hydrogen (see Information Box 6.03). In addition to green ammonia standards, green hydrogen standards could be relevant for future ammonia production.

A global approach to verifying the emissions intensity of hydrogen could complement trade rules. Internationally harmonised regulation, codes and standards, coupled with data sharing (including environmental impact assessments), will help develop a sustainable and robust market for hydrogen and ammonia produced with low, direct and electricity emissions (International Partnership for Hydrogen and Fuel Cells in the Economy 2020). Customers and trade partners are seeking transparency on standards and protocols. To this end, Australia is a partner country in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE partners n.d.).

A ‘Guarantee of Origin’ scheme is currently being designed by the Australian Clean Energy Regulator (CER) to give customers assurance of the emissions intensity of hydrogen. Trials commenced in December 2021 (DCCEEW 2021c).

INFORMATION BOX 6.03

Establishing renewable energy exports with ammonia

An opportunity exists for Australia to become a 'Hydrogen superpower' (AEMO 2022a), with the ammonia industry potentially playing an important role. Ammonia is already a widely traded and transported commodity. Ammonia can also act as a renewable energy carrier when produced using green hydrogen, so it could be a pathway to creating an export industry. Hydrogen would be used as feedstock for ammonia, which could then be transported as usual. When it reaches its destination, it could theoretically be converted back to hydrogen through a catalytic cracking process. The cracking process consumes 30-40 per cent of the energy stored, but this could decrease to 14-15 per cent with design optimisation (International Renewable Energy Agency 2022).

Rather than being converted back to hydrogen, ammonia could also be used directly as a fuel. For electricity, possibilities include co-firing of ammonia into coal or gas power plants as a percentage of the fuel for electricity generation. It could also be used in industrial furnaces (Kobayashi et al. 2019), direct ammonia fuel cells and fuel switching from oil in applications such as shipping. According to BloombergNEF, use of ammonia as fuel could surpass its non-fuel applications by 2045 (BloombergNEF 2021b). Approximately 176Mt of ammonia is produced globally every year (Royal Society 2020), with global exports equating to around 10 per cent of production (IEA 2021a). According to one analysis, global ammonia demand could reach 690Mt/year by 2050, with almost 80 per cent used as chemical feedstock and as fuel for shipping and power and only 20 per cent used as a hydrogen carrier (IEA 2021c).

There are also benefits for shipping ammonia over hydrogen:

- There are already established shipping chains and distribution networks for ammonia.
- Liquefied hydrogen requires higher pressure and much lower temperatures to export, requiring additional capital investment and new infrastructure (BloombergNEF 2019).
- Ammonia could replace heavy oil in shipping tankers (IEA 2021c), which is a significant source of emissions for Australia's exported goods.

Markets for low-emissions ammonium nitrate

Commercial explosives manufacturers can work with mines to optimise the use of explosives. The most significant emissions reduction can come from moving less material following blasting, leading to lower diesel consumption for haulage. Precision blasting also results in finer rock sizes, reducing the amount of energy needed for beneficiation and refining. Digital and automation technologies can enhance precision (Hall 2021). Precision blasting can be improved by chemical industry expertise. Chemical experts may provide this as a value-add service.

Ammonium nitrate manufacturers can ensure a market exists for low-emissions, commercial explosives by working with large customers, including major mining companies and major infrastructure delivery companies, for quarrying and construction blasting. Ammonium nitrate is also required as a feedstock for nitrogenous fertilisers, but it is likely that a low-emissions product would be taken up more quickly by commercial explosives customers than agricultural customers.[58]

Deploying mature technologies

Hydrogen as a feedstock for ammonia is a mature technology, but it requires retrofitting of ammonia production plants (Information Box 6.02).[59] A barrier to rapid deployment is a current lack of hydrogen supply and the current high cost of green hydrogen. Hydrogen is also a highly combustible substance and requires appropriate regulatory and safety protocols.

58 Insight from industry consultation.

59 See companion technical report for assumptions on retrofitting of ammonia plants.

Another mature technology is using tertiary catalyst abatements in nitric acid production for commercial explosives manufacturing. Tertiary catalysts abate emissions of nitrous oxide, a potent greenhouse gas.[60] In the coordinated action scenario, tertiary catalysts are deployed very rapidly.

A diverse portfolio of hydrogen production

To achieve the high level of abatement required this decade, the ammonia industry would require a rapid expansion of hydrogen with low, direct and electricity emissions as early as possible. This could include blue hydrogen as a transition fuel. Using blue hydrogen would mean that some emissions are not abated by switching to hydrogen feedstock, but they would be reduced, substituting some of the considerable volume of grey hydrogen. The Australian Industry ETI modelling investigates the potential for hydrogen to be produced through these processes, including using gas price sensitivities as grey and blue hydrogen costs are significantly impacted by gas price (Information Box 6.04). To grow green hydrogen capacity, electrolyser capacity would need to increase, and rare earth minerals must be available to scale production of PEM electrolysers.[61]

INFORMATION BOX 6.04

Sensitivity study: the effect of gas prices on low-emissions hydrogen deployment

A series of gas sensitivity studies were conducted on the 'Coordinated action scenario' in response to the high gas prices seen in Q2 2022 (IEA 2021c) (see chapter two 'Pathway for heavy industry decarbonisation'). The coordinated action gas price assumptions were replaced with a medium, high and maximum gas price in the NEM states.[62] In all these scenarios, the chemicals technology pathway remains the same, with almost all gas replaced by hydrogen by 2030. However, the type of hydrogen used is different at higher gas prices.

In the 'Coordinated action scenario', in 2030 most hydrogen is produced with gas. With higher gas prices, green hydrogen becomes more dominant in the model findings. When gas prices remain constant at the maximum price ($32/GJ), 90 per cent of hydrogen is green by 2030.

Grow expertise and support workers

Implementation of new technology will depend on the skills and experience of the current chemicals labour force. Capabilities in the design and deployment of zero-emissions hydrogen feedstock and expertise in hydrogen electrolysers will be particularly in demand. Workers will need to be upskilled to operate the new plants.

Investment in new technologies

The technologies used to decarbonise the chemicals supply chain are capital-intensive and may have long lifetimes. Securing investment is key to deployment.

Integrating renewable energy

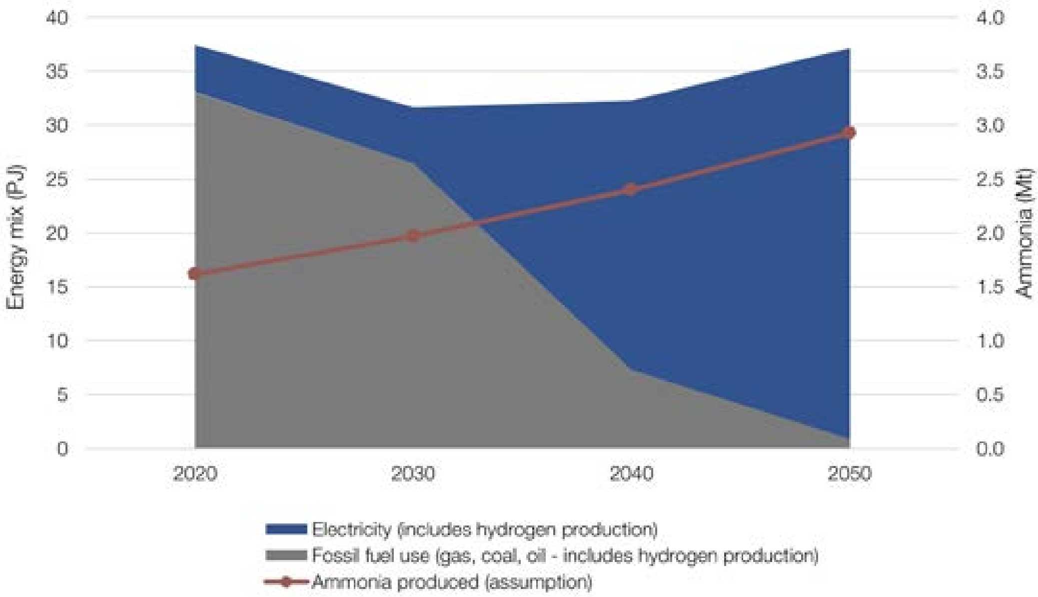
In the 'Coordinated action scenario', the deployment of abatement technologies has a significant impact on the energy mix (Figure 6.08). Direct fossil fuel combustion in plants declines rapidly and remains relatively consistent between 2030 and 2050. Electricity use steadily increases from 2020 to 2050 due to increases in electrification and production. The fuel used to produce hydrogen for ammonia is the biggest change between 2030 and 2050, transitioning from gas-based production to electricity.

60 The commercial explosives industry is also deploying secondary catalyst abatement. This was not modelled because input from industry suggests that secondary catalysts are already being deployed widely.

61 There is no assumed limit on electrolyser capacity from manufacturing constraints in the model. Input assumptions are described in the companion technical report. Alkaline electrolysers may not be exposed to the same level of supply risk as PEM electrolysers (Kiemel et al. 2021).

62 See companion technical report for more details.

FIGURE 6.08: Change in energy mix for ammonia production in the 'Coordinated action scenario'[63]



Green ammonia and green fertilisers require copious supplies of renewable electricity to decarbonise electrical processes and for the production of green hydrogen via electrolysis. In the 'Coordinated action scenario', approximately 10TWh per year is required by 2050. As with other industries, this will mean a significant scaling of renewable energy capacity and investment in the energy system.[64]

Electricity transmission build-up

In regions where it is not feasible to build and scale renewable electricity proximal to the plant, electricity may need to be transmitted via high-voltage transmission lines. This is dependent on geography and existing infrastructure. In some industrial regions, network capacity may currently be too low to significantly boost electrification. Regional system planning can support this.

Co-locating ammonia and hydrogen production

Co-locating plants with renewable energy and green hydrogen production could have cost advantages for green ammonia production by reducing transmission and hydrogen transport and storage costs. Hydrogen hubs or renewable energy industrial precincts can facilitate partnerships for co-located industry and create integrated supply chains. Co-locating plant with renewable energy and green hydrogen production could be optimised if ammonia production technology is able to tolerate greater intermittency and to allow for the use of electricity at times of high generation and low demand. With a lower requirement for uninterrupted production, plants could reduce the need for expensive hydrogen storage and capitalise on low electricity prices. (See chapter two 'Pathway for heavy industry decarbonisation', for more information on potential ideal locations of hydrogen production.)

Hydrogen transport infrastructure

Where it is not possible to build renewable energy capacity close to ammonia plants, green hydrogen must be produced in areas with affordable renewable energy and storage (see chapter two, 'Pathway for heavy industry decarbonisation'). Hydrogen can be transported via ship or pipeline, depending on location.

63 Existing energy usage by fuel type is derived from the Australian Energy Statistics, Table F (2020) (DISER 2020).

64 See chapter 2 'Pathway for heavy industry decarbonisation' for more information on energy system investment.

System planning with electrolysers

Electrolysers consume a great deal of electricity, but they may also support the electricity grid by acting as a storage method as discussed in chapter two. Electrolyser operators could work with energy system planners to optimise efficiency and therefore costs.

Achieving scale in hydrogen and ammonia

Global demand is building for green hydrogen and ammonia, and the industry is under pressure to decarbonise. Limited supply of low-carbon hydrogen is likely to be a significant barrier to scale production and deliver ammonia to a rapidly decarbonising world. Stringent regulatory requirements and community opposition to new projects could slow down the process of decarbonisation at scale. However, these problems must be balanced against safety and other concerns. The need for expertise and the high cost of blue and green hydrogen are also challenges that require strategic planning and partnerships to supply the scale of low-emissions hydrogen that industry will require.

Collaboration and consultation with regulators and communities

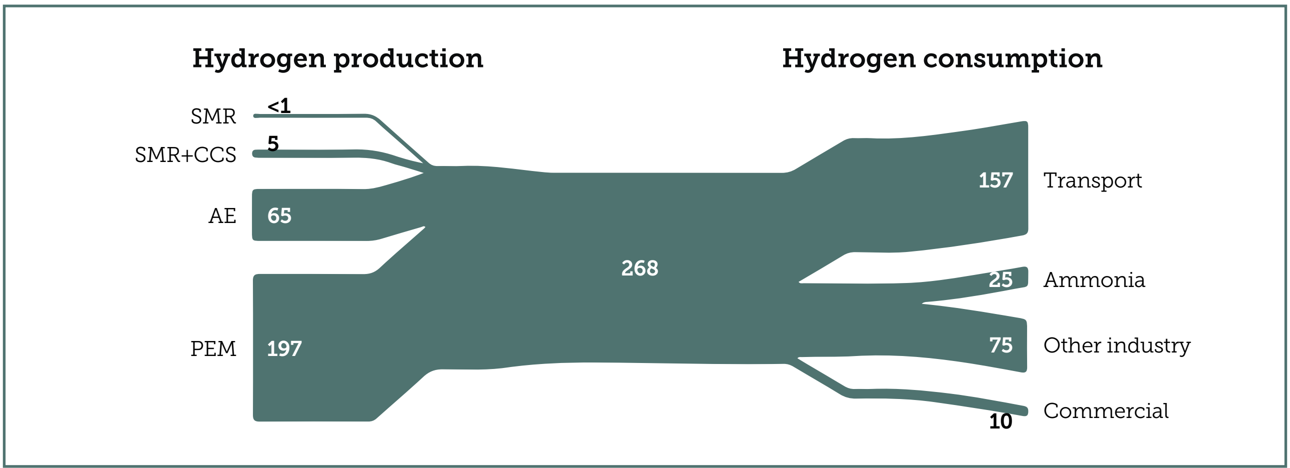
The chemicals industry could bring a best-in-class approach to the expansion of plants and infrastructure, improving community acceptance and shared understanding with regulators. Nitrogenous chemicals are hazardous and can pose safety concerns in highly populated areas. Being transparent with communities and regulators, and holding the bar of health and safety high to mitigate the potential risks are critical. Speeding up the process as much as possible while protecting communities is necessary. The social licence of chemical plants can also be supported by active consultation and avoiding impacts on Traditional Owners and cultural heritage.

Reduced costs of blue and green hydrogen

The higher cost of blue and green hydrogen compared to grey hydrogen currently prohibits their uptake (see chapter two 'Pathway for heavy industry decarbonisation'). Reducing costs for ammonia producers will remove one of the greatest barriers for scaling decarbonisation in the industry.

Boosting domestic consumption could bring down cost curves. Hydrogen consumption is currently dominated by industry in Australia. Between now and 2050, there may be significant uptake in other parts of the economy, including residential and commercial applications through gas blending. Uptake by heavy industry (notably the steel industry) could increase demand with the use of new low-emissions technologies. By 2050, under the conditions of the 'Coordinated action scenario', the majority of hydrogen consumption could be in the transport sector, notably in articulated trucks (Figure 6.09). Hydrogen usage in trucking would likely benefit from economies of scale after the installation of refuelling stations (IEA 2021c). Spurring adoption in these sectors early could help make blue or green hydrogen more viable for ammonia production. The trade-off for this is that there could be greater competition for hydrogen if it is not produced at scale.

FIGURE 6.09: Hydrogen production and consumption in 2050 in the 'Coordinated action scenario' (PJ/year)[65]



65 Numbers may not sum due to rounding.

Establishment of international offtakers for green ammonia

A new green hydrogen or green ammonia export industry could also bring down cost curves. As discussed previously in Information Box 6.03, ammonia can be used as a fuel or hydrogen carrier. This makes it well suited as a means of exporting renewable energy from Australia, if produced using green hydrogen. Exploring the possibilities of a large-scale green ammonia industry in Australia would benefit from long-term planning and partnerships. Research into processes to optimise ammonia combustion and improve safety could also encourage uptake (Kobayashi et al. 2019).

6.4 Momentum is building across the Australian and global chemicals industry

CHEMICALS

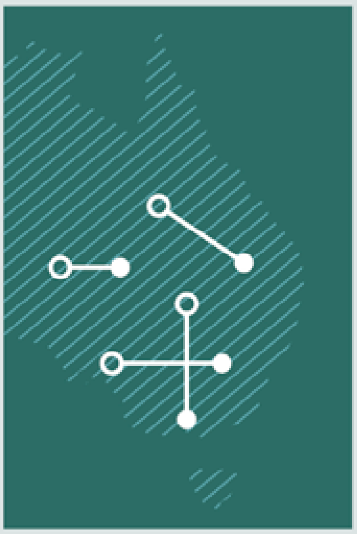
Chemicals producers are reducing their emissions through nitrous oxide abatement catalysts

Both Orica and WesCEF have committed to reducing their greenhouse gas emissions by installing nitrous oxide abatement catalysts at their manufacturing facilities.

Long-term supply agreements are being made

ACME and Norwegian firm Scatec have signed an offtake agreement for the supply of green ammonia from a project in Oman. The joint venture aims to facilitate the building of a state-of-the-art facility.

Fortescue Future Industries has signed a long-term supply agreement with Covestro– a German-based polymer supplier—for the supply of green hydrogen and its derivatives, including green ammonia, and has signed a MOU to provide 200,000 tonnes of green hydrogen from Australia to energy company Eon as early as 2024.



Partnerships are being formed in Australian regions

Orica and H2U have partnered to explore opportunities for domestic green ammonia offtake and supply agreements which would see green ammonia from H2U's proposed Yarwun production facility supplied to Orica's Yarwun manufacturing plant. The partnership will also include exploration of an ammonia export terminal at the Port of Gladstone.

Incitec Pivot Limited has partnered with Fortescue Future Industries to assess the feasibility of industrial-scale green ammonia production at Gibson Island, Queensland. The first phase showed that the project is technically feasible and the study has now progressed to investigate the feasibility of infrastructure conversions.

Orica and Origin have partnered to assess opportunities for green hydrogen and ammonia in the Hunter Valley, with a proposed hydrogen hub using recycled water.

Orica, Alpha HPA, and Rio Tinto have signed a statement of cooperation with the Queensland Government, helping to grow the region as an industrial and renewable energy powerhouse. Focus will be placed on accelerating lower-carbon manufacturing, firmed renewable generation, and lower-carbon products. Orica and Alpha HPA have also signed an agreement for the supply and offtake of process reagents and by-products to serve the growing eMobility and electric vehicle battery market.

Green ammonia is being developed internationally

ACME—an Indian solar company—has revealed its plans to develop a 1.5GW scale green hydrogen and ammonia facility in southern India. The project will produce 1.1 million tonnes of ammonia and be used to decarbonise fertiliser production.

Unigel - a Brazilian chemicals company - has partnered with German-based Thyssenkrupp Nucera to construct the world's largest integrated green hydrogen and ammonia plant in the Camaçari Industrial Complex with 60MW of capacity in its first phase by 2023.

There are 30 commercial-scale plants in development, which could produce 34.1Mt/year of ammonia by 2030 - about 19 per cent of total global production.

6.5 Enabling the transition

The 'Coordinated action scenario' shows that a transition in the Australian chemicals supply chain aligned with 1.5°C is challenging. While commitments from industry to the long-term transition have been a step forward, strong, effective and coordinated action is needed from industry, government and investors and will be critical to achieving the emissions reductions needed to stay within a 1.5°C carbon budget.

The objectives in Figure 6.10 have been identified by the Australian Industry ETI to help create a prosperous, globally competitive, net zero chemicals supply chain in Australia.

FIGURE 6.10: Objectives and recommended actions for chemicals

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia's industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower	Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	Develop **integrated regions, supply chains and energy network** solutions

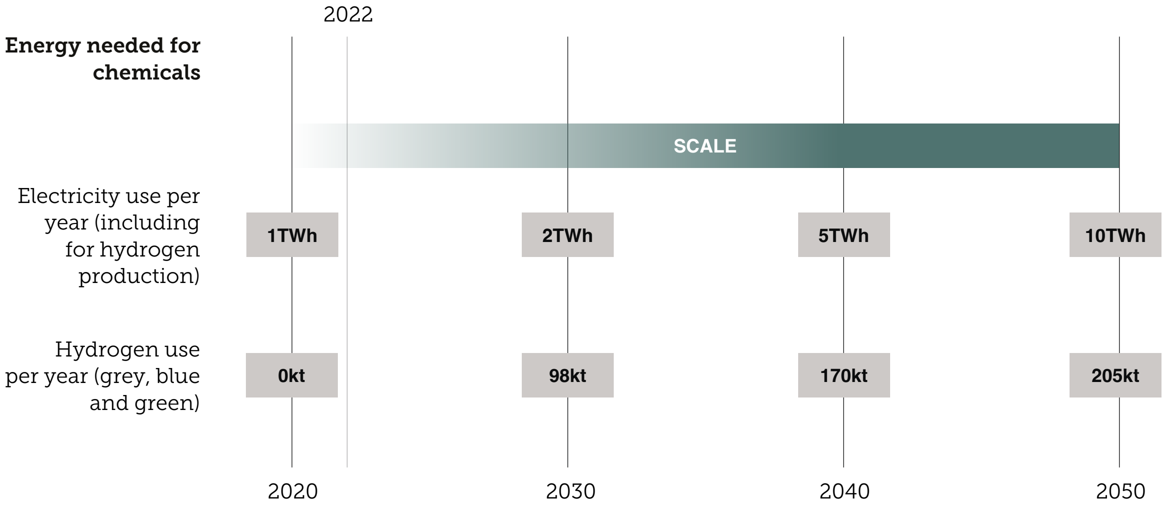
FIGURE 6.10: Objectives and recommended actions for chemicals (continued)

A STRONG, ENDURING FRAMEWORK

1. Develop chemicals supply chain roadmaps for heavy industry
2. Develop a national strategy for the development of new export markets for green hydrogen and green ammonia
3. Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions

LARGE-SCALE, COST-COMPETITIVE, RENEWABLE ENERGY SYSTEM OF THE FUTURE

4. Set targets for deployment of renewable energy
5. Set targets that drive the development of a diverse portfolio of hydrogen production



ACCELERATED DEVELOPMENT AND DEMONSTRATION

6. Prioritise funding and support for pilots and demonstrations
7. Develop partnerships with mining companies for low-emissions commercial explosives and precision blasting

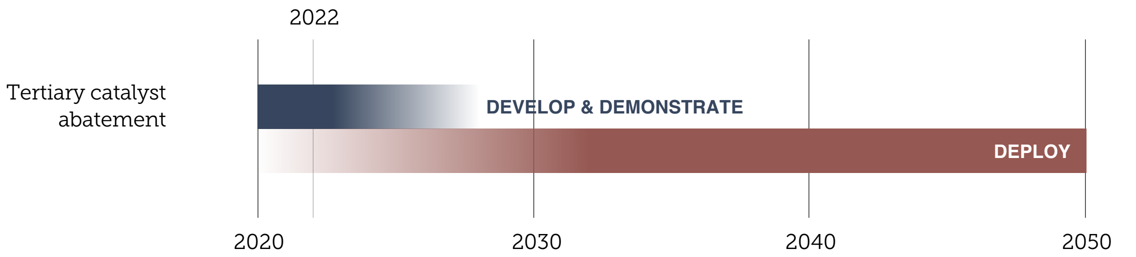
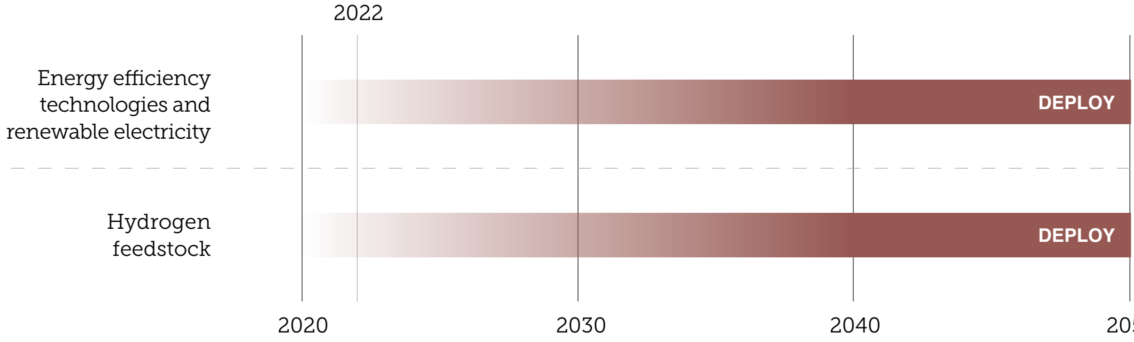


FIGURE 6.10: Objectives and recommended actions for chemicals (continued)

DEPLOYMENT OF LOW CARBON SOLUTIONS

8. Develop early supply, demand and enabling infrastructure to scale net zero solutions



INTEGRATED NET ZERO REGIONS, SUPPLY CHAINS AND ENERGY NETWORK SOLUTIONS

9. Develop a series of net zero industrial precincts or hydrogen hubs

To ensure a timely and effective transition of the chemicals supply chain, Table 6.01 shows a list of recommended actions. They are mapped against the four enabling themes that the Australian Industry ETI has identified as being important for driving decarbonisation in heavy industry, which are discussed in chapter eight `Enabling the transition to heavy industry decarbonisation'. This mapping is represented by the coloured boxes. Chapter eight also contains key recommended actions to decarbonise all supply chains, which complement these recommended actions specific to chemicals.

TABLE 6.01: Recommended actions to achieve the decarbonisation of the chemicals supply chain.

Objective	#	Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Develop chemicals supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation. Particular attention should be given to consultation with regulators and communities on the safety and acceptance of nitrogenous chemicals in proximity to highly populated areas.		■	■	■
	2	Develop a national strategy for the development of new export markets for green hydrogen and green ammonia. Green ammonia has potential as a green fuel and as a carrier for hydrogen. International trade partnerships for offtake in other countries and by shipping companies would encourage more rapid scaling.		■	■	■
	3	Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions.		■		■
Transition to the large-scale, cost-competitive, renewable energy system of the future	4	Set a series of short, medium and long-term goals and enable effective investment for the development of the energy needed for the chemicals industry decarbonisation. This could be at the scale of 1.5TWh/year in 2030 and 10TWh/year in 2050 (including the electricity needed to produce green hydrogen).	■			■
	5	Set targets that drive the development of a diverse portfolio of hydrogen production. Create a large-scale, decarbonised hydrogen market, at the scale of 98kt by 2030 (including 93kt per year of blue hydrogen and 5kt per year of green hydrogen, and 205kt by 2050 (including 5kt per year of blue hydrogen and 200kt per year of green hydrogen). Undertake a planned approach to develop and update regulation for rapid and safe development of hydrogen production, transport and storage.	■			■

Objective	#	Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower	6	Prioritise funding and support for pilots and demonstrations that build capability and expertise to enable Australia to expand into green hydrogen and ammonia. Develop partnerships and allocate funding for research and development of priority technologies.	■			■
	7	Develop partnerships with mining companies for low-emissions commercial explosives and precision blasting. Develop agreements on offtake of low-emissions commercial explosives and sharing industry expertise around the effective use of precision blasting as a method to reduce emissions and inefficiency associated with commercial explosives use.	■	■		■
Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	8	Develop early supply, demand and enabling infrastructure to scale net zero solutions through levers such as offtake commitments, government procurement contracts, aggregation of industry demand, feed-in tariffs, voluntary pledges, mandates, certification schemes and a guarantee of origin. Targets and incentives for hydrogen production may be linked to demand in the chemicals sector as an early offtaker, using a range of mechanisms including targets, contracts for difference, offtake guarantees, etc.	■	■	■	■
Develop integrated net zero regions, supply chains and energy network solutions	9	Develop a series of net zero industrial precincts or hydrogen hubs, designed to leverage shared infrastructure and draw in large scale renewable energy from renewable energy zones or equivalent. This could enable co-location of hydrogen production with ammonia plants and use of hydrogen electrolysis as a load balancing mechanism. Coordination may be enabled by regional roadmaps and mechanisms for co-investment across regional developments.	■	■	■	■

7. Focus on LNG

In Australia, liquified natural gas (LNG) is produced for export to overseas markets, where it is used for electricity generation, heat, transport and for industrial feedstocks (Department of Industry, Science and Resources 2022c). Natural gas is a fossil fuel primarily consisting of methane either found in geological formations underground (conventional natural gas) or in sedimentary rock such as shale (unconventional natural gas) (Energy Information Administration n.d.). LNG is produced via a process of liquefaction of natural gas. Over 80 per cent of Australia's gas production is attributable to LNG production, most of which is exported and some of which is used to power the liquefaction process (Department of Industry, Science, Energy and Resources 2021a). The production of LNG is currently growing, with a cumulative A$305 billion of investment in the LNG export industry over a decade from 2009 (Department of Industry, Science and Resources 2022a). As of October 2021, there were 45 LNG, gas and petroleum projects in the investment pipeline in Australia (Department of Industry, Science, Energy and Resources 2021b).

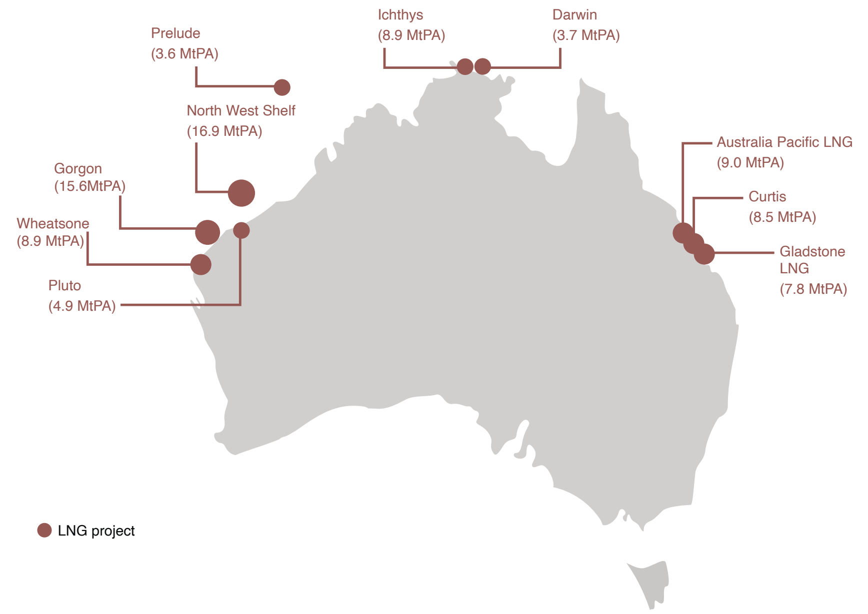
Globally, LNG accounted for 12 per cent of gas demand in 2020 and trade reached 391Mt in 2021, an annual increase of 9.8 per cent. Of the 391Mt, Australia exported 81Mt (Department of Industry, Science and Resources 2022c). Changes in international demand for natural gas have a material impact on the market for Australia's LNG exports. The IEA reports that Asian spot LNG prices rose more than fourfold in 2021 (IEA 2022a) and in 2022, geopolitical crises (notably the Russian invasion of Ukraine) and extreme weather events exacerbated price spikes in LNG. According to the Australian Competition and Consumer Commission (ACCC), the Australian LNG netback price[66], a measure of an export parity price, was more than three times higher in August 2022 than in August 2021, and nearly seven times higher in April 2022 than April 2021 (Australian Competition and Consumer Commission 2018). This, combined with delays in scaling up new forms of energy, could see continued volatility in natural gas and LNG prices (Birol 2022).

The IEA net zero scenario sees global LNG trade increasing between 2020 and 2025, then falling by roughly two-thirds (IEA 2021c). Increases in the emissions reduction ambition of key export markets could reduce demand for LNG as these countries seek alternative sources for energy and industrial feedstocks. LNG emissions from existing Australian operations would naturally decrease as reserves are depleted. This IEA scenario underpins Australian Industry ETI modelling (see below). Forecasting LNG demand is very challenging, and different studies see different futures for natural gas, even in a net zero or 1.5°C aligned world. In addition, 74 per cent of the volume of Australia's 2020 exports is being sold on contracts with an end year after 2029,[67] and these may be broken by a dramatic decrease in production. If demand does not decrease as assumed in this report, then emissions from LNG production would be different. For every tonne of LNG produced, around 0.64tCO_2e is produced, including CO2 and methane from fuel combustion, venting, leakages and flaring, and electricity generation. Emissions from LNG production are likely to continue to represent a considerable proportion of Australia's emissions. Therefore emissions from operations must be reduced significantly in a 1.5°C aligned scenario.

66 The ACCC bases the LNG netback price on Asian LNG spot market prices. This is intended to represent the price that a gas supplier 'would expect to receive from a domestic gas buyer to be indifferent between selling the gas to the domestic buyer and exporting it.'

67 Source: based on analysis from DISER (Department of Industry, Science and Resources 2021) and BloombergNEF.

LNG in Australia

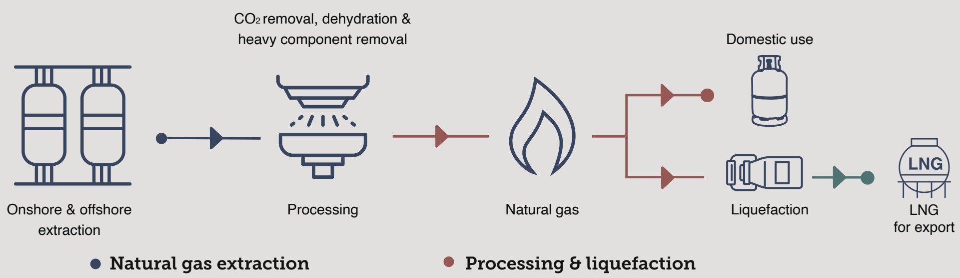


up to **26,400** jobs in LNG

4393PJ of LNG produced, generating **A$50 b** in exports

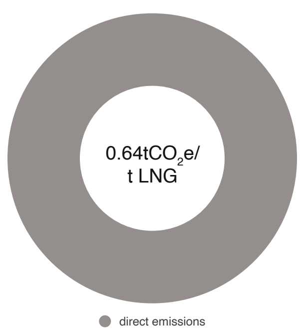
approximately **52MtCO_2e** emitted each year

LNG extraction, processing, and liquefaction

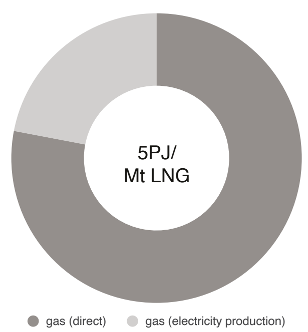


LNG

Emissions



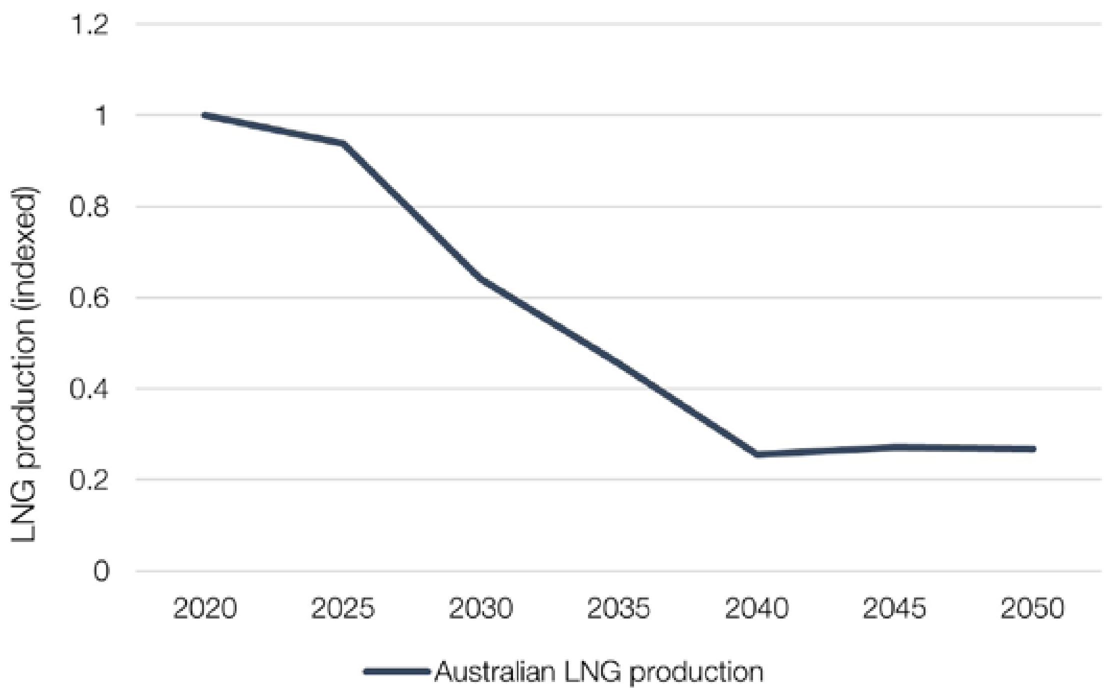
Energy Use



7.1 LNG production assumptions

For this research, LNG production model inputs (Figure 7.01) have been aligned to the IEA's 'Net zero by 2050' (NZE) (IEA 2021c) as well as to Australian government short-term projections (Department of Industry, Science and Resources 2021). Although emissions reductions associated with Australian exports are not modelled in this study, aligning demand to the IEA NZE scenario shows changes in production and export demand as key trading partners attempt to reduce their emissions. The IEA NZE scenario is consistent with limiting the global temperature rise to 1.5°C without a temperature overshoot, based on an analysis of IPCC scenarios, and is compared with three other scenarios (see Information Box 7.01). Guided by the NZE scenario, the Australian Industry ETI assumes a 36 per cent reduction in Australian LNG exports between 2020 and 2030 and a 73 per cent reduction between 2020 and 2050, in response to emissions reductions in key export markets (such as China, Japan and South Korea).[68]

FIGURE 7.01: LNG production assumptions in Australia



68 The assumptions for 2020-23 are from the Australian government (Department of Industry, Science and Resources 2021), while the 2024-2050 assumptions are from the IEA scenario ((IEA 2021c) - Figure 04.17). There is a big difference between the Australian government estimates and the IEA NZE scenario in the short term. In the IEA NZE scenario, LNG exports increase from 2020 to 2025 before decreasing. Australian government estimates however only extend to 2023, and start at a higher value than IEA NZE. Due to the model only operating in five yearly increments, it doesn't see a peak in production in 2023. For that reason, LNG production decreases between 2020 and 2025.

INFORMATION BOX 7.01

Modelling LNG and natural gas demand

The future global energy mix is often projected as part of climate change modelling. Scenarios in which temperature increase is limited to 1.5°C (or net zero emissions scenarios) invariably see a substantial shift in energy mix although there is significant uncertainty around the relative changes in different fuel types such as natural gas (and LNG) due to a range of technological, social, economic and policy assumptions that inform these projections. Australia is impacted by changes in demand in key export countries, making decarbonisation pathways in Asia are very important.

- There are three IEA scenarios other than NZE, including a 'Sustainable development scenario' (SDS) in which temperature increase is 1.65°C (50 per cent probability) (IEA 2021b). The other two scenarios result in a higher temperature increase. The SDS scenario sees significant effort to decarbonise while also aiming to meet other United Nations Sustainable Development Goals (SDGs), including access to clean energy and reduced air pollution. Unabated natural gas as a share of global total energy supply decreases 24 per cent in 2020 to 22 per cent in 2030 and to 10 per cent in 2050. Natural gas with carbon capture, utilisation and storage (CCUS) increases to 4 per cent of total energy supply in 2050. In contrast, in NZE the share of unabated natural gas in 2050 is 3 per cent, and natural gas with CCUS is 8 per cent. However, actual energy consumption from gas is more than 40 per cent higher in SDS because more energy of all kinds is consumed (including from oil, nuclear, renewables, etc.). The NZE scenario results also show that global production of hydrogen could be 520Mt/year by 2050, of which 322.4Mt/year may be electrolysis-based hydrogen and the remainder gas-based (IEA 2021c).
- In four illustrative 1.5°C compatible pathway archetypes, the Intergovernmental Panel on Climate Change (IPCC) shows the impact that differences in modelling have on the future energy mix. It notes that natural gas consumption varies significantly by scenario and that high-gas scenarios tend to rely on high levels of CCS (Rogelj et al. 2018). In an analysis of modelled pathways that limit warming to 1.5°C (with a greater than 50 per cent chance and no or limited overshoot), the global use of gas in 2050 is projected to decline with median values of 45 per cent on 2019 levels (or 70 per cent in pathways without CCS) (IPCC 2022). The IPCC also finds that scenarios with higher energy demand see a more rapid scaling of hydrogen (Clarke et al. 2014).
- CSIRO's 2022 GenCost modelling finds that gas remains part of the global electricity generation mix in 2050 under the 'Global net zero emissions by 2050' scenario, although CCS is applied to 100 per cent of consumption (CSIRO 2022). In that scenario, blue hydrogen production commences early, reducing the investment needed for CCS technology.
- The Network for Greening the Financial System's (NGFS) net zero scenario (which has a 1.5°C temperature rise) finds that gas consumption as part of global final energy use declines substantially by 2050 (NGFS scenarios portal n.d.). The Reserve Bank of Australia's analysis shows that Australia's LNG exports fall to roughly half their current level by 2050 under this scenario, led by sharp declines in Japanese and South Korean demand (Kemp et al. 2021). In the 'Below 2°C scenario', LNG exports slightly increase but decline after about 2040.
- Energy company Shell does not model a 1.5°C or net zero scenario, but the 'Sky' scenario, in which temperature rise is limited to below 2 degrees Celsius, sees natural gas consumption increase significantly against 2000 levels by 2030 and remain higher than 2000 in 2050, declining by 2075 (Shell n.d.). Green hydrogen grows as an energy carrier from 2040 onwards and accounts for 10 per cent of global final energy consumption by 2100. Shifts toward hydrogen consumption in heavy industry do not occur until after 2050, with coal and natural gas remaining prominent until that time.
- Energy company bp models three scenarios, including an 'Accelerated' scenario and a 'Net zero' scenario which are 'broadly aligned with a range of IPCC scenarios which are consistent with maintaining global average temperatures to 2°C and 1.5°C respectively' (bp global 2022). In the net zero scenario, global natural gas demand peaks in 2025 before declining slightly relative to 2019 demand by 2030. Between 2019 and 2050, natural gas demand decreases from 3900 billion cubic metres of natural gas (Bcm) to 1681Bcm. Natural gas use in power, industry and buildings all decline substantially, while an additional 270Bcm is used to produce hydrogen.

7.2 Technology deployment timeline

The ‘Coordinated action scenario’ shows what could be done to decrease emissions in the LNG supply chain, in addition to decreasing production in the IEA NZE scenario. Emissions from the production of LNG are largely due to the combustion of fossil fuels in processing and liquefaction (mainly combustion of gas) and non-energy emissions (unintended releases of methane, intended venting of methane and intended venting of CO_2 into the atmosphere). Emissions intensities of Australian LNG projects vary (Gan et al. 2020). This may be due to natural variations in the quantity and composition of available gas or technological variations, including plant design.

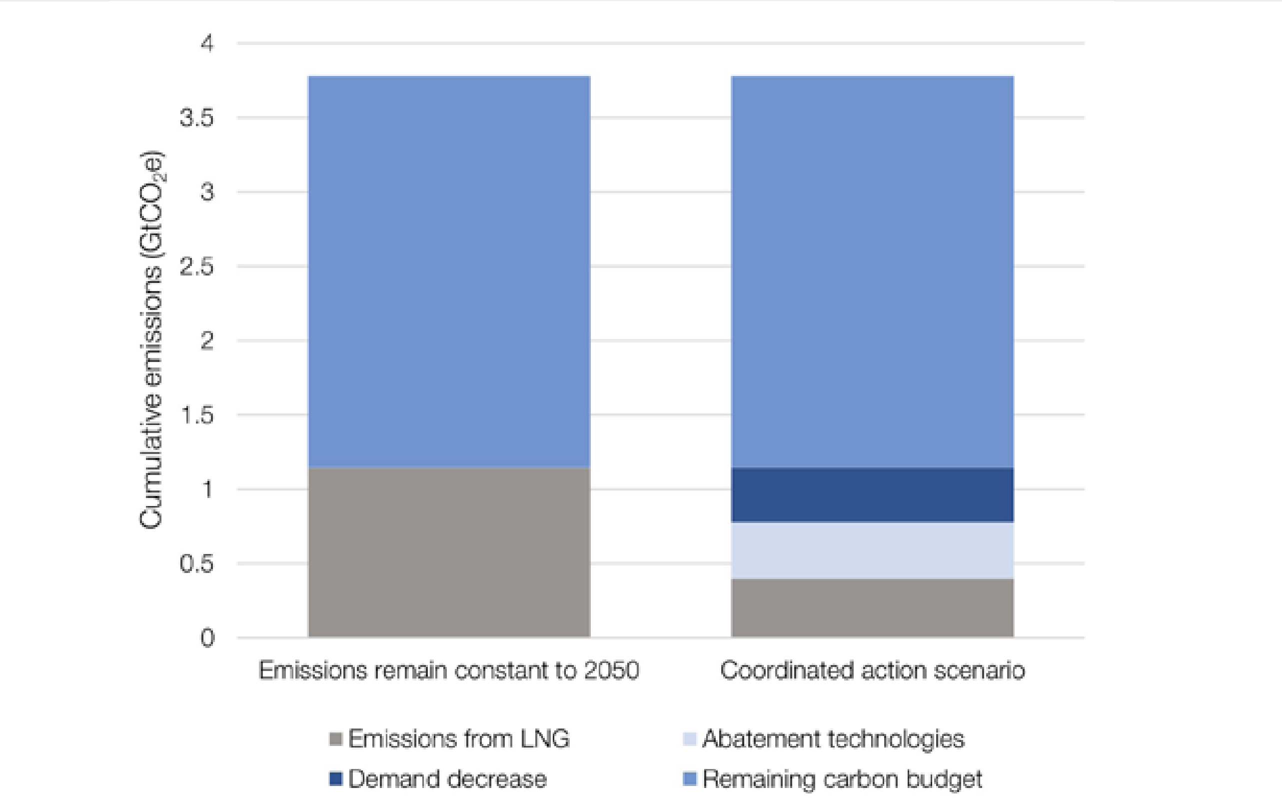
INFORMATION BOX 7.02

LNG production and Australia’s carbon budget

In the ‘Coordinated action scenario’ , emission reductions in the supply chain are driven by both LNG exports demanding the implementation of technologies to abate emissions from remaining gas and LNG production (Figure 7.02). Direct emissions from operations and electricity use in LNG production are large. If Australia’s 1.5°C aligned carbon budget lasted until 2050, and the emissions from LNG reported by the Australian government remained at the same level, cumulative emissions would consume a sizeable portion of Australia’s 1.5°C aligned carbon budget[69].

To meet the 1.5°C aligned carbon budget, the ‘Coordinated action scenario’ sees a rapid deployment of new abatement technologies as well as a demand decrease, resulting in cumulative emissions from LNG reducing by roughly two-thirds. Under the assumptions of the ‘Coordinated action scenario’, the LNG industry’s emissions are a smaller but still significant amount. The carbon budget for the rest of the Australian economy would be larger as a result.

FIGURE 7.02: LNG emissions up to 2050 as part of Australia’s 1.5°C aligned carbon budget (50 per cent probability) (Australian Industry ETI analysis)[70]

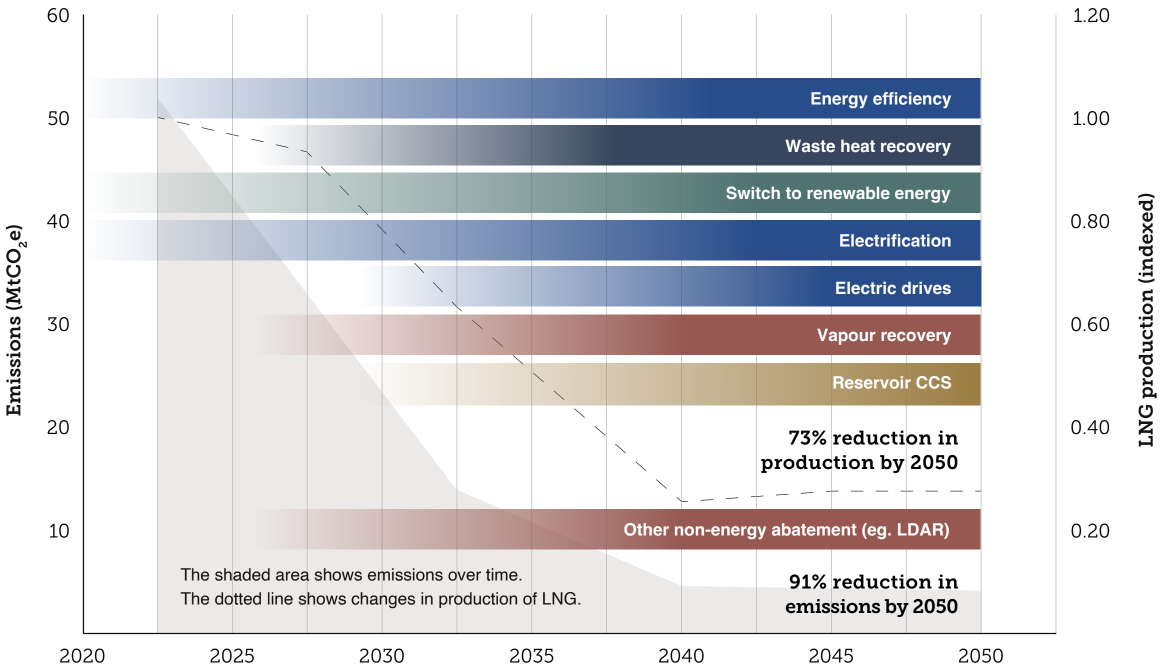


69 The portion is estimated to be 30 to 39 per cent of a 1.5°C budget: 30 per cent of the budget for a 50 per cent chance (no overshoot) or 39 per cent of the budget for a 67 per cent chance (with overshoot). See the companion technical report for carbon budget assumptions.

70 Assumes that LNG is responsible for 38MtCO_2e emissions/year per DISER estimates (Department of Industry, Science, Energy and Resources 2021d), and remains constant until 2050. This is a more conservative estimate than Australian Industry ETI’s analysis (see companion technical report for underlying assumptions). Australia’s carbon budget may be consumed prior to 2050.

In the 'Coordinated action scenario', in which ambitious action is needed to stay within a 1.5°C carbon budget, 91 per cent of the emissions caused by producing gas and LNG are abated by 2050 (Figure 7.03). This emissions reduction is largely driven by reduced production in light of global shifts in energy demand, as described in the production assumptions. There is also a reduction of 67 per cent per unit of LNG produced.[71] In other words, the emissions intensity of the industry reduces by roughly two-thirds due to the development and deployment of technologies that reduce emissions. The 'Coordinated action scenario' shows that technology investment is required early and at scale in order to stay within a 1.5°C carbon budget, and that a variety of interventions are needed. This chart shows the timeline of implementation that the model finds to be the least-cost pathway, based on technology assumptions and other changes across the Australian economy.[72]

FIGURE 7.03: Technology deployment time for the decarbonisation of LNG in the 'Coordinated action scenario'



2020 – 2030

In 2020, gas extraction and liquefaction results in the release of approximately 52MtCO_2e/year. Electrification and energy efficiency technologies (including waste heat recovery) continue to be deployed in the 'Coordinated action scenario',[73] while some fossil fuels are replaced with bioenergy as a transition fuel. Emissions reduce 72 per cent by 2030 due to less use of fossil fuels and a decrease in production of 36 per cent. With the scaling of renewable energy generation and decarbonisation of the electricity system under this scenario, electricity emissions decrease.[74] The electrification of the liquefaction process through the deployment of electric drives (e-drives) could commence at the end of the decade.

71 For the Australian Industry ETI research, the LNG supply chain includes the energy use and emissions from LNG liquefaction and export, in addition to a proportionate allocation (based on overall production) of the emissions upstream of LNG facilities (that is, extraction and processing related emissions). This definition excludes supply of domestic gas and their relative portion of upstream emissions. Emissions from the production of gas for domestic consumption are included in the emissions findings. Emissions from the transmission and consumption of gas for domestic use are not included. This analysis also only covers domestic emissions from production and excludes shipping.

72 Not all technology solutions that may play a role in decarbonising the supply chain are represented by the model. Technologies may be available before the model implements them. Assumptions regarding which technologies were included in the modelling are given in the companion technical report, including CAPEX, OPEX, emissions reduction potential and energy usage.

73 Business-as-usual energy efficiency improvements are assumed throughout the model in all sectors. Generic electrification limits are imposed in each supply chain. In addition, specific electrification technologies such as electric drives are implemented. See the companion technical report for details.

74 Because many LNG operations are off-grid, the rate of renewables integration and electricity emissions reduction would vary by site. A limitation of the model is that it assumes that all electricity consumption is grid-connected. See the companion technical report.

The 'Coordinated action scenario' assumes considerable adoption and use of technologies that capture methane emissions (many of which could be economical as they may result in the prevention of a loss of product[75] (IEA 2022b) as well as vapour recovery units for vented methane emissions. Reducing methane emissions in this decade would have a significant impact on the immediate global warming impact of the sector, given the shorter-term but intense effect of methane on climate change (Global Methane Initiative n.d.).

2030 – 2040

The start of the next decade sees the deployment of, new CCS for reservoir gas (CO_2) projects in the 'Coordinated action scenario'. This reduces the emissions that result from venting during the processing and purification process.

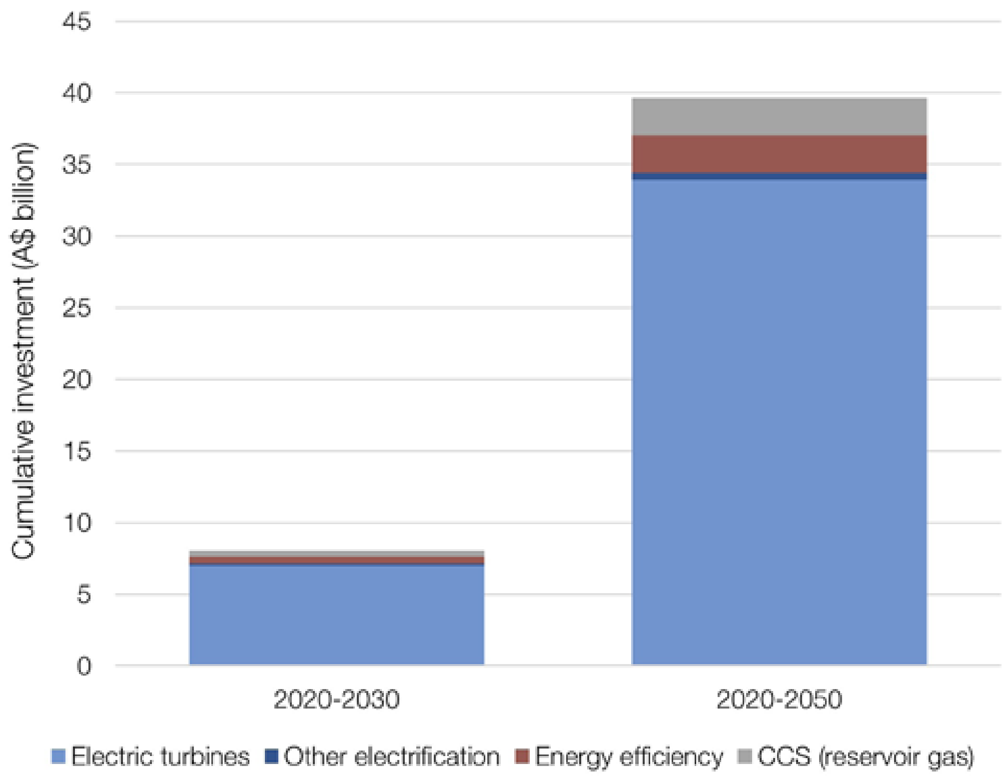
E-drives could also be optimally scaled during this decade, replacing incumbent gas compression technology. E-drives have high installation costs, in large part due to significant losses in revenue during plant downtime, but may lead to long-term cost savings because of reduced operating and maintenance costs, and relative energy costs if renewable electricity is able to be deployed.

In the 'Coordinated action scenario', the reduction in methane and CO_2 emissions, coupled with a decrease in production of 74 per cent by 2040, result in an emissions reduction of nearly 90 per cent from 2020 levels.

2040 – 2050

The 'Coordinated action scenario' shows continued electrification, renewable energy integration and changes to reduce fugitive emissions resulting in significant emissions reductions. This would be enabled by a total of A$40 billion of investment in technology between 2020 and 2050, with the largest in e-drives (A$34 billion) (Figure 7.04). Because the model has perfect foresight, it can find the least-cost pathway as demand goes down, and can optimise for a pathway in which only 27 per cent of 2020 production remains in 2050. Investment would be more challenging with more uncertainty around demand.

FIGURE 7.04: Cumulative investment in LNG technologies



75 A number of fugitive abatement processes, such as leak detection and repair (LDAR) and the early replacement of devices are considered to be zero or negative cost, based on the assumption that the prevented gas loss covers the cost of implementing the technology.

The ‘Coordinated action scenario’ results in Australia’s national emissions from LNG reducing by 91 per cent: a 25 per cent reduction due to operational changes and a 66 per cent reduction due to changes in demand.

7.3 LNG supply chain decarbonisation

The ‘Coordinated action scenario’ shows that decarbonising LNG processes in line with a 1.5°C carbon budget is challenging, and requires significant investment in the development and deployment of low emissions technologies in addition to the energy system transformation needed. The investment seen in the ‘Coordinated action scenario’ is equivalent to less than one seventh of the investment in LNG projects over a decade from 2009 to 2019 (Department of Industry, Science and Resources 2022a).

As shown in Information Box 7.01, there is a wide range of uncertainty in future gas demand in 1.5°C aligned scenarios, which presents a challenge for investing in LNG production decarbonisation.

Technology, strategy, and the achievement of decarbonisation and new energy goals will go hand in hand to achieve the ‘Coordinated action scenario’. The push to decarbonise the supply chain and to enter new markets could lead to a prioritisation of research and development and as technology capabilities increase, demonstrations and pilot programs that begin to show promise and help support certain technology pathways; to be more successful than others, particularly when adapting technologies for an Australian context. With a defined roadmap, technologies may be scaled along with the renewable energy generation or other infrastructure needed enabling a more orderly transition.

A coordinated pathway for the LNG industry with strong policy, regulatory and financial signals could give direction and empower industry to make a commercial case for greater and more rapid action, deploying technologies that may see little or no financial return on investment but deeper emissions reductions. Success would mean that companies meet 1.5°C aligned targets and are able to transition to provide the products and services needed for a decarbonising world. This could provide Australian industry with the strategic benefits of being an early mover and avoiding the risks of being left behind (see ‘Enabling the industry transition in Australia’).

This section discusses opportunities to reduce or overcome the uncertainties holding back a coordinated approach to decarbonising the LNG supply chain in line with a 1.5°C carbon budget (Figure 7.05).

FIGURE 7.05: Challenges for LNG decarbonisation in Australia

Developing emerging technologies with demonstration and planning	**Deploying mature technologies** and achieving decarbonisation quick wins early	**Integrating** renewable energy at scale	**Achieving scale** despite global demand changes

Actions can be taken to overcome these challenges. This section discusses key enablers of the transition for the LNG supply chain, with a set of recommended actions at the end of the chapter.

Developing emerging CCS technologies: technical, financial and social challenges

One of the emerging technologies included in the modelling is CCS of reservoir CO_2. CCS plays a prominent role in the ‘Coordinated action scenario’ for LNG, but faces unique challenges. The challenges for early development lie in both the technology and the need for accompanying infrastructure. The economics of abatement through CCS[76] vary dramatically by application and location (Geoscience Australia 2021). In the ‘Coordinated action scenario’, CCS of reservoir CO_2 in

76 The term ‘CCS’ is used generically in this section rather than carbon capture, utilisation and storage (CCUS). Storage of carbon in geological formations is the focus of this chapter, but utilisation solutions are also considered.

gas production is a central technology for industry decarbonisation. CCS can address emissions caused by CO_2 venting: the intentional release of reservoir gas into the atmosphere during separation from methane, which is a necessary process prior to liquefaction (turning natural gas into LNG). Because reservoir gas produces a concentrated stream of CO_2 it is one of the most economical forms of CCS, as less energy is required to purify the stream of gas prior to transport and sequestration than other forms of CCS. New CCS projects are expected, with the Australian government announcing the approval of two new offshore storage areas in August 2022 (Minister for Resources and Minister for Northern Australia 2022).

CCS may also be deployed after the combustion of gas in liquefaction plant gas turbines. This could allow LNG producers to partly or entirely abate emissions during the time they continue to produce energy using fossil fuels. However, the model finds that because of the current high investment required for post-combustion CCS, this solution is not as attractive as other technologies.

The business case for CCS relies on signals to encourage investment. In the Australian Industry ETI's 'Incremental scenario', with no carbon budget constraint and no incentive for emissions abatement, no CCS is deployed. In the more ambitious 1.5°C aligned, 'Coordinated action scenario', a tight carbon budget means CCS begins to be deployed at scale by 2030, increasing by 2050. Note that quantities of greenhouse gases captured are relatively low in Australian Industry ETI modelling because of the considerable assumed reduction in demand.

INFORMATION BOX 7.03

CCS at the Gorgon gas project

Variability between sites impacts the potential for CCS of reservoir gas. For example, the Gorgon offshore gas project in Western Australia has a very high CO_2 content (about 15 per cent by volume) and, consequently, high processing emissions (Gan et al. 2020). For this reason, CCS at the site is a necessary abatement technology if the project is to comply with the emissions framework set out in environmental approvals. Estimates of the degree to which emissions could be reduced by CCS were included in the approval of the project in 2009 (Department of the Premier and Cabinet 2009).

The CCS process at Gorgon separates CO_2 from reservoir gas and injects it underground. Pressure in the Gorgon CCS technology is regulated by producing water to allow CO_2 to be injected. Water is then injected into a different water disposal reservoir. As of July 2022, Gorgon has injected 6Mt with a target of a total of 100Mt over the 40 to 45 year life of the project (40 per cent of Gorgon's total greenhouse gas emissions) (Department of Mines, Industry Regulation and Safety n.d.) (Chevron 2020). Challenges to date with the project have had the effect that it has not met its capacity for injection of 4Mt per annum from 2016 onwards and Gorgon reported an injection shortfall of 5.23Mt in 2021 (Robertson & Mousavian 2022).

Research and development of CCS

Although there have been some successful implementations of CCS in LNG, progress would be hastened by greater investment in research and development. The pace of development of CCS currently falls short of what may be needed, according to some studies (Energy Transitions Commission 2022). The IPCC has also identified a knowledge gap in comparative analyses of CCS options, limiting certainty about how much can reasonably be expected from those technologies (de Coninck et al. 2018).

Post-combustion CCS is not considered to be as economically attractive as reservoir CCS, as it requires capturing a diluted stream of CO_2. However as one of the few technologies that could target emissions at the liquefaction stage it could also add to the collective volume of CO_2 captured (in addition to reservoir CO_2), increasing the scale and lowering costs per unit. Allam cycle turbines are one proposed CCS technology (Allam et al. 2017), and other technologies could produce more concentrated CO_2 streams. These technologies would require capital investment at the liquefaction plant, and the Allam cycle may be less economical than traditional gas turbines (Kennedy et al. 2021). Prioritising post-combustion CCS could be driven by a strong emissions reduction target. The economics of post-combustion CCS compared with electric drives (see below) could vary by site, and both cost and capture rate are considerations.

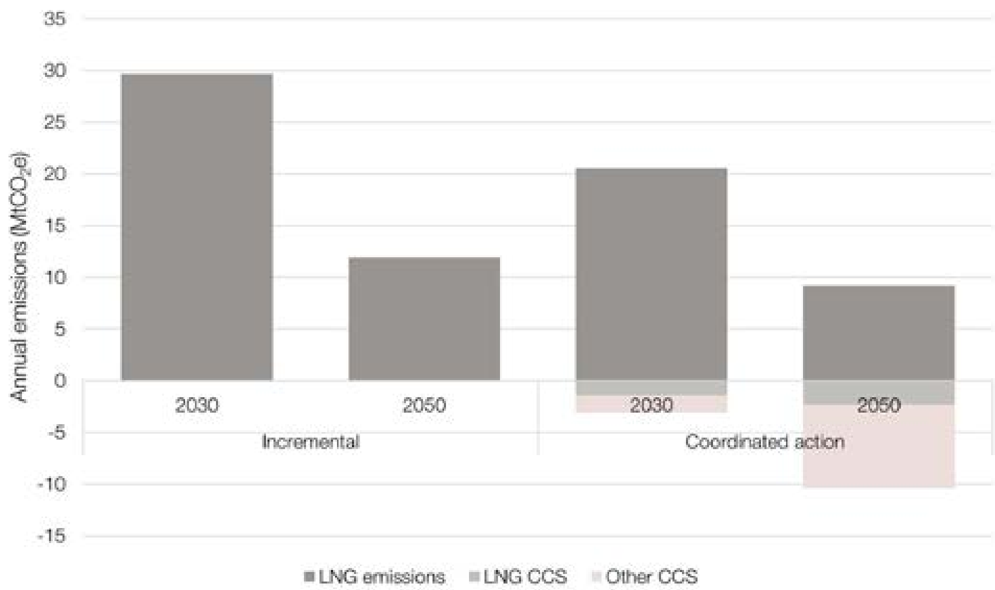
Appetite for investment in CCS would increase with greater certainty of the abatement potential. Successful pilot projects and demonstrations could help to build confidence in the technology in an Australian context.

Shared CCS infrastructure and partnerships

LNG is not the only supply chain in which CCS could play a role. CCS technologies are used in the 'Coordinated action scenario' in LNG, alumina and the production of blue hydrogen, and other industries. Other supply chains that could use CCS include steel (see 'Focus on steel' chapter), ammonia (see 'Focus on chemicals' chapter) and cement. Transmission and sequestration of carbon is not in scope for Australian Industry ETI, but modelling by Net Zero Australia also finds that building direct air capture (DAC) near sequestration sites may also be an efficient placement for technologies that remove greenhouse gases directly from the atmosphere (Net Zero Australia 2022).

Collaboration with other industries could enable faster scaling of CCS technologies through the sharing of infrastructure. One example where this is already being planned is in the Humber Industrial Cluster in the United Kingdom (Zero Carbon Humber 2019). The use of depleted gas fields for carbon storage could be of value to industrial users, and is an area where the LNG industry could leverage experience and know-how, and by building technology capabilities. Figure 7.06 shows the scale of CCS seen in the 'Coordinated action scenario', and any captured carbon would need to be either utilised or sequestered, possibly in depleted gas fields. Knowledge exchange of best practices could be key enablers of CCS. Oil and gas companies could help by sharing experiences and insights for effective management (Energy Transitions Commission 2022).

FIGURE 7.06: Emissions by Australian Industry ETI scenario in 2030 and 2050, including the impact of reservoir CCS



CCS could become an attractive proposition if industrial and government stakeholders share the risks and benefits of new infrastructure. Among these are pipelines for CO_2 (or other methods of transportation) and central hubs for geological sequestration, creating economies of scale (IEA 2022c). CO_2 must be compressed before being transported in a pipeline, a process already in use globally for the purposes of enhanced oil recovery (EOR) (Cooney et al. 2015). If deployed, infrastructure must be inspected and maintained to prevent leakages, and safety standards applied.

Heavy industry may also require the use of geological formations for hydrogen storage. If CCS is chosen as a pathway, it will be important to understand the degree to which there may be competition for these sites and weigh up the benefits of each option carefully in case of any conflict.

Regulation of CCS

Regulation would support CCS during its development and demonstration phases, and could cover all parts of the CCS value chain (IEA 2022c). CCS is subject to uncertainty about the feasibility of timely upscaling with reference to regulations, safety and costs (de Coninck et al. 2018). Regulation would remove some of this uncertainty. Robust monitoring and regulation could help to ensure high carbon capture rates and reduce the risk of leakages if CCS is deployed. The success of CCS projects are, in part, connected to public perception and acceptance (L'Orange Seigo et al. 2014).

Legal frameworks for CCS are currently partly the responsibility of federal government and partly of states and territories, and are inconsistent (Power 2021). The federal government is responsible for offshore areas within their waters, while states and territories impose laws on both onshore and offshore projects in their own jurisdictions. Greater consistency could be achieved in CCS project planning.

Transitioning existing plant and operations

Some of the most important technologies for abatement in LNG are mature and commercially available. The prevention of fugitive emissions through leaking, venting and flaring could be improved through process changes. Digital technology can make it easier to introduce these changes. Measurement technologies are advancing and now include drone, satellite, and infrared fugitive emissions monitoring (Australian Industry Energy Transitions Initiative 2021a).

Process efficiency changes and energy efficiency technologies (such as waste heat recovery (Othman et al. 2021)) are also very important, and a strong business case may be made because they reduce energy costs.

Financing for retrofit in brownfield sites

Brownfield sites see a two-fold transition cost: capital investment in new technology as well as the cost from reduced production volume while the retrofit is taking place. Some of these retrofits may be large projects and could be enabled by financial backing, such as decarbonisation-linked loans.

Implementation of practices to prevent venting and leakages

Operational improvements and best-practice technologies can address a large portion of emissions from venting and leakages (Australian Industry Energy Transitions Initiative 2021a). These are often cost-effective interventions, because they reduce the amount of gas escaping along the supply chain. The IEA estimates that an average of 40 per cent of methane emissions in oil and gas operations could be avoided at no net cost (IEA 2022b). A key opportunity for existing sites lies in leak detection and repair. This requires changes to current practices, but provides relatively quick wins. Preventing the venting and leakage of methane can be achieved by more regularly replacing valves, pumps and equipment used during ship loading. Regulatory pressure is a strong motivator to improve measurement and practices (Methane Guiding Principles 2019). Estimating, modelling and demonstrating the potential financial benefits of improving these practices could result in quicker adoption, or at least enable the identification of a low-cost option to reduce emissions quickly.

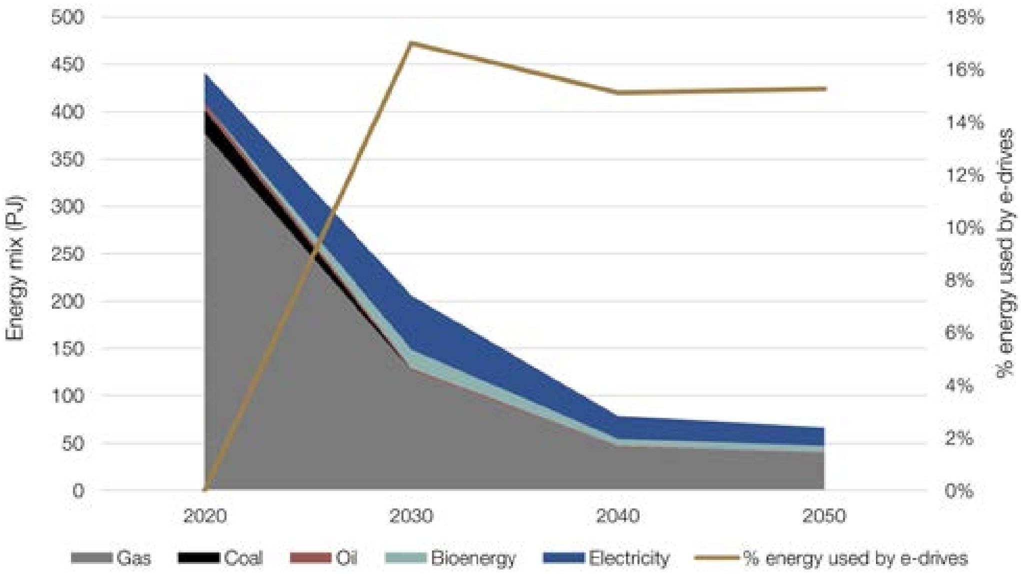
Implementation of practices to reduce flaring

Limiting flared gas is a potential means of reducing emissions at extraction. However, flaring is used for safety reasons. Making operational changes to reduce events that make flaring necessary could decrease emissions, and digital technologies for monitoring and analysis can support this (Siemens 2020). However, this is operationally challenging while also upholding high safety standards. Eliminating routine flaring by 2030 is one of the objectives of the Global Gas Flaring Reduction Partnership (GGFRP) (World Bank n.d.).

Electrification technology implementation

There are multiple opportunities for electrification of LNG production which are anticipated to become commercial over time. Small scale electrification technologies, such as electric helper motors, are likely to be relatively easy to implement as they become available (Trombley and Thennadil, 2021). There is also an opportunity to electrify train turbines. Train turbines are used to cool the natural gas and convert it to liquid form, and are currently typically powered using gas. Electric drives replace gas turbines with technology that uses electricity. E-drives reduce direct combustion emissions, as well as methane emissions resulting from incomplete combustion (methane slip). Because of this, and other kinds of electrification, the 'Coordinated action scenario' sees a dramatic increase in the proportion of overall energy consumption from electricity (Figure 7.07).

FIGURE 7.07: Energy mix in 'Coordinated action scenario' and the percentage of energy used by e-drives[77]



To enable the switch to e-drives, technical and financial challenges would need to be addressed. Technical integration issues could include impacts on hot water supply, fuel gas balance, electrical distribution and process safety systems that are site specific and require assessment and potential mitigation.[78] As with all electrification technologies, the availability of electricity is also an important enabler (see below).

E-drives have the potential to deliver financial benefits due to reduced operating costs, but implementation would be highly capital-intensive and would lead to a loss of production during time taken to retrofit the plant. Therefore, financial enablers are required as well as technical enablers. The economics of retrofitting will be driven by:

- confidence in longevity of site activity
- confidence in long-term lower operating costs to offset capital investment (the cost of installation of e-drives would vary by site)
- confidence in safety systems
- incentives or penalties requiring reductions in emissions from fossil fuel combustion

77 Existing energy usage by fuel type is derived from the Australian Energy Statistics, Table F (2020) (Department of Industry, Science, Energy and Resources 2020).

78 Insight from industry consultation.

Demonstration of benefits to offset capital investment

The energy efficiency, lower operating and maintenance costs of e-drives can potentially reduce in the costs of production. Building confidence that lower operating costs can be realised in production can be achieved through demonstrations in developing the case at the large scale of deployment needed. Demonstrating and operating e-drives or prototypes will provide greater certainty, and could help to make the business case for this level of investment (as well as acceptance of the necessary disruption to operations).

Transitional approach

Installing e-drives disrupts the production of operations. Long-term suspension of operations for retrofitting will affect the business case for deployment. An approach that enables gradual deployment of e-drives, such as Hybrid e-drives would allow co-firing of gas into an e-drive before complete switching to electricity, therefore reducing disruptions and improving the business case for deployment.[79]

Planning alongside renewable energy deployment

Electrification and renewable energy should be planned and executed in concert to ensure new low-emissions assets can be used as soon as retrofitting is completed. This will require considerable coordination, both at liquefaction plants and within the region. Roadmaps and partnerships to build out renewable energy generation could provide certainty that there will be minimal disruption from electrification. If switching to electricity is particularly challenging at a site, gas turbines could also be retrofitted to use hydrogen, which could be produced using renewable energy in another area, and transported to the liquefaction plant.

Integration of renewable energy at scale

In addition to processing gas into LNG, gas is used to drive gas turbine generators (GTG) powering equipment such as utilities, lights, control systems and metering tools. This is in addition to the gas-powered train turbines mentioned above. To enable the rapid introduction of e-drives and other electrification seen in the 'Coordinated action scenario', 10GW of new electricity generation capacity is built - nearly 20 per cent of the current generation capacity of the National Electricity Market. To reduce emissions from electrification to the degree required, renewable energy would need to be used. Building renewable energy at sufficient scale will require planning and the capabilities of a major project. LNG sites are often off-grid and face challenges in integrating variable renewable electricity generation and storage, which is compounded by the need for the plant to operate continuously (Trombley and Thennadil, 2021).

Planning for environmental protection

Solar and wind energy and supporting infrastructure require land, which may be protected for environmental reasons. Planning of new projects must anticipate these constraints. Renewables projects at LNG sites risk losing their social licence or being blocked by regulators, if they lack sufficient community consultation or if there is a risk of significant environmental impact.

Best practices for involvement of First Nations communities in renewable energy projects

Traditional Owners of the land are an important stakeholder group who may have property rights and interests in the land. Establishing best practices for partnerships and involvement of First Nations people in the planning and execution of large renewable energy projects is important for project success. Creating an agreement provides an opportunity for private companies and First Nations people to positively negotiate and create a long-term ongoing relationship, and should begin early (O'Neill et al. 2021). Industrial partnerships can be productive with a 'sharing the benefits' approach, including involvement in design and the securing of local jobs (First Nations Clean Energy Network n.d.)

Shared transmission and infrastructure

Transmission and energy infrastructure in industrial regions could be shared by multiple users to reduce the costs and risks of the transition to renewables. Transmission partnerships would require regulation to protect all users.

Achieving scale despite global demand changes

A net zero emissions world requires substantially more low-emissions energy, and there are many opportunities to generate and provide that energy. The 'Pathway to heavy industry decarbonisation' chapter describes the potential for Australia to diversify its energy exports, and this chapter shows some of the means by which the LNG industry can

79 Input from industry participant

reduce its emissions in remaining facilities. Australian LNG companies are well-placed to support the global switch to zero emissions fuels, because they have access to infrastructure (that may be modified), a skilled workforce, and existing relationships with large energy customers.

The model creates a pathway based on a future in which LNG demand decreases significantly because this reduces emissions within Australia as well as from Australian exports in other countries. In the ‘Coordinated action scenario’, LNG achieves moderate reductions in emissions intensity in comparison with other industries, with more decarbonisation driven by a reduction in production. Not all research shows a medium-term decline in LNG or natural gas demand (see Information Box 7.01). Some of Australia’s export nations have signalled that they intend to continue to use gas and LNG in the context of their energy transition. For example, Japan has expressed interest in LNG as a ‘transition fuel’, and may place importance on the reduction of upstream emissions (Minister of Economy, Trade and Industry 2021). If Australia continues to export LNG, then gas extraction and liquefaction will remain a major source of emissions. Achieving a 1.5°C pathway under those conditions would require greater investment in abatement technologies.

Understanding of customer future energy product needs

Long-term strategic planning for energy exporters depends heavily on understanding the needs and priorities of offtakers of energy products. Australian LNG companies are well-placed for this, because they have existing relationships with large energy customers.

Globally, natural gas has a relatively low additional cost for low-emissions products for industrial buyers, compared with other industrial products (World Economic Forum 2022). This suggests the market for LNG with lower emissions could be easier to build than with other Australian exports. However, unabated consumption of gas by international customers at current levels would be incompatible with limiting temperature increase to 1.5°C, even with the reduction in Australian emissions.

The LNG industry can support demand for a green premium by working with customers and global industry collaboration initiatives (Woodside 2021). Standardised and improved measurement, reporting and verification regimes across global value chains could help improve the transparency of emissions and offsets (Baker Institute 2020). Certification schemes for methane and CO_2 emissions intensity could be established to incentivise the purchase of lower emissions LNG. Internationally, carbon prices and methane fees could help incentivise companies to reduce scope 1 and 2 emissions (World Economic Forum 2022).

Leveraging strengths to support new industries

There are opportunities for the LNG industry to leverage its existing infrastructure that could potentially be leveraged in order to export other products. However, the transition in infrastructure will not be like-for-like. For example, it may not be possible to transition liquefaction technologies currently used for LNG to hydrogen. Hydrogen liquefies at -253°C, while LNG liquefies at -161°C. However, planning and large-scale modification of supporting infrastructure would benefit from a defined export strategy. Other industries could also share this existing infrastructure for new exports.

The LNG industry has a very highly skilled workforce that could be successfully retrained as part of a just transition and to support new industries.

7.4 Momentum is building across the Australian and global LNG industry

LNG

LNG production emissions reduction is seeing more attention internationally

A liquefaction plant in Freeport USA uses electric drives, claiming that they reduce carbon emissions by over 90 per cent compared with gas turbines.

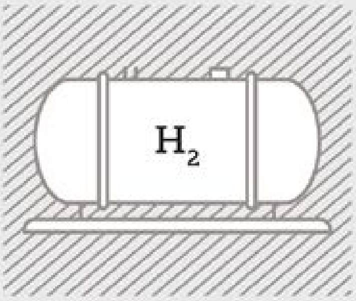
The greenfield Snøhvit offshore gas development in Norway uses electric drives and manages high power demands with automated systems.

Qatar Petroleum is building a CCS facility alongside a 126MT per year liquefaction capacity expansion and aims to abolish routine flaring by 2030.

Green hydrogen is being embraced as an opportunity

Woodside Energy is building hydrogen capabilities at H2TAS, partnering with Japanese companies to potentially build 1.7GW of electrolysis for export as ammonia.

BP has a 40.5 per cent stake in and operatorship of the Asian Renewable Energy Hub (AREH) in the Pilbara region, which could produce 1.6Mt of green hydrogen per annum, and has also found strong potential to export green hydrogen and ammonia at scale from a site at Geraldton in Western Australia.



7.5 Enabling the transition

The 'Coordinated action scenario' shows that a transition in line with 1.5°C is challenging for Australia. The Australian Industry ETI modelling assumes that LNG production will decrease with a global push for decarbonisation (IEA 2021c), but also shows that strong, effective and coordinated action is needed from industry, government and investors to achieve a pathway in which Australian emissions from LNG production decrease substantially. The objectives in Figure 7.08 have been identified by the Australian Industry ETI to help to achieve a pathway for remaining LNG production in Australia.

FIGURE 7.08: Objectives and recommended actions for LNG

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia's industry

Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower

Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy

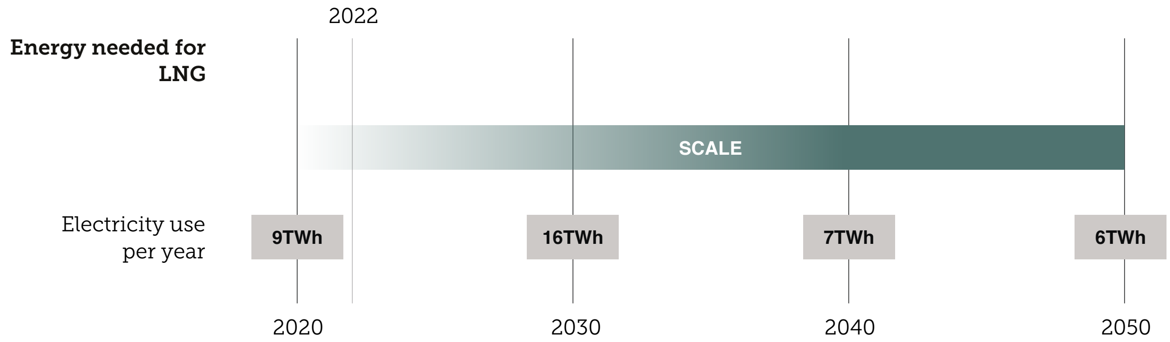
Develop **integrated regions, supply chains and energy network** solutions

A STRONG, ENDURING FRAMEWORK

1. Develop LNG supply chain roadmaps for heavy industry
2. Develop a roadmap for future energy supply in a decarbonising global economy
3. Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions

LARGE-SCALE, COST-COMPETITIVE, RENEWABLE ENERGY SYSTEM OF THE FUTURE

4. Set targets for deployment of renewable energy

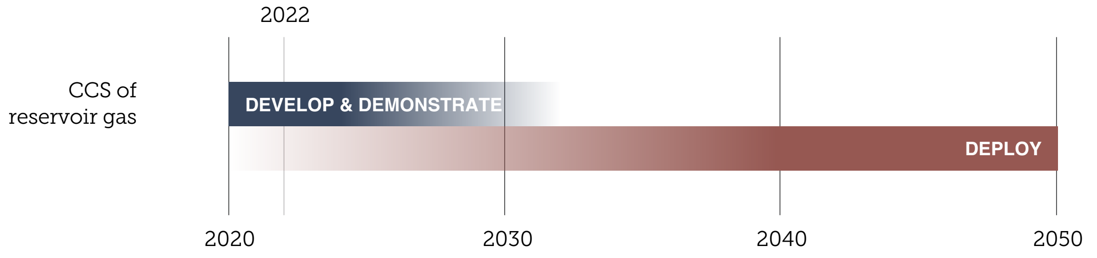


Note: Achieving scale in renewable energy is needed before 2030. Electricity use declines over time in coordinated action, and the remaining renewable energy capacity can be diverted for other energy-intensive uses, such as green hydrogen.

FIGURE 7.08: Objectives and recommended actions for LNG (continued)

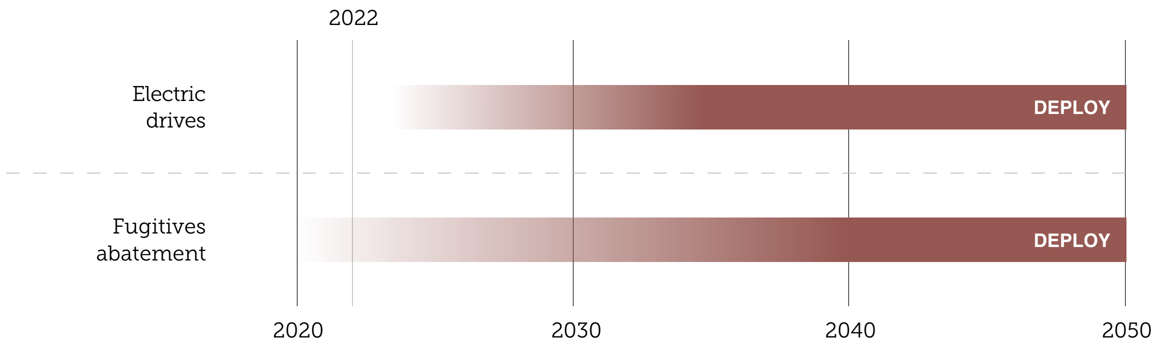
ACCELERATED DEVELOPMENT AND DEMONSTRATION

5. Ensure that public funding for development and demonstration activities catalyses greater industry investment



DEPLOYMENT OF LOW CARBON SOLUTIONS

6. Develop early supply, demand and enabling infrastructure to scale net zero solutions
7. Improve the business case for the reduction of emissions intensity at brownfield sites
8. Prioritise practices and upgrades to capture fugitives and improve efficiency
9. Implement practices to reduce flaring while upholding high safety standards



INTEGRATED NET ZERO REGIONS, SUPPLY CHAINS AND ENERGY NETWORK SOLUTIONS

10. Regional roadmaps to develop electricity and CCS infrastructure
11. Create roadmaps and partnerships to provide the energy needed for liquefaction

To ensure a timely and effective transition of the LNG supply chain, Table 7.01 shows a list of recommended actions. They are mapped against the four enabling themes that the Australian Industry ETI has identified as being important for driving decarbonisation in heavy industry, which are discussed in chapter eight `Enabling the transition to heavy industry decarbonisation'. This mapping is represented by the coloured boxes. Chapter eight also contains key recommended actions to decarbonise all supply chains, which complement these recommended actions specific to LNG.

TABLE 7.01: Recommended actions to achieve the decarbonisation of the LNG supply chain

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Develop LNG supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation.				
	2	Develop a roadmap for future energy supply in a decarbonising global economy partnering with international customers and domestic industry to produce new forms of energy, and plan for the future of energy export infrastructure.				
	3	Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions. LNG's highly skilled workforce may be retrained to enable hydrogen production, offshore wind and CCS-as-a-service as part of a just transition and to boost the new industry.				
Transition to the large-scale, cost-competitive, renewable energy system of the future	4	Set targets for deployment of renewable energy and enable effective investment at the scale required for heavy industry decarbonisation. This could be at the scale of 16.0TWh/year by 2030 and 6.1TWh/year by 2050. Facilitate development of off-grid energy systems, including through engagement, environmental protection, and establishing and following best practices for involvement of First Nations communities.				

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower	5	Ensure that public funding for development and demonstration activities catalyses greater industry investment, and develop mechanisms to better enable private finance and investment in early stage technologies. CCS and CCU should be a particular focus in order to realise the potential of these technologies. Collaboration and knowledge exchange of best practices can support timely upscaling with reference to regulations, safety and cost management.	■	■	■	■
Drive deployment of emissions reductions solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	6	Develop early supply, demand and enabling infrastructure to scale net zero solutions. One lever is to develop partnerships with international governments to support the decarbonisation of our energy export industries. Governments may collaborate to ensure that nations intending to remain customers of Australian LNG are able to support the reduction of upstream emissions from processing and exporting.		■		■
	7	Improve the business case for the reduction of emissions intensity at brownfield sites by benchmarking emissions and providing supporting evidence of technology pathways. Demonstrating and operating prototypes to provide greater confidence in performance could help make the business case for the high capital investment, especially for e-drives. Engagement in knowledge sharing would help ensure the safe and timely deployment of e-drives with minimal downtime.	■	■	■	■
	8	Prioritise practices and upgrades to capture fugitives and improve efficiency. Estimating, modelling and demonstrating the potential financial benefits of improving these practices as well as regulation could also support the business case for these changes.	■			■
	9	Implement practices to reduce flaring while upholding high safety standards. Operational changes, digital technologies for monitoring and analysis, and international partnerships can support this.	■	■		■

Objective		Recommended action	Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Develop integrated net zero regions, supply chains and energy network solutions	10	Regional roadmaps to develop electricity and CCS infrastructure. Share risks and benefits of CCS with industrial and government stakeholders through shared transportation for CO_2 and central hubs for geological sequestration, creating economies of scale. Mechanisms for co-investment in the shared system and infrastructure will be needed to coordinate investment across regional developments.				
	11	Create roadmaps and partnerships to provide the energy needed for liquefaction. Plan and build out renewable energy generation and provide certainty that there will be minimal disruption from electrification. If plants plan to retrofit gas turbines for hydrogen, create the necessary infrastructure.				

8. Enabling the transition to net zero emissions in Australian industry

The modelling and analysis undertaken through the Australian Industry ETI has identified a possible pathway aligned to 1.5°C for Australia, including for heavy industry.

While this pathway shows what is needed, it is also extremely challenging and the key measures required to achieve this pathway are not yet in place. A 1.5°C pathway would require strong, effective and coordinated action across the economy to: overcome the challenges to establish the large-scale, cost-competitive, decarbonised energy system of the future; deploy solutions for the transition of existing operations; and integrate systems and infrastructure to effectively decarbonise industry.

The 'Incremental scenario' shows that on current trends alone, Australia will fail to keep emissions in line with a 2°C carbon budget and may face declining global competitiveness through increased costs of emissions, relatively higher energy costs and failing to keep pace with global action to decarbonise.

The 'Coordinated action scenario' reveals a future in which the industrial sector and the rest of the economy work together to achieve a major transformation, and in which Australia does its fair share to achieve a 1.5°C-aligned future.[80] If strong, effective and coordinated action is taken, the 'Coordinated action scenario' shows opportunities for Australia and Australian industry. A large scale, decarbonised energy system can potentially deliver, in the long-term, firmed, low-cost energy for growing industrial supply chains relative to an 'Incremental scenario' which presents higher energy costs, contracting industrial production and declining competitiveness in a decarbonising global economy.

Australia could become a leader in the transition to lower-emissions supply chains, leveraging abundant renewable energy and mineral resources, home-grown intellectual property and experience to drive a competitive advantage for low-emissions production. Economies of scale and efficient supporting service industries could enable Australia to form a sustained, long-term competitive advantage. Australia could also position itself strategically to develop new markets and meet the needs of the future in terms of ores, refined metals, chemicals, manufactured products and energy.

There are other benefits to strong, effective and coordinated action. Analysis undertaken by Accenture, which will be published in a forthcoming report and based on the data presented in this report, also shows under the 'Coordinated action scenario', from 2025 to 2050, up to 1.35 million jobs can be supported across the Australian energy system (excluding NT) (Accenture, 2023). The 1.2 million jobs created from CAPEX investment are construction jobs that typically have a one to two year time span. On an annual basis, there is a need for at least 64,000 workers to fill the annual construction job demand. This is approximately three times the number of jobs of the 'Incremental scenario' (additional 18,000 workers per annum). The 129,000 workers required for the ongoing operations and maintenance of solar and wind farms, hydrogen plants and storage facilities, equates to 30,000 jobs above the 'Incremental scenario'.

On the other hand, there are risks of being left behind. Many key export markets, including Japan, China and South Korea, have each set net zero emissions targets, and momentum towards net zero emissions is building internationally (see Information Box 8.01). As other countries act, mechanisms such as the EU's CBAM impose a carbon penalty on imports (Chahim n.d.).

Strong, effective and coordinated action now is critical to achieve a 1.5°C aligned pathway, to develop the capabilities needed for the transitions, and to avoid the risk of stranded assets.

Alongside the environmental benefits of early action, there may also be first mover advantages in building the skills, capabilities and market, positioning Australia for competitive advantages in emerging net zero production. Because of these potential advantages, the Business Council of Australia advocates for Australia to be an early mover in achieving a net zero economy (Business Council of Australia 2021). Focussing on how Australia might achieve these advantages, while addressing how costs and risks can be appropriately distributed, requires a national competitiveness strategy for a global, decarbonising economy. To compete in a net zero world, Australia will need to understand major barriers to action as well as its relative strengths, weaknesses and abilities.

INFORMATION BOX 8.01

Momentum is building internationally

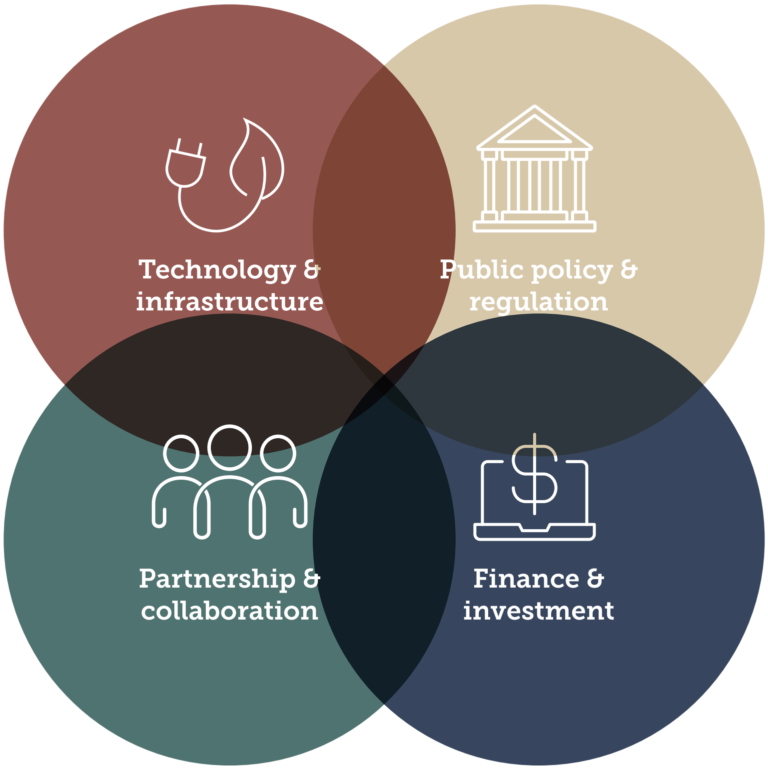
Other countries and regions are already moving to decarbonise their supply chains and build scale. Some high-profile examples include:

- Australia's top trading partners have put in place decarbonisation targets. In 2019-20, Australia's top export markets were China (35.3 per cent), Japan (11.8 per cent), Republic of Korea (5.8 per cent) and the United States (5.8 per cent) (Department of Foreign Affairs and Trade [DFAT] n.d.). Each of these now has 2030 targets and stated net zero ambitions as part of their nationally determined contributions (NDCs) (UNFCCC n.d.).
  - China: emissions peak before 2030 (lowering emissions by 60-65 per cent by unit of GDP from 2005 levels), 'carbon neutrality' by 2060
  - Japan: 46 per cent reduction by 2030 from 2013 levels, net zero by 2050
  - Republic of Korea: 40% reduction by 2030 from 2018 levels, carbon neutrality by 2050
  - USA: 50-52 per cent reduction by 2030 from 2005 levels, which sets a 'straight-line path' to net zero by 2050.
- The European Union is implementing a carbon border adjustment mechanism (CBAM) intended to equalise the cost of decarbonisation between domestic products and imports. This provides a compelling reason for Australia to introduce net zero emissions aligned frameworks to ensure goods including iron and steel, aluminium, fertilisers, ammonia and hydrogen can remain competitive (Chahim n.d.).
- The Hydrogen Breakthrough Ironmaking Technology project (HYBRIT) in Sweden is aiming to demonstrate commercial scale by 2026 and transition entire operations to fossil free production by 2030.
- Renewable energy is being scaled dramatically in China, with 156GW of wind turbines and solar on track to be installed this year (Bloomberg News 2022), roughly three times the capacity of Australia's east coast National Electricity Market (NEM) (Australian Energy Regulator 2015). China's state planning agency has said it will aim for grids to source around 33 per cent of power from renewable sources by 2025 (Reuters 2022).
- The USA's 2022 Inflation Reduction Act represents a US$369 billion investment in clean energy across multiple sectors, with the government estimating that its provisions will lead to emissions reduction of around 1,150 $MtCO_2e$ in 2030. Programs to support industrial emissions reduction include financial assistance for use of advanced industrial technologies, government procurement of low-carbon construction materials and tax credits for hydrogen and CCS (US Department of Energy Office of Policy 2022). Following that, US$7 billion of funding was announced for six to ten 'regional clean hydrogen hubs' (Energy Department 2022).

8.1 Enablers of a coordinated transition

Through modelling, analysis and industry consultation, the Australian Industry ETI has identified enablers across the areas of technology and infrastructure; public policy and regulation; partnerships and collaboration; and finance and investment (Figure 8.01). Each of these enablers will need to focus on achieving coordinated action in line with 1.5ºC if there is to be an effective transition towards net zero emissions for Australia and its industry sector.

FIGURE 8.01: Types of enablers of industrial decarbonisation



Momentum in Australia is starting to build along each of these enabling themes. Technology and infrastructure requirements are being investigated through a concerted effort to introduce novel and transformative technologies to industrial operations, as well as planning to develop the integrated systems that will be required in the short and medium term. The Australian financial sector is committing to net zero across lending and investment, and is beginning to provide financing linked to ESG targets, following a growing international trend. A suite of energy and climate change policies now exist at all levels of government, with more planned at the national level. Australian companies are also developing partnerships and collaborations to accelerate the transition to net zero emissions through partnerships, including as part of the Australian Industry ETI.

Technology and infrastructure

Australia has one of the world's most abundant clean energy resource bases along with established expertise in energy infrastructure, exporting critical energy and material resources.

With the right technologies and infrastructure, Australia would be well positioned to meet the challenges of decarbonisation pathways and could continue to be a globally competitive export economy, based on energy and commodities by:

- Capitalising on increasing global demand for emerging low-carbon technologies and energy exports, such as green hydrogen and iron and steel
- Rapidly deploying technology solutions
- Supporting the development and demonstration of emerging technologies
- Initiating and continuing to co-develop regional roadmaps, including for infrastructure needs
- Bringing together commercial interests, community need, and federal, state and territory government priorities to tackle climate change.

The Australian Industry ETI's analysis has identified opportunities to address industrial emissions through both technology and infrastructure. Program modelling shows that technology shifts required to achieve emissions reductions range from replacing equipment or building new equipment to developing technologies that capture and sequester carbon emissions. Additionally, process and technical changes can enhance efficiency and increase fuel switching to electricity. To achieve the results of the scenario, a number of incumbent technologies would need to be retired early, but some new technologies could potentially result in lower operating costs in the long-term, however there is significant uncertainty around what the future technology mix will be. Overall, new abatement technologies can help reduce emissions through energy and material efficiency; zero emissions energy and feedstock supply; electrification and other fuel switching; non-energy emissions abatement; and capture or offset of residual emissions. Many of these solutions are mature and already available for commercial deployment. These include many energy efficiency measures, renewable electricity, electrification through heat pumps and electric boilers and a range of other technologies described in each of the supply chain chapters. Other technologies require further development or are not yet considered to be commercially viable.

Additionally, major projects will be needed to transition existing and develop new infrastructure. While some of these actions will be led by a single industry actor (such as an off-grid energy system to support remote mining), others will need to be developed in collaboration with multiple users.

As discussed in chapter two, 'Pathway for heavy industry decarbonisation', under the 'Coordinated action scenario' Australia requires over 350TWh/year of electricity by 2030. By 2050, that number increases to just under 600TWh/year, more than double the current supply. The five supply chains in focus in this report alone would require around 105TWh, an increase of about 60TWh. Most electricity currently comes from fossil fuel generation which would need to be replaced. By 2050, this would require renewable electricity generation capacity of around 260GW (including rooftop solar) and storage of 70GW. To provide a sense of the scale of this storage, the Hornsdale big battery in South Australia is 0.15GW (CEFC 2021), the Victorian big battery near Geelong is 0.3GW (CEFC n.d.) and the big battery to be installed following the closure of Eraring, Australia's largest coal-powered power station in the Hunter Valley, is planned to be 0.7GW[81] (Origin Energy 2022; Carroll 2022). By 2050, Australia could require an immense build-out of infrastructure to transport energy. Transmission lines and pipelines could deliver energy from locations where renewable electricity is cheap and abundant to industrial regions and hydrogen electrolysers. Governments and industry will need to make complex choices on the appropriate energy transmission infrastructure, including the role of electricity and hydrogen and the extent to which supply and demand can be co-located.

In addition to energy infrastructure, other kinds of infrastructure and their impacts should be expected and planned. New products, such as green hydrogen and green iron, may not be well-suited to existing ports and shipping due to infrastructure type, capacity or location. Roads, bridges and rail networks need to be able to support future import and export loads. Means of transporting goods must be made fit-for-purpose to export low-emissions products or to use them domestically. Port facilities will be needed for refuelling green shipping, and infrastructure for transporting and storing of hydrogen or derivatives. Hydrogen storage is also critical to ensuring reliable supply for use in industrial processes. And CCS requires significant investment in infrastructure such as carbon transport, which is highly dependent on the distances between points of capture relative to sequestration. Much of this infrastructure may be shared by multiple users to reduce costs and co-located in hubs and precincts if space and multiple users are available. Less tangible infrastructure, such as programs to develop the necessary skills to facilitate this transformation are also needed (Accenture, 2023).

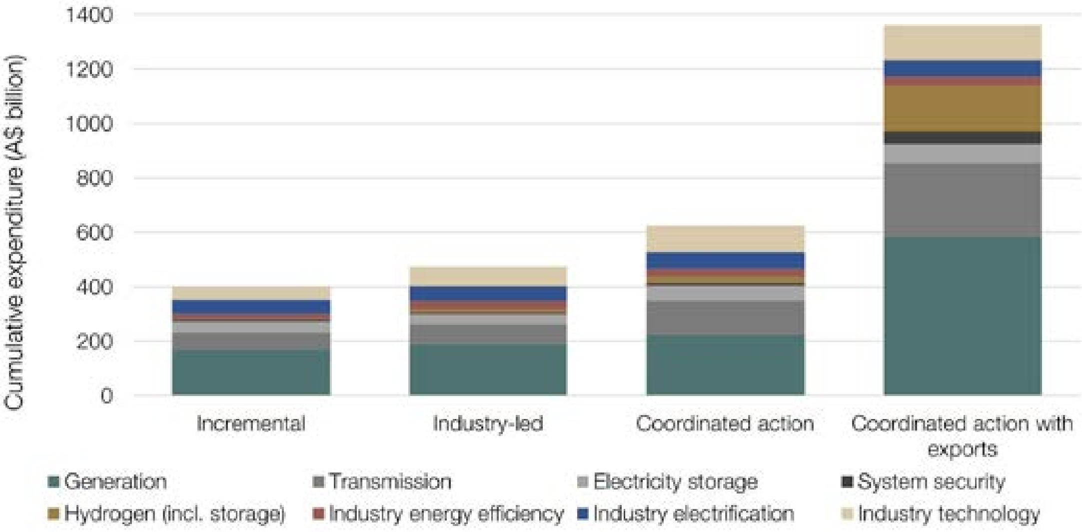
Finance and investment

Given the need for significant capital expenditure to meet a 1.5°C-aligned pathway, the financial sector and other financing bodies will continue to be an essential enabler of industry transition. Investment is needed to develop and deploy the transformative technologies and infrastructure that provide the greatest short and long-term abatement potential. It is also critical to invest in an energy system that supports integration of industry with firmed renewable energy.

There is significant uncertainty on the investment required for the technologies needed to decarbonise industry into the future. The Australian Industry ETI's scenarios present the outlook for technologies modelled, showing the scale of investment that would enable a potential 'Coordinated action scenario', as well as investment that would unlock export opportunities. The comparison between the scenarios in Figure 8.02 is highly useful for this, because modelling and analysis finds that hundreds of billions of dollars would be invested even under the 'Incremental scenario' with no carbon budget or net zero commitments.

81 The battery's capacity will be 2.8GWh for four hours of storage.

FIGURE 8.02: Cumulative investment between 2020 and 2050 in each scenario



The 'Coordinated action with exports sensitivity' shows additional investment needed in the energy system to stimulate and scale new green iron and green hydrogen industries. There is relatively little change to investment in industrial technologies when exports are added, but energy system investments are much higher, reflecting the substantial energy infrastructure required to support new export industries. In addition to this, it would be necessary to invest in enabling infrastructure for these exports, including what is required for increased liquid organic hydrogen carrier production or hydrogen liquefaction.

Through its banks, superannuation funds, the CEFC, ARENA, private equity and other financial institutions, Australia has a large, sophisticated financial system capable of allocating the substantial capital needed, provided mechanisms are in place to ensure allocation is aligned to a net zero emissions goal.

According to one study, investment of around $20 trillion will be invested in Australia's economy out to 2050, regardless of whether it transitions to net zero. However, the allocation of this investment must be structurally different across energy, transport, manufacturing and land use systems if the Australian economy is to transition effectively to net zero in a low-emissions world (National Australia Bank 2022). Given that significant investment is needed, it will be essential to ensure it effectively drives the long-term transition Australia needs, rather than lock it into further emissions and potential stranded assets.

A range of actions across the finance and investment sector are already driving changes in the production, purchase and flow of goods and services to better align with net zero emissions by 2050 or a 1.5°C trajectory. Examples of projects enabling deeper disclosure and engagement include:

- Reporting in line with the Taskforce for Climate-related Financial Disclosure (TCFD) is ensuring that companies undertake and disclose risk assessment and establish governance processes to consider the physical and transition risks associated with climate change (Nisanci 2021).
- Through the Glasgow Financial Alliance for Net Zero (GFANZ), more than 500 major financial institutions have individually committed to transition the emissions of their financed portfolios to net zero by 2050, to develop net zero transition strategies, to set interim targets and to report progress annually (GFANZ 2021).
- Superannuation funds are continuing to develop their stewardship and engagement activities with industrial companies on net zero by 2050 alignment. An important aspect of this is gaining a detailed understanding of investee companies' trajectories and pathways in hard to abate sectors. Investors are continuing to evolve their engagement frameworks to include the assessment of companies' climate transition action plans.
- As the world's largest investor engagement initiative on climate change, Climate Action 100+ is helping investors collaborate and coordinate engagements with 166 of the world's largest listed corporate emitters to accelerate action on climate change. The initiative brings together more than 700 investors responsible for US$68 trillion in assets under management (Climate Action 100+ n.d.).
- Lenders and investors are also increasingly developing financing vehicles such as green and transition bonds which are expected to surpass $US1.5 trillion in 2022 (S&P n.d.).

Partnerships and collaboration

Working together, companies can solve problems that would be much more difficult to solve alone.

It enables greater effectiveness in dealing with common challenges and rapidly speeding up the development, deployment and scaling of solutions. Partnerships[82] can be established to achieve specific goals, to focus on a specific supply chain or have a place-based focus such as in the development of, or transition to, net zero industrial regions. They may be composed of companies as well as enablers of business model changes, including finance, energy providers and researchers. New collaboration models to support organisations working together in a meaningful way will help industry navigate the complexities of the transition more effectively. Partnerships that could enable industry transition may range from Joint Venture Partnerships through to informal, occasional collaborations. In addition to new partnerships, many groups and bodies already exist in Australia and are described in this chapter.

Through the transition, partnerships and collaboration may be leveraged to support multiple companies to decarbonise at the same time. Industry can lead the way in creating partnerships that support their strategic objectives, but should be supported by governments. Governments, equity owners or other third-parties can act as facilitators. Coming together to create a regional roadmap can guide the development of shared infrastructure and increase the potential for innovation, coordination and breaking down siloes. It can offer all stakeholders an integrated view of existing and potential assets such as ports, water availability, gas supply and CO_2 storage potential. Roadmaps can also include a plan for financing and can help maintain social licence in the region by showing communities the types of changes that are expected. They may also guide investment planning for energy providers. Regional collaboration could take many forms – from formal agreements to informal yet proactive co-design and consultation.

First Nations custodians are often critical stakeholders, especially in the deployment of renewable energy generation. Traditional Owners may have property rights and interests in the land. Project success will rely on establishing and following best practices for partnerships and involving First Nations peoples early to sets the stage for long-term, beneficial relationships (O'Neill et al. 2021). Other examples of important stakeholders within a region include trade unions, regional workers groups and TAFEs. It is important to establish these relationships early and in a way that shares the benefits of the transition with communities, including involvement in design and the securing of local jobs. Without beneficial outcomes, major transformations can lose social licence. Regional partnerships should also take into account specific challenges and strengths such as skilled workforces and the history of the region.

82 In this report, unless noted otherwise, the term 'partnerships' is used in a broad sense, taking in strictly legal 'partnerships' but also the full gambit of mechanisms for collaborating, including incorporated and unincorporated joint ventures, strategic alliances, joint applicants in a program etc.

Other reasons to collaborate are not necessarily place-based. Sectoral actors can come together to understand and even create demand for green products and establish offtakers. Firstly, the aggregation of perspectives and data sharing can help build confidence in future demand at a national and global scale. Secondly, companies across industries may work together to pool early demand and supply so that scale can be reached for an appropriate buyer. For example, multiple chemicals companies may work together to produce green ammonia at scale for a large buyer during the time that production is constrained by a lack of green hydrogen. Governments can act as an offtaker, procuring green products for government-owned projects through mandates and commitments. Another reason to collaborate is to support the development of new technology. Collaboration may enable faster development of new technology, followed by early deployment and rapid scaling. It is important to note there may be sensitivities when competitors work together, but there are multiple examples of partnerships that have managed this potential issue, although generally in smaller partnerships such as joint ventures. Further efforts to demonstrate and share appropriate models for multi-stakeholder collaboration as well as navigate anti-competitiveness regulation can help build comfort in deeper collaborative partnerships. An important example of a potential collaboration within a supply chain would be the development of solutions to the common challenge faced by iron ore miners and steelmakers in the potential incompatibility of certain ore types with hydrogen DRI technology.

Industry partnerships that allow room to introduce new stakeholders who may not have been initially considered, may help broaden participation and build community buy-in. Especially at a regional level, zero carbon growth may require the establishment of new organisations and should build on what is already happening, including existing consortia and government bodies. In some regions, governments may be leading the way in this transition, while in other regions, industry has thus far forged its own path.

Some of the reasons partnerships and collaboration may be useful in Australia include:

- The creation of hubs to simultaneously scale supply and demand
- Sharing of energy data to coordinate the energy transition
- Energy system planning and development of infrastructure and storage, including collaboration between the financial sector and energy users
- Skilled workforce planning, which considers whole-of-community impact
- Engagement with the community, for example around energy, to design and involve all stakeholders in achieving outcomes that are beneficial to people living and working in the region
- Building the entire green hydrogen value chain, as well as pairing hydrogen producers with high volume hydrogen users
- Studies on CCS's technical and economic potential in energy intensive regions and the potential development of the CO_2 value chain for carbon capture and utilisation in a region.

Public policy and regulation

Governments have a key role to play in supporting the transition to a low-carbon economy. This includes putting in place the policy, regulation and surrounding frameworks for the transition, which are essential to achieving the pathway. Governments can drive emissions reductions through a range of policy mechanisms and spending programs.

Government policy levers to facilitate a transition can be classified as 'push' or 'pull' mechanisms. Push mechanisms 'push' or kickstart a market using short-term impetus like grants, subsidies and other financial incentives. Pull mechanisms 'pull' the market and its participants in a particular direction through longer-term structural interventions like targets, changes to regulation and market structures. These longer-term measures influence the nature of future demand and signal which products and services are likely to have access to the market. Both 'push' and 'pull' mechanisms can operate on either the supply or demand side of markets. By combining these policy measures, it is possible to encourage short-term actions that underpin larger, structural changes and create a more economically effective transition.

Government policy levers can support the deployment of essential infrastructure (e.g. electricity transmission, rail transport and electric vehicle charging infrastructure) and reduce non-price barriers (e.g. by providing consumer information and requiring companies to disclose climate strategies and actions).

There are a large number of relevant policies in place or in development at federal, state and territory levels related to environment, energy, industry, regional development, education and training, treasury and international affairs that will have a significant impact on the effectiveness of the transition to net zero. Local government decisions and functions are also relevant, particularly in relation to land use applications and planning. Their role is significant in facilitating place-based decarbonisation. Some key policies in place or in development at the time of writing are highlighted in Information Boxes 8.02, 8.03 and 8.04.

The effectiveness of policies and approaches at different levels of government can be increased by ensuring they are complementary and coordinated, and by consulting stakeholders, including industry, during policy development.

INFORMATION BOX 8.02

Key current national policy relevant for industry decarbonisation

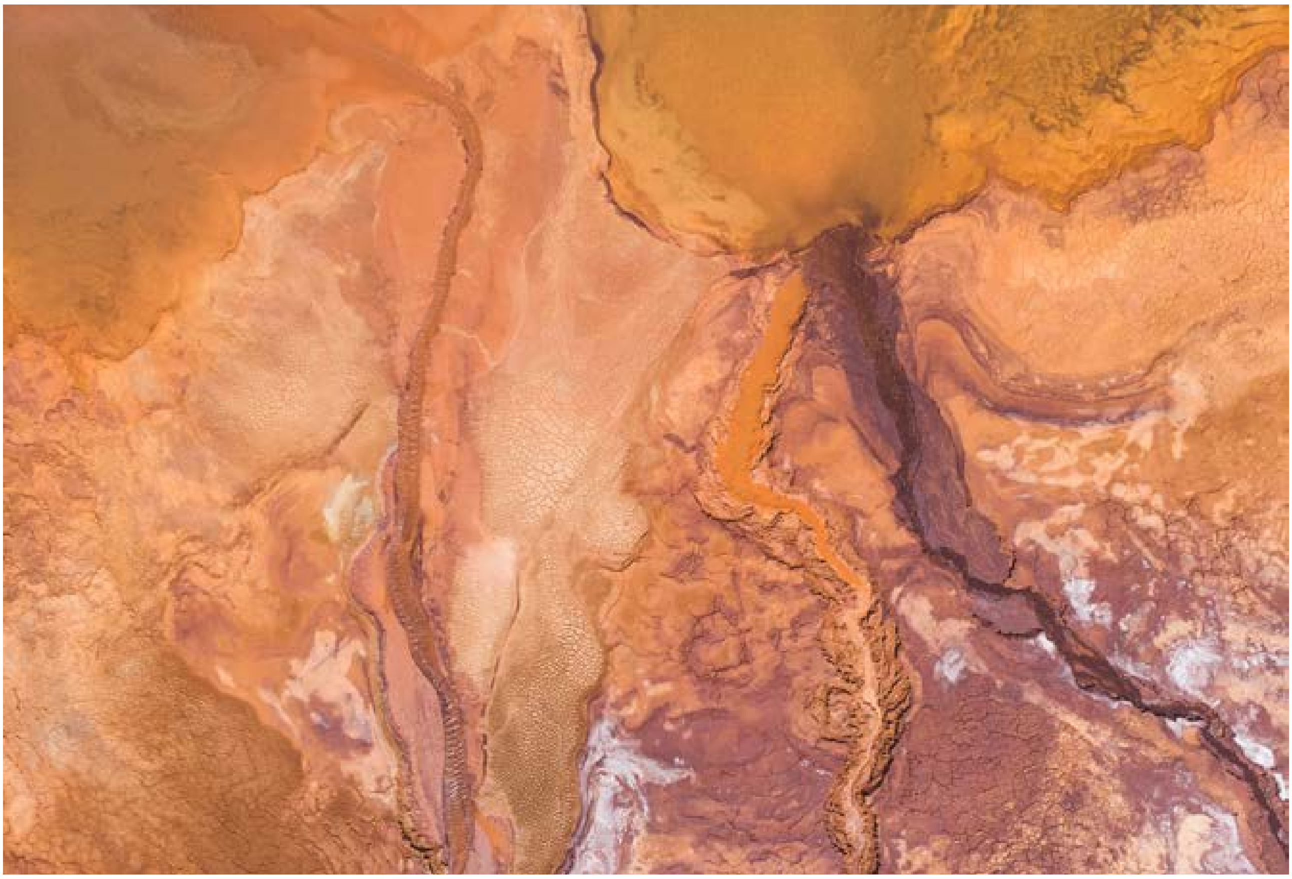
- Climate Change Act 2022 legislates national greenhouse emissions reductions targets, requires an annual climate report including effectiveness of government policies and revisiting of targets (both informed by advice from the Climate Change Authority). It also includes greenhouse gas emissions reduction objectives and/or criteria across 14 pieces of energy, climate, infrastructure and financing legislation (Australian House of Representatives 2022)).
- The CEFC is Australia's 'green bank' and invests to catalyse and leverage private sector finance for the commercialisation and deployment of renewable energy, energy efficiency and low-emissions technologies (ARENA n.d.).
- Australian Renewable Energy Agency (ARENA) provides funding aimed at increasing the supply and competitiveness of pre-commercial renewable energy innovation (ARENA n.d.) Following amendments made in the Climate Change (Consequential Amendments) Act 2022 it may expand its operations to energy efficiency and electrification[83].
- Jobs and Skills Australia (Department of Employment and Workplace Relations 2022)
- Safeguard Mechanism reform (DISER 2022a)
- Rewiring the Nation (DCCEEW n.d.)
- Powering the Regions fund (DISER 2022d)
- National Reconstruction Fund (DISER 2022d)
- Skills and jobs policies (e.g. New Energy Skills Program (ALP 2021))
- Hydrogen Guarantee of Origin (Clean Energy Regulator n.d.)
- National Energy Transformation Partnership (DCCEEW n.d.)
- National Hydrogen Strategy (DISER 2019)

INFORMATION BOX 8.03

Examples of state and territory policies relevant to industry decarbonisation

- Funds for industry decarbonisation, such as NSW's Net Zero Industry and Innovation (New South Wales Government n.d.)
- The Queensland energy and jobs plan (Queensland Government 2022)
- State level hydrogen strategies funds and industry development, such as the Renewable Hydrogen Strategy (The Government of Western Australia 2021a) and the Queensland Renewable Energy and Hydrogen Jobs Fund (Queensland Treasury 2020)
- Concierge and matchmaking services, such as the new hydrogen collaboration platform announced by the New South Wales state government in August 2021 (Mazengarb 2021)
- The Zero Carbon Certification Scheme (Smart Energy Council 2021)
- Strategic land planning
- Western Australia's Carbon Innovation Grants Program (The Government of Western Australia n.d.)
- Support for transition of the electricity system, such as the Victorian Renewable Energy auctions (Victorian Government 2021) and the NSW Electricity Infrastructure Roadmap (New South Wales Government n.d.).

83 See particularly the Note to s8(f) Australian Renewable Energy Act 2011



PATHWAYS TO INDUSTRIAL DECARBONISATION

INFORMATION BOX 8.04

Examples of international bilateral agreements and partnerships

- Mission Innovation is a group of countries (including Australia) committed to doubling governmental investment in clean energy innovation over five years (Mission Innovation n.d.)
- Australia has multiple bilateral agreements to support the development of low-emissions technologies. For example, Australia's agreement with Singapore identifies priority areas of cooperation as long-term emissions reduction strategies, hydrogen, CCS, renewable energy trade, and measurement, verification and reporting (DFAT n.d.)

International community commitments are shifting and setting policy for the transition to net zero that will affect Australia's competitiveness. Commitments by Australia's trading partners to mechanisms like carbon border adjustments (European Commission 2021) are being considered and implemented with the objective to equalise the cost of decarbonisation between domestic products and imports to avoid carbon leakage.

8.2 Recommended actions to unlock 1.5°C-aligned pathways

With targets now set at state and national levels and a willingness to drive towards net zero in place from government, industry and investors alike, there is now an opportunity to take strong, effective and focused action towards net zero emissions.

The Australian Industry ETI has identified the following objectives, outlined in Figure 8.03 to help create a globally competitive, net zero industrial economy in Australia.

FIGURE 8.03: Objectives to unlock 1.5°C-aligned pathways

Set a **strong, clear, enduring framework with a net zero goal** to align industry, finance and government efforts on the transition of Australia's industry
Transition to the **large-scale, cost-competitive, renewable energy system** of the future

Accelerate **development and demonstration** of the emerging technologies needed for Australia to be a net zero emissions superpower	Drive **deployment of low carbon solutions across the economy**, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	Develop **integrated regions, supply chains and energy network** solutions

These objectives present priorities rather than sequential steps and in many cases will need to be developed concurrently to achieve the required rate of transition.

Objective: Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry

The transitions required for Australia and its industry sector to remain globally competitive are complex by nature, requiring significant action across technology and infrastructure, finance and investment, policy and regulations, and partnerships and collaboration. To ensure these efforts align, the transition will need goal-oriented frameworks across government, industry, investors and other supporting actors that are strong, clear, and enduring.

The federal Climate Change Act 2022 and associated amendments (Australian House of Representatives 2022; Climate Change Act 2022 2022) came into law in September 2022 and provide a strong start in establishing an overarching climate framework in Australia. The Act can play a valuable role in setting a long-term direction for Australia's climate policy, increasing certainty for business and communities. The associated amendments embed emissions reduction objectives and criteria into some government functions and help align the government's decision-making, spending and planning with its climate goals. The Act legislates a target to reduce Australia's net greenhouse gas emissions to 43 per cent below 2005 levels by 2030.

Importantly, the targets in the Act are not yet aligned with a trajectory limiting a temperature increase to 1.5°C. According to Climate Action Tracker, the 43 per cent emissions reduction target is in line with keeping warming below 2°C, but Australia's policy and action is aligned with less than 3°C (Climate Action Tracker 2022b). The processes established in the Act can, however, be utilised to allow the Australian government to continue to lift ambition, with further opportunities to build on this legislation and align action to help limit global warming to 1.5°C.

Recommended action 1: Ensure that federal, state and territory policy and programs are complementary, and designed to transition Australia's industry and broader economy to net zero emissions

All Australian states and territories, as well as the federal government, have net zero emissions targets, and some have interim targets. It is important to ensure that federal, state and territory policy and programs are aligned and can enable a more effective industrial and energy system transition to achieve these net zero targets. Coordinating policy and programs at all levels of government can support and enable industry's efforts to navigate the policy and regulatory regime across jurisdictions.

Industrial transition will be challenging and take time. Significant investment over a number of decades will be required to deploy zero carbon technologies and build infrastructure to decarbonise industry and the economy more broadly. It is anticipated that many technologies will not be commercially viable for the next five to ten years, if not longer. This will require federal, state and regional action to overcome barriers and achieve emissions reduction in line with a 1.5°C pathway.

The next decade should be used to scale the infrastructure needed to meet long-term objectives, develop technologies needed for the transitions as well as to deploy mature technologies, as waiting until this gap has closed before beginning to implement decarbonisation solutions will prevent Australia from meeting net zero ambitions and lock industry out of lucrative global markets.

Immediate action by governments can help to ensure financing is aligned and proactive in addressing these gaps in development, deployment, scale and integration (see later in this chapter). It can also help to streamline reporting and applications, such as permits and licensing, as well as applications for funding by a business or partnership. Coordinating policy and programs across state, territory and federal governments with the aim of strategically targeting barriers and driving investment will help enable an effective pathway towards net zero goals.

Recommended action 2: Develop a national strategy to become a leading supplier in new export markets such as green ammonia and green iron in the decarbonising global economy

The global transition to a decarbonised economy will have winners and losers. While Australia is well placed relative to other countries for large scale deployment of renewable energy as it has huge endowments of renewable energy resources, this advantage alone will be insufficient in driving the development of new export-oriented industries. With new export markets and carbon tariffs like the EU's CBAM on the horizon, future competitiveness is likely to depend in part on Australia keeping pace with global ambition and with key trading partners.

The investment required to build an energy system that can support new export industries based on renewable energy is much higher than to build without accounting for export opportunities. Cumulatively, between 2020 and 2050, energy system investment in the 'Coordinated action scenario' is around A$440 billion, nearly A$150 billion greater than the 'Incremental scenario' (see Figure 8.02). But the energy system investment needed for the modelled new exports industries could be more than $700 billion greater than the 'Coordinated action scenario'. The policy needed to support this additional investment would encourage much more renewable energy and would also need to consider potentially higher costs of energy for domestic consumption. A strategy for Australian exports is essential to determine the appropriate scale of Australia's renewable energy exports and what the trade-offs might be.

National strategies for the development of new export products can inform planning for skilled labour, knowledge, infrastructure, markets, suppliers and related industries needed to compete in new global markets. National export strategies for green products could be akin to the 'National Hydrogen Strategy', which was developed at the federal level with state and territory governments through the former Council of Australian Governments (COAG) structure, and with a diverse range of workstreams such as regulation and legal hurdles, jobs and training requirements and technical requirements. These workstreams would be steered by and coordinated across different federal, state and territory governments. Such a strategy could help Australia pursue broader opportunities and drive competitiveness in a decarbonising global economy.

Existing and new bilateral agreements around low-emissions technologies and trade partnerships can also be useful mechanisms for the federal government to support the development of export markets (see Information Box 8.04).

Export Finance Australia is an example of a government initiative that could provide financial support for Australian green products. It currently uses its financial expertise and solutions to support a few key areas, including critical minerals (Export Finance Australia n.d.).

Recommended action 3: Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required within key regions

A workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions, should be a priority for government, industry, local communities and other stakeholders. A skilled workforce is critical to an effective transition (Accenture, 2023). This includes many specialised and potentially novel skills such as specialist certifications to safely manage new industrial processes, like those requiring hydrogen and ammonia. Workforces at existing operations impacted by energy or technology transitions will require clear pathways and opportunities to re-skill. Industry will need expertise and experience in the design and operation of new technologies and processes. Re-skilling can take time, and in some instances, the capabilities required for the transition do not yet exist in Australia or even globally. Analysing current jobs and future job and skills requirements is a key step in planning industry transitions.

There are a range of relevant initiatives at the state and territory level, with a fair degree of variability across governments. These cover some ‘just transition’ and place-based decarbonisation planning that includes (or will include) workforce transition planning and implementation, jobs and skills mapping as well as more overarching work to identify future jobs and skills needs. For example, the WA government, created a ‘Just Transition’ plan for the town of Collie (The Government of Western Australia 2020), and the NSW government is working on decarbonisation roadmaps for the Hunter and Illawarra regions (New South Wales Government n.d.). The Victorian government has been working on a broader ‘Clean Economy Workforce Development Strategy’ to identify future skills and training needs in the clean economy (Department of Education and Training 2022). These examples demonstrate the importance of collaboration across multiple stakeholders to deliver a successful transition.

The federal government has a number of relevant planned programs in this area, such as the ‘National Reconstruction Fund’, which aims to create 34,000 direct new jobs in zero and low-emissions manufacturing, and ‘Rewiring the Nation’. There are also programs specifically for workforce development such as the ‘New Energy Skills Program’, which is planned to collaborate with TAFE partners to support new energy industries (Australian Labor Party n.d.)

Perhaps the most relevant change at the federal level is the creation of ‘Jobs and Skills Australia’ (Department of Employment and Workplace Relations 2022), a statutory body providing independent advice to government on Australia’s current, emerging skills and workforce needs. It will function across federal, state and territory governments, as well as with unions, industry and education providers. The group will operate as an interim body before undertaking a comprehensive consultation process to set up a permanent entity.

Investment in skills and workforce development will be essential to ensuring there are sufficient workers with skills required for a net zero future. The Australian government, potentially through ‘Jobs and Skills Australia’, could play a valuable role in bringing together governments and other stakeholders for knowledge sharing and to ensure that adequate planning takes place to develop this skilled workforce. Additional assistance for retraining workers in industries at risk of decline should be made available to fill this skills gap.

A skilled workforce is critical for the timely deployment of new technologies for specific industries. Some examples where skilled workers will be needed include the production and integration of hydrogen and in the build-out of renewable energy generation (Accenture, 2023). Alongside skills and workforce planning, clear signals could foster the timely development of supply chains for relevant technologies and materials. This will be important to helping ensure industry decarbonisation can happen at the scale and pace shown in the 'Coordinated action scenario'.

Recommended action 4: Further financial sector commitment and action for net zero in line with a 1.5°C transition

A significant capital reallocation is required for companies to transition to net zero in line with a 1.5°C trajectory. While overall capital investment will be needed in Australia regardless of the transition, capital will need to be spent differently. The Australian economy should be structurally different when optimised for a net zero world, in order to ensure it is best-placed to emerge as a standout economy in a low-emissions future (National Australia Bank 2022).

The financial sector must also transition alongside every sector of the economy to mobilise the capital needed to achieve net zero emissions (GFANZ 2021). More than 500 major financial institutions have already individually committed to transition the emissions of their portfolios to reach net zero by 2050. Greater ambition is needed, however. Commitment to the GFANZ principles by the financial sector and asset owners would include transition strategies, interim targets and annual reporting on progress. Continued engagement of the financial sector, including superannuation funds, with other key sectors of the economy including industry, government, climate science and the community can further align actions needed in Australian production, purchase and flow of goods and services to the trajectory needed.

Recommended action 5: Support the development and adoption of an Australian investment taxonomy to provide transparent and credible definitions of what constitutes sustainable investment

Decarbonisation should be considered as part the investment decision process, given its impact for universal owners (such as large superannuation funds and insurance companies), accelerating the development, adoption and mainstreaming of practices and tools to align investment to 1.5°C. Thus, a common classification system for sustainable economic activities (or 'taxonomy') will be an important tool to guide investment, providing transparent and credible definitions of what constitutes sustainable investment. Government could provide support for finalisation and adoption of a taxonomy specifically adapted for the Australian market and focused on national priorities and opportunities. This would ideally be developed in harmony with ASEAN's (Association of Southeast Asian Nations) emerging taxonomy (ASEAN Taxonomy Board 2021).

The Australian Sustainable Finance Institute's (ASFI) 'Taxonomy Project' is a financial industry-led initiative that will work with experts and stakeholders in the financial system to understand what a sustainable finance taxonomy should look like in Australia (ASFI n.d.). The financial sector benefits from a taxonomy because it provides a standard to be able to make more informed decisions and to better understand the activity of their industrial clients during the transition. Collaborations in the financial sector with the support of government may help to accelerate development and adoption.

Objective: Transition to the large-scale, cost-competitive, renewable energy system of the future

Investment in the transition to net zero in heavy industry, at the scale identified in this pathway, will only be possible if there is confidence that a large-scale, reliable, low-cost energy system is available to power the needs of industry in the future and drive comparative advantages in low-cost sustainable production. Around 350TWh of renewable energy will be needed by 2030 and around 600TWh by 2050 to achieve the 'Coordinated action scenario', with nearly 400TWh of renewable energy needed by 2030 and around 1,450TWh by 2050 to enable new export industries. The need for firmed renewable energy, particularly in industrial applications, will require around 70GW of storage in the 'Coordinated action scenario' and around 84GW to enable new export industries as examined by the 'Coordinated action with exports sensitivity'.

An increasing penetration of renewables in the electricity grid increases the hours per year where coal-powered plants are incurring costs to pay the market to continue generating. This can result in faster than expected retirement of coal generators resulting in poor reliability conditions when coal powered plants have retired without sufficient planning for replacement capacity. Planning and investment in firming solutions before existing baseload generators retire will be important to ensure continued reliability and to reduce high price events.

Recommended action 6: Ensure that energy planning, including through the National Energy Transformation Partnership, includes deployment of renewable energy and energy management to unlock investment at the scale required for heavy industry decarbonisation and new export industry development

Domestic decarbonisation could require renewable electricity in the order of a capacity of around 130GW by 2030, and an almost nine-fold increase in renewable energy capacity to around 260GW by 2050 (including rooftop solar). Powering a new export industry could require more than double that capacity by 2050, increasing renewable energy generation by around nineteen times from 2020 levels.

Development of renewable energy zones (and the equivalent in WA) at the scale needed for industrial decarbonisation are advanced in various locations. Ensuring these are well planned and that delivery is developing at pace will help build confidence that the new energy system will be available when required for industrial operations.

Targets will be most effective when set by the federal government to send a clear, nationwide investment signal on the scale of development in Australia. Company level targets and commitments can also play a role, providing confidence in a pipeline of future offtake to encourage developers to build capacity for large-scale development.

The scale of renewable energy developments needed will require huge amounts of land. A scenario modelled by Net Zero Australia involves a build-out of renewables to meet demand for electricity generation three times as large as the 2022 NEM in 2030, which is a little higher than the 2050 requirement for the 'Coordinated action scenario'. According to the study's preliminary findings, this would involve 135 solar PV projects, 79 onshore wind projects and one offshore wind project (noting these findings allow for factors including Native Title, environmental reserves, population centres, irrigated farmland and capacity (Net Zero Australia 2022)). To ensure social licence is maintained given the likely scale of requirements, project proponents and governments will need to demonstrate high integrity planning and development approval processes, including measures to minimise environmental impacts of these projects, appropriate compensation to land owners, and quality engagement with Traditional Owners and local communities for support in the development and clearing of land.

The recent federal, state and territory 'National Energy Transformation Partnership' includes a number of priority actions of direct relevance to the system planning needs identified here. The initial priorities of the Partnership are well aligned, and there are excellent opportunities to ensure that implementation will assist adequate forward planning, and that it will encompass energy requirements for decarbonised industry, and requirements for the potential of export industries.

Recommended action 7: Set targets that drive the development of a large-scale, decarbonised hydrogen market and coordinate updated regulation for rapid and safe development of hydrogen production, transport and storage

Substantial growth in hydrogen is needed to enable many industrial decarbonisation opportunities across supply chains. Under the 'Coordinated action scenario', 364,000 tonnes (44PJ) of hydrogen is required by 2030 and 2,230,000 tonnes (268PJ) is required by 2050. In this scenario, the industrial sector consumes 52 per cent of all hydrogen in 2030 and 37 per cent in 2050. Even in the 'Incremental scenario', around 640,000 tonnes (77PJ) of hydrogen is required by 2050. In the exports sensitivity (see chapter two, 'Pathway for heavy industry decarbonisation'), by 2050 roughly 2900PJ of hydrogen is produced, mostly for export as an energy carrier or in a new green iron industry.

To achieve the huge volumes of hydrogen needed, it will be necessary to develop a large-scale, hydrogen market that is well-integrated into the energy system to enable load balancing and effective energy transmission.

Setting targets for large-scale hydrogen production with the goal of developing a large-scale, integrated domestic hydrogen market is one way to achieve the coordinated action pathway. There are multiple options for achieving this, for instance, through an overarching RET-type hydrogen target with tradable certificates, or regional-based targets for hydrogen that could be built into regional decarbonisation planning. This can be complemented by other levers for market development, discussed above, including green hydrogen certificates of origin, contracts for difference, offtake agreements, and government procurement to build demand.

Coordination of regulatory measures is also needed to enable production for new hydrogen applications (e.g. hydrogen storage and transport, 100 per cent hydrogen pilots, hydrogen transmission via pipeline from offshore wind farms). In some cases, the timely development of regulation (e.g. around safety and licensing) can enable rapid uptake in new and emerging technologies. It will be critical for governments to ensure a coordinated approach to regulation that enables transition with industry input.

Under the 2019 'National Hydrogen Strategy', the review of federal, state and territory laws to identify regulatory hurdles and what is needed to enable hydrogen industry development (DCCEEW n.d.) forms a large body of work. The status and the timeline for the 'National Hydrogen Strategy' could be an area considered for annual reporting as part of the Climate Change Act. As new technologies are developed and deployment considered, there will likely be a need for a similar, multi-government approach to removing regulatory hurdles, and setting appropriate standards for safety, transport, sequestration of CO_2 and so on. These could be made consistent across jurisdictions to equitably regulate CCS projects.

Recommended action 8: Strengthen energy market system planning such as the ISP and WOSP to anticipate decarbonisation of heavy industry in line with 1.5°C warming scenarios with energy and green metals export scenarios as the central case. Energy planning in SA, Queensland, NSW and WA should account for potential electricity demand several times greater than 2020 levels, and Australia-wide wind and solar generation may need to be as much as 12 times higher. Planning should be expanded to support more holistic infrastructure considerations such as pipelines to support the energy transition alongside electricity transmission

Planning should be consistent with 1.5°C warming scenarios, including planning for energy and green metals export scenarios. In order to develop low-cost, firmed, decarbonised energy systems to support industry's decarbonisation over the coming decades, a range of efforts can be deployed in industrial regions. These plans should also ensure that energy and associated infrastructure requirements are reflected in system planning and energy market structure and that plans consider the complex interplay between electrons and molecules (such as hydrogen and ammonia) in a changing energy landscape.

The AEMO ISP in the NEM and the WA government's WOSP in the Wholesale Energy Market can send powerful signals and help direct investment into electricity networks by indicating to the market where it is most likely to be needed. Increasing penetration of renewables in the electricity grid can result in faster than expected retirement of coal generators. Where coal powered plants have retired without sufficient planning for replacement capacity, this can result in poor reliability conditions, price volatility and loss of competitive advantage in the global market. A carefully planned transition to renewables is therefore required to ensure that generation capacity is available in advance of coal generator retirement. In addition to integration of renewable energy into the NEM and the SWIS, planning should consider the need for renewable energy projects to be built in new areas; the most advantageous locations for wind and solar generation at the scale needed may require build-out of renewables in more remote areas of northern Australia (Net Zero Australia 2022).

System plans should actively consider an accelerating transition towards firmed, zero-emissions electricity and hydrogen networks at the scale needed. The increase in capacity required is not uniform across Australia and will require consideration of regional factors driving demand and supply for energy. For heavy industry to take advantage of the electrification technologies needed in a 1.5°C scenario, the rapid scaling of renewable energy needs to begin now.

While the 'Coordinated action scenario' overall requires an approximate doubling of electricity generation across the economy, in some regions, the increase will be more dramatic. To give a sense of the differences and scale of transition required, while generation roughly doubles in Queensland (125TWh/year) in the 'Coordinated action scenario', it more than doubles in NSW (161TWh/year) and quadruples in South Australia (52TWh/year). Generation in Western Australia increases roughly four-fold (127TWh/year). Large-scale solar PV capacity sky-rockets in Western Australia (9GW), Queensland (21GW) and NSW (47GW). Wind generation capacity increases dramatically almost everywhere, especially in Western Australia (28GW), Queensland (14GW), Victoria (14GW) and NSW (11GW). Overall, rooftop solar, large-scale solar and wind generation increases more than twelve-fold across the economy by 2050, and even in the 'Incremental scenario' it increases more than ten-fold.

Recommended action 9: Undertake coordinated, detailed energy system and infrastructure planning studies that consider the regional context of industrial decarbonisation to enable AEMO to integrate industry's future energy infrastructure needs into the ISP and WOSP and to direct investment into the infrastructure projects identified

A transition to a zero-emissions electricity system will require an expansive build-out of supporting energy system infrastructure including renewable generation, transmission and storage as well as hydrogen production, transport and storage solutions. Development of this system will need to consider a range of regional factors such as existing infrastructure, skilled workforces, geography, distances between generation and use of energy as well as water availability (for green hydrogen production). Governments and energy system planners can work with regional stakeholders to understand regional challenges and optimise for the least-cost pathway.

The priorities of the National Energy Transformation Partnership look promising for enabling alignment on the energy transition across federal, state and territory governments. Importantly, the agreement covers all of Australia (not just the NEM) and relates to all energy, not just electricity. In particular, initial priorities include regional-level scenario planning, coordinated gas and electricity planning, and identification of needs associated with transmission. It is not clear to what degree this will take in broader energy infrastructure planning.

To meet the needs of a changing energy landscape, it would be beneficial for actions under the National Energy Transformation Partnership, along with ISP and WOSP updates, to expand to support more holistic infrastructure planning. Planning should include pipelines for gas and hydrogen as well as for electricity. Detailed energy system and infrastructure planning studies, coordinated between industry and energy planners in key regions, could enable better integration of industry's future energy needs with energy planning. Holistic regional planning should also consider regional workforces as well as supply chain security and social license of new infrastructure.

Recommended action 10: Drive international energy competitiveness by benchmarking energy development at globally competitive costs of generation by making the most of Australia's vast renewable resources at scale

Competitiveness in a decarbonised global economy will be driven by access to low-cost, reliable renewable energy. Renewable energy development will require access to land where high-quality renewable energy is located as well as investment in shared infrastructure to deliver energy as either electricity or hydrogen to areas of high industrial concentration. Capital investment and labour costs in Australia may be higher than its competitors, so an energy cost advantage over international benchmarks is required by many industries to maintain an international competitive advantage.

Electricity system developments should benchmark at the lowest global costs of generation by making the most of Australia's vast renewable resources, and ensuring technology and infrastructure are focused on driving industry and competitiveness. Energy system planners could collaborate with energy companies, governments and large industrial energy consumers to set these benchmarks and make plans based on those benchmarks.

Objective: Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower

The pathway set out in this report for a 1.5°C scenario uses a range of existing technologies, systems and solutions as well as emerging options that require further development and demonstration before they will be ready to be deployed commercially (Figure 8.04).

Significant efforts are needed to ensure that emerging technologies are available within the required timeframes to stay within a 1.5°C carbon budget.

Recommended action 11: Prioritise funding and support for pilots and demonstrations that build capability and expertise to enable Australia to maintain and grow market share in existing industries, and expand into new industries where Australia has natural advantage

Investment in research and development will help advance industry's ability to deploy technologies earlier. Pilots and demonstrations are valuable to ensure Australia builds the capabilities, expertise and workforce it needs to be a leader or fast follower.

Part of R&D is planning for the commercialisation of technology solutions, and the time needed for this should be factored in from the outset. Many pilots and demonstrations are currently being undertaken in each supply chain, but the scale and pipeline of projects needs to increase. Efforts to accelerate research, development and demonstration should target and prioritise technologies where:

- Australia has a natural endowment of co-located resources and renewable energy, which can be value-added (such as in the processing of critical minerals and the production of hydrogen, ammonia, decarbonised alumina and green iron)
- there are limited existing alternatives to high-emitting processes (such as CCS for reservoir gas in LNG and alternative technologies for alumina calcination)
- there are risks to the viability of major export and export-exposed industries if solutions are not developed (such as iron ore and green steel. See Information Box 8.05)
- Australia has existing strengths that can be turned to the decarbonisation challenge, such as global centres of excellence.

INFORMATION BOX 8.05

Recommended actions for meeting challenges for the future of iron ore

Australia's hematite-goethite iron ore is not readily suitable for use in H2 DRI-EAF, the most advanced green steel technology. See chapter 3 'Focus on iron and steel' for more information.

Three strategies should be investigated to ensure the ongoing viability of iron ore exports in light of this potential technology shift. Firstly, investment in research and development of advanced beneficiation and pre-treatment of hematite-goethite ore to enable compatibility with H2 DRI-EAF. Secondly, green steelmaking such as DRI-Melter-BOF and electrolysis technologies, which are more compatible with hematite-goethite iron ore. Thirdly, prioritisation of the development of magnetite resources to diversify Australia's iron ore production.

ARENA was set up to accelerate pre-commercial innovation and renewable energy deployment. The CEFC invests in renewable energy, energy efficiency and low-emissions technologies to accelerate Australia's transition to net zero emissions by 2050. Together with the new 'National Reconstruction Fund' and the 'Powering the Regions Fund', ARENA and the CEFC could be harnessed to help accelerate and focus action on strategic priorities for decarbonising heavy industry.

These strategic priorities could also be supported through international bilateral partnerships, particularly low-emissions technology partnerships (DCCEEW 2021a), Australia's membership to initiatives such as Mission Innovation (Mission Innovation 2010), and commitment to attracting foreign investment (DFAT n.d.).

FIGURE 8.04: Some emerging technologies in the Australian Industry ETI supply chains

Iron and steel			
Hermatite processing	*Electrolysis in steelmaking*	*Fuel cell and battery electric vehicles*	*Hydrogen DRI-Melter-BOF*
Techniques for making hematite ore compatible with green steelmaking	Process for extracting metal from ore using electricity	Haulage trucks at mine site that use hydrogen or electricity rather than diesel	Use of hydrogen to produce green iron from iron ore
Aluminium			
Process heat abatement in alumina	*Inert anodes for aluminium smelters*	*Fuel cell and battery electric vehicles*	*Mechanical vapour recompression*
Replacement of fossil fuels in high temperature calcination process	Substitutes to carbon anodes for aluminium smelting	Haulage trucks at mine site that use hydrogen or electricity rather than diesel	Use of electricity to produce alumina with high efficiency
Other metals		**LNG**	
Fuel cell and battery electric vehicles	*Mineral carbonation*	*Carbon capture, utilisation and storage*	
Haulage trucks at mine site that use hydrogen or electricity rather than diesel	Sequestration of CO_2 in tailings from nickel mines	Capture of carbon dioxide produced during gas processing after extraction	
Chemicals			
Third generation ammonia production	*Green hydrogen feedstock*	*Haber-Bosch process electrification*	
Novel processes such as electrochemical ammonia synthesis	Use of green hydrogen instead of natural gas feedstock	Use of electricity to replace use of natural gas as fuel	

Recommended action 12: Address common strategic risks and enable cost sharing by supporting supply chain partnerships and multi-stakeholder collaboration

Industry partnerships are needed for emerging supply chain solutions or where several organisations face similar strategic challenges and see an opportunity to share risk and costs.

Government program funding that prioritises collaboration between multiple industry partners can help provide supply and demand solutions, shared infrastructure and supply chain level initiatives. For example, the Australian Government's 'Hydrogen Hubs Development and Design Grants' were for 'hydrogen industry-led consortia', and preferenced applications with multiple project partners (Australian Government 2022). The NSW government's expression of interest for decarbonisation roadmaps for the Hunter and Illawarra regions will fund a 'coordinating body' that demonstrates support and involvement of a number of regional bodies across supply chains and sectors (New South Wales Government n.d.).

Recommended action 13: Direct public funding towards development and demonstration activities, develop mechanisms to catalyse greater industry investment and better enable private finance and investment in early stage technologies

Increased investment is needed in early-stage technology development and demonstration. While Australia has very mature capital markets and private equity industries, these are often not leveraged towards the early-stage financing needed for many emerging decarbonisation technologies.

While these early-stage technologies will need greater capital, mechanisms are also needed to blend public and private capital, in order to create a risk profile more conducive to large-scale financing.

Objective: Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy

Following development and demonstration comes the complex and capital-intensive stage of deploying those technologies. There are multiple abatement technologies that already exist and have been proven viable, but are not yet available or considered to be commercial in Australia, such as mechanical vapour recompression and electric boilers in alumina processing. Challenges for this stage include concerns around the investment required and availability of necessary infrastructure (energy or otherwise) as well as a lack of confidence that markets valuing 'green' or low-carbon products can provide adequate incentives to justify investment.

Consultation with industry participants has indicated that some more mature technologies could be deployed in the next few years. Some of these would be deployed as interim measures to bring emissions down early, while other technologies are seen as essential to the pathway through to 2050, such as the use of tertiary catalyst abatements and mechanical vapour recompression (Figure 8.05).

FIGURE 8.05: Some mature technologies in Australian Industry ETI supply chains

Iron and steel			
Biodiesel haulage Replacement of diesel in haulage trucks with biodiesel		*Electrification* Replacement of diesel-powered plant at mine sites	*Scrap-EAF* An electric process that makes use of recycled steel
Aluminium			
Biodiesel haulage Replacement of diesel in haulage trucks with biodiesel	*Aluminium recycling* Highly efficient secondary production using recycled aluminium	*Electrification* Replacement of diesel-powered plant at mine sites	*Electric boilers* Use of electricity instead of fossil fuels in boilers to produce alumina
Other metals		**Chemicals**	
Biodiesel haulage Replacement of diesel in haulage trucks with biodiesel	*Electrification* Replacement of diesel-powered plant at mine sites	*Tertiary catalyst abatements* Abatement of nitrous oxide from ammonium nitrate producation	*Hydrogen feedstock* Retrofitting of ammonia plants to use grey, blue or green hydrogen
LNG		**All supply chains**	
Electric drives Replacement of gas turbines at liquefaction plants with electricity	*Fugitives abatement* Reduction of CO2 and methane emissions through process changes and recovery	*Energy efficiency* Emerging processes to optimise energy	*Renewable energy* Use of firmed, variable renewable energy for electricity and biogas as a transition fuel

Recommended action 14: Governments can ensure their industry and climate policies enable efficient emissions reductions across the economy through mechanisms such as the Safeguard Mechanism, while also committing to targeted measures to reduce barriers and support investment towards the transition

Heavy industry has an important role to play in emissions reductions: the five supply chains in focus for Australian Industry ETI alone represent 25 per cent of emissions across the economy.[84] Coordinated action is needed across economic sectors to ensure lower cost and most efficient emissions reduction measures are taken.

The federal government's 'Safeguard Mechanism' applies to around 215 facilities in Australia that emit over 100,000 tonnes of CO_2e annually. Safeguard Mechanism facilities contribute around 28 per cent of Australia's national emissions, spanning mining, manufacturing, transport, oil, gas and waste sectors (DCCEEW 2022b, 2022c). The Australian government is in the process of reforming this mechanism to reduce baselines in alignment with Australia's greenhouse gas emissions reduction targets, and to enable safeguard facilities to earn credits where emissions are reduced below their baseline. It is proposed that the 'National Reconstruction Fund' and 'Powering the Regions Fund' will assist safeguard facilities in meeting their new baselines, and the deployment of low-emissions technology across industry more broadly. These reforms are supported in principle for the roles they can play in driving emissions reductions.

Regular reviews of the Safeguard Mechanism and supporting measures, such as funds, will help to ensure Australia's transition keeps pace with the global transition, builds international competitiveness and mitigates transition risks in a decarbonising global economy. The annual report required under the new Climate Change Act 2022 could be one way to measure and report on this. Federal government mechanisms are complemented by various state and territory government programs and grants to help industry decarbonise (see Information Box 8.03 for some examples of this). One mechanism gaining traction is for state Environmental Protection Authorities (EPAs) to broaden their activities and regulate greenhouse gas emissions. For example, the New South Wales EPA recently released a draft climate change policy and action plan, which would treat greenhouse gas emissions as a pollutant. This draft policy is described as 'a clear signal to regulated industries that we [EPA] will be working with them to support and drive cost-effective decarbonisation' (NSW Environment Protection Authority 2022). The Western Australian EPA has a more limited approach which outlines cases where the EPA may require a 'Greenhouse Gas Management Plan' along with information about measures to mitigate emissions (Environmental Protection Authority 2020)[85].

Recommended action 15: Develop early supply, demand and enabling infrastructure to scale net zero solutions through levers such as offtake commitments, government procurement contracts, aggregation of industry demand, feed-in tariffs, voluntary pledges, mandates and certification schemes for green products

Building early supply, demand and the enabling infrastructure that allows new markets such as hydrogen and green metals to develop and scale are critical to decarbonisation. Policies can play a key role to these ends. Levers such as offtake commitments, government procurement contracts for green products, feed-in tariffs, mandates and certification schemes for green products such as green metals and hydrogen can be used to bridge the gap between supply and demand for decarbonised industrial production.

Partnerships can help drive the simultaneous development of supply, demand and shared infrastructure needed to scale green solutions by bringing together multi-sectoral offtakers and producers. They can also support repurposing infrastructure with the goal of launching scaled supply chains that deliver green industrial products such as hydrogen, ammonia and green metals (Green Hydrogen Coalition n.d.).

The scale-up of technologies can be facilitated through regulation, standards and market signals as well as enabling infrastructure, business models, user and customer practices and technical skills and capabilities.

Deployment can be accelerated if there is an increased demand for low-emissions products, or a heightened risk for high-emissions products. There should be a demonstrated willingness for customers to pay a 'green premium' for decarbonised products, confidence in large-scale future offtake for these products or certification requirements for low embodied emissions (such as in construction of new buildings). Confidence in products' green credentials can be assured through effective certification schemes for products such as green metals and green hydrogen.

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84 Australian Industry ETI analysis

85 This policy was being reviewed at the time of writing.

Collaboration between industry and government to raise public awareness about the scale of the transition needed may help increase customer willingness to pay a price premium. Certifications and guarantees of origin should assist with this, clearly labelling green products to help empower the public to choose these over carbon-intensive alternatives. A hydrogen guarantee of origin that verifies emissions intensity is currently being developed by the Clean Energy Regulator (Clean Energy Regulator n.d.) and could serve a similar purpose for both domestic and international hydrogen offtakers. A number of state governments have also joined the industry-led 'Zero Carbon Certification Scheme' for green hydrogen products and derivatives such as green ammonia and metals (Smart Energy Council 2021). Other policy tools that can be valuable to developing early supply, demand and enabling infrastructure include:

- Contracts for difference: Where the government agrees on a strike price with hydrogen producers and tops up payments when the wholesale price falls below this. Two-way contracts for difference provide for payments back to the government where the wholesale price goes above the strike price. This allows producers to price green products competitively against fossil-fuel produced products. More price certainty for producers also means greater certainty for potential investors. This approach has been proposed in several jurisdictions, including a pilot program in Germany (Germany's Hydrogen Industrial Strategy 2021).
- Offtake agreements: Hydrogen projects that have offtake arrangements are much better positioned to receive finance and grants. Government can also facilitate renewable hydrogen offtake agreements through services that help to aggregate industry demand and match supply with demand.
- Government procurement: Aligning government procurement with greenhouse gas emissions targets, which could include requirements or preferential treatments for low-carbon emissions from products procured by government.
- Mandates: Targets of 10 percent hydrogen blending in gas networks such as in NSW (Department of Planning, Industry and Environment 2021) and Western Australia (Department of Jobs, Tourism, Science and Innovation 2020) could also become part of government procurement (see point above).

Recommended action 16: Financial institutions should continue to focus their stewardship and engagement with industrial companies to align lending and investment to net zero emissions by leveraging credible pathways and benchmarks for industrial transition and reflecting lower risk of transition for aligned companies in lending and investment criteria

The transition requires a substantial rebalancing of capital allocation across the economy. Finance can play an important role driving changes in the flow of goods and services consistent with a decarbonised trajectory that reflects lower transition risks associated with climate change.

Lenders and asset owners should continue to steward lending and investment to align to net zero emissions pathways by:

- Working with companies, across their portfolio, on their decarbonisation and climate transition action plans informed by sectoral roadmaps
- Engaging with portfolio or investee companies to close the gap between their forecasts and net zero emissions or 1.5°C-aligned pathways
- Ensuring that companies undertake and disclose risk assessments that consider the physical and transition risks associated with climate change
- Discussing barriers to action and identifying where finance can play a catalytic role in driving emissions reductions.

By investing in the development and maintenance of sectoral net zero emissions pathways to inform sectoral roadmaps, the financial industry can direct capital towards companies with appropriate net zero emissions targets, strategies and disclosure.

Objective: Develop integrated net zero regions, supply chains and energy network solutions

Supply chain and energy system integrations in key industrial regions can enable a lower-cost transition and greater Australian competitiveness in a decarbonised global economy.

Recommended action 17: Commitment from government to develop a number of coordinated net zero industrial precincts, designed to leverage shared infrastructure and draw in large scale renewable energy from renewable energy zones or equivalent

The complex, systems challenge of industrial transition will require coordination of stakeholders across industry, governments, finance, communities and the energy sector to manage the simultaneous shifts needed. This includes changes to infrastructure and the energy system, regulation and policy, workforce and skills, corporate strategy, technology solutions, new demand and markets, and finance and investment.

Development of clustered industrial precincts that leverage multi-user infrastructure and build a skilled workforce present an opportunity for more efficient investment in low-emissions industrial production (Australian Industry ETI 2021b).

A range of efforts at a precinct level, such as demand-side response sector coupling and integrated hydrogen systems to balance energy loads from renewables, could allow for more effective use of transmission, distribution and storage infrastructure as part of decarbonisation transformation.

Development of clustered industrial precincts, designed to leverage low-cost renewable energy drawn from proximate renewable energy zones (or equivalent), can reduce regional energy costs through shared access to critical energy and transport infrastructure, inputs and labour sharing, cheaper green hydrogen and circular economy practices. Establishing renewable energy industrial precincts (REIPs) can also attract new players in emerging industries (such as battery and green hydrogen production), potentially increasing the return on investments made in shared infrastructure. REIPs are already in development around Australia (Beyond Zero Emissions 2021). Regional roadmaps can align multiple regional stakeholders on the vision and milestones for the infrastructure, capabilities and partnerships needed to decarbonise effectively. Mechanisms for co-investment in the shared system and infrastructure will be needed to coordinate investment across regional developments and to leverage the necessary levels of investment for the transition.

Attracting private capital is important for reaching the scale of finance needed to fully decarbonise industry in potential REIP locations. Co-investment partnerships between state and territory governments, funded through the federal budget or financed by the CEFC (and potentially from new pools of finance such as the National Reconstruction Fund), could provide a strong signal to the private sector. This opens opportunities to leverage greater private investment compared to funding provided by governments alone. Offtake agreements for renewable energy, such as power purchase agreements, can induce investment by providing guarantees of cash flow for higher-risk projects (e.g. where technology is not yet ready to be commercially deployed). Power purchase agreements for renewable energy can have the dual effect of providing confidence for investors in electricity generation as well as for companies planning to electrify processes (Ernst & Young 2016).

Recommended action 18: Energy market reforms, including through the National Energy Transformation Partnership, should give equal weight to energy efficiency, demand management, hydrogen production as a load balancing mechanism and customer owned storage to facilitate lower costs; special focus should be given to firming variable renewable energy for industrial processes

Energy market reforms are opportunities to support essential infrastructure and technological elements of an integrated, low-emissions energy system. Greater flexibility and efficiency mean that less renewable electricity capacity needs to be built to meet Australia's energy needs. This will be achieved with coordination across governments as well as large industrial energy consumers and energy system planners.

The National Energy Transformation Partnership (DCCEEW n.d.) is a promising example of a partnership within government to coordinate the transition of the energy sector. Federal, state and territory ministers all agreed 'the time is right to work together on a new agreement to set the vision for Australia's energy sector transformation to net zero'. This includes a number of priority work areas relevant to energy and industry decarbonisation, such as modelling and mapping of regional decarbonisation pathways and opportunities, and gaining a better understanding of dynamics for future energy demands, including electrification and fuel switching.

The Partnership's priorities for action look promising for aligning the transition across federal, state and territory governments. Importantly, the agreement covers all of Australia and relates to all energy, not just electricity. One particularly relevant priority is an agreement to cooperate across levels of government on plans for adequate generation and storage, demand evolution, and workforce, supply chain and community needs. This would encompass work in areas including:

- Coordination of gas and electricity planning
- Identification of enabling requirements for the clean energy transition
- Regional level scenario planning that accounts for increasing electrification and demand management, including energy efficiency, electric vehicles and demand response (DCCEEW n.d.).

These priority areas of the Partnership are supported in principle for the role they can play in a more holistic consideration of issues such as demand management, the role of consumer owned storage and expanded energy (i.e. not just electricity) planning. In undertaking work in the initial priority areas of the Partnership, it is recommended that system planning designs for an efficient energy system, taking into consideration the complex interplay between electrons and molecules in a changing energy landscape.

The ISP and WOSP can be effective tools to enable energy system planning. It would be valuable for the ISP, WOSP and work under the National Energy Transformation Partnership to support more holistic infrastructure planning, including investigation of the potential roles and trade-offs of developing pipelines) and powerlines (for transmission of electricity) to deliver the energy needed for industry's decarbonisation.

Energy efficiency is also essential to success. Under the 'Coordinated action scenario', which assumes high support for energy efficiency, nearly 500PJ/year is saved across the economy in 2050 by making processes and technologies more efficient, with half of that efficiency coming from industry.[86] Without such substantial improvements in energy efficiency, more abatement technologies would need to be deployed to remain aligned with 1.5°C of warming, especially technologies that allow industry to switch from fossil fuels.

Hydrogen could play an important role in decarbonising heavy industry, acting as a fuel, chemical feedstock, and energy storage solution. Robust hydrogen supply chains will need to be integrated into Australia's current energy system, requiring the build-out of hydrogen production, storage and transport facilities. There are a range of relevant workstreams within the 'National Hydrogen Strategy', including identification of regulation needed and current legal hurdles, jobs and training requirements and technical aspects regarding hydrogen in pipelines and appliances (DCCEEW n.d.). These workstreams are steered by and coordinated across different federal, state and territory governments.

Projections by AEMO indicate that the future capacity of customer-owned storage, including in the form of home batteries and electric vehicles, is likely to exceed conventional large-scale storage such as pumped hydro and grid-scale batteries as well as community-level storage. Customer-owned storage – if considered as a grid resource – could therefore reduce electricity supply costs relative to building new large-scale storage. Integrating customer-owned storage into current market systems as virtual power plants faces barriers to becoming a forecastable and dispatchable resource without changes to operational behaviour, control methodology and price signals for following forecast schedules.

Recommended action 19: Build supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation

Greater clarity is needed on the scale and timing of transition, to provide certainty and investment confidence for decarbonisation across supply chains.

Supply chain roadmaps would align suppliers, finance, consumers and decision-makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions for that supply chain. Roadmaps should identify new opportunities in potential markets such as hydrogen, green metals and energy export, regularly report on the effectiveness of activity, and focus on new export opportunities in these markets.

Supply chain roadmaps could be undertaken by a relevant, independent body to complement regional decarbonisation roadmap work, which is already happening in some parts of Australia (such as NSW government's ongoing work on roadmaps for Illawarra (New South Wales Government 2021) and Hunter (New South Wales Government 2016)), or potentially as an extension to sectoral roadmap work (e.g. WA government's planned 'Sectoral Emissions Reduction Strategies' (The Government of Western Australia 2021b)). It will also be important for stakeholders to coordinate these roadmaps with relevant work streams under the National Energy Transformation Partnership – especially on demand evolution and regional-level scenario planning. Equity owners may also have a role in connecting industry partners and supply chains, as large financial institutions such as superannuation funds and insurance companies may be stakeholders in many companies within a supply chain.

86 This is in addition to autonomous (business-as-usual) energy efficiency improvements. Energy efficiency encapsulates process improvements and equipment upgrades. See the companion technical report for details on energy efficiency assumptions and modelling.

Recommended action 20: Build the circular economy through extensive build-out of scrap collection, processing, and recycling facilities in Australia; design products and services for circularity; and update business models to include data-driven, `product-as-a -service' models

A circular economy for Australia will encompass many industries and their products, but metals and mining subsectors are the main focus of this report (see chapter 3 'Focus on iron and steel', chapter 4 'Focus on aluminium' and chapter 5 'Focus on other metals'). Greater recycling of end-of-use waste is a big emissions reduction opportunity, because secondary production can be a relatively inexpensive way of producing lower emissions products. In the 'Coordinated action scenario', uptake of steel and aluminium recycling was very strong and limited only by a lack of materials. Miners, manufacturers and governments can collaborate to create greater circularity in steel and aluminium value chains with increased onshore recycling. Recycling of other metals, such as those found in batteries, could also be essential to meeting demand, but may be more technically challenging. Enabling this would require an extensive build-out of scrap collection, processing, and recycling facilities in Australia. The 'National Waste Policy Action Plan 2019' already targets a ban on the export of waste plastic, paper, glass and tyres (DCCEEW 2019), which could be extended to other materials. It also recommends that governments create demand by procuring more goods and infrastructure containing recycled material, improve awareness and improve waste data collection. The 'National Product Stewardship Investment Fund' was created as part of the Plan, and offered grants of up to A$1 million for stewardship schemes. Grants were awarded to 24 schemes, including for batteries and vehicles. Batteries, photovoltaics and electrical, and electronic products are included on the 'Minister's Priority Product List' (Product Stewardship Centre of Excellence 2021). Steel and aluminium are potential opportunities to extend this ambition.

According to the OECD, economic instruments such as taxes, subsidies and fees and charges can be effective to improve waste recovery rates. Economic instruments give financial incentives to behaviours that support environmental and human health costs, encouraging polluters to adopt initiatives that recover waste. Other policy measures, used elsewhere in the OECD, include regulatory instruments, extended producer responsibilities, green public purchasing, monitoring and reporting, and promotion of enforcement and compliance (OECD 2019).

Manufacturers and primary producers can also support lower-emissions production by designing products and services for circularity, and with business model changes such as data-driven 'product-as-a-service' models. (Lacy et al. n.d. 2020; World Economic Forum 2020a).

Another circular economy opportunity significant to the industrial energy transition includes the use of biomass waste for industrial supply chains (e.g. biodiesel for heavy haulage) as well as in transport (e.g. sustainable aviation fuel). Building efficient bioenergy supply chains requires collaboration between waste producers (particularly the agriculture sector), biogas producers and end users.

9. Conclusion and summary of recommended actions

The pathway to reduce emissions consistent with global efforts to limit warming to 1.5°C will be challenging, but we cannot afford to fail. The modelling, analysis and industry consultation undertaken through the Australian Industry ETI has shown a potential pathway to transition in line with 1.5°C, although this requires strong ambition and coordinated action from government, industry, and finance. Given that the five supply chains in focus for the Australian Industry ETI represent 25 per cent of Australia's emissions, and that the industries face significant challenges and opportunities to take advantage of the global transition to net zero, now is the moment to act.

The 'Coordinated action scenario' shows that a transformational shift in the energy system is required to power a net zero emissions Australia. This will require a doubling of total current electricity generation by 2050, achieved primarily through multi-gigawatt renewable generation developments. Australia could require nearly 330TWh per year of renewable electricity generation by 2030, and nearly 600TWh per year by 2050 in line with the ambitious 1.5ºC aligned scenario. From now until 2050, A$625 billion of coordinated investment is required to decarbonise Australia's industry and energy system. It is estimated that the business as usual investment needed is A$400 billion, with an additional A$225 billion required to transition the energy system and invest in technologies to achieve the ambitious pathway seen in the 'Coordinated action scenario'.

Each of the supply chains in focus for the Australian Industry ETI faces challenges in achieving the emissions reduction found in the 'Coordinated action scenario'. Overcoming these challenges requires Australia to leverage its abundant renewable energy and mineral resources, home-grown intellectual property and experience.

The transition will need to be supported by four enablers: investment in technology and infrastructure, continued action by the financial sector to support the significant capital investment needed, partnerships and collaboration to solve problems that can't be solved alone, and an alignment of public policy and regulation.

These enablers will be essential to the achievement of the five key objectives that will help create a globally competitive, net zero industrial economy in Australia. Table 9.01 shows the Australian Industry ETI's recommended actions to achieve the objectives, and coloured boxes indicating the role of the enablers. See chapter 8, 'Enabling the transition to net zero emissions in Australian industry' for details.

This report presents potential pathways and provides recommended actions to decarbonise heavy industry supply chains. The next step is for policy-makers, financial institutions and industry to take strong, effective and coordinated action to enable the transition. The transition will be challenging but now is the time to act to realise the opportunities for Australia and Australian industry in a decarbonised global economy.

FIGURE 9.01: Table of recommended actions

Objective	No	Recommended action	Type of enabler			
			Technology & infrastructure	**Partnerships & collaboration**	**Finance & investment**	**Policy & regulation**
Set a strong, clear, enduring framework with a net zero goal to align industry, finance and government efforts on the transition of Australia's industry	1	Ensure that federal, state and territory policy and programs are complementary, and designed to transition Australia's industry and broader economy to net zero emissions.				■
	2	Develop a national strategy to become a leading supplier in new export markets such as green ammonia and green iron in the decarbonising global economy.		■	■	■
	3	Develop a workforce plan to invest in and develop the skills needed for the transition, at the scale required, within key regions.		■		■
	4	Further financial sector commitment and action for net zero in line with a 1.5°C transition.			■	
	5	Support the development and adoption of an Australian investment taxonomy to provide transparent and credible definitions of what constitutes sustainable investment.			■	■

Objective	No	Recommended action	Type of enabler			
			Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Transition to the large-scale, cost-competitive, renewable energy system of the future	6	Ensure that energy planning, including through the National Energy Transformation Partnership, includes deployment of renewable energy and energy management to unlock investment at the scale required for heavy industry decarbonisation and new export industry development.				
	7	Set targets that drive the development of a large-scale, decarbonised hydrogen market and coordinate updated regulation for rapid and safe development of hydrogen production, transport and storage.				
	8	Strengthen energy market system planning such as the ISP and WOSP to anticipate decarbonisation of heavy industry in line with 1.5°C warming scenarios with energy and green metals export scenarios as the central case. Energy planning in South Australia, Queensland, NSW and Western Australia should account for potential electricity demand several times greater than 2020 levels, and Australia-wide wind and solar generation may need to be up to more than twelve times larger. Planning should be expanded to support more holistic infrastructure considerations such as pipelines to support the energy transition alongside electricity transmission.				
	9	Undertake coordinated, detailed energy system and infrastructure planning studies that consider the regional context of industrial decarbonisation to enable AEMO to integrate industry's future energy infrastructure needs into the ISP and WOSP and to direct investment into the infrastructure projects identified.				
	10	Drive international energy competitiveness by benchmarking energy development at globally competitive costs of generation by making the most of Australia's vast renewable resources at scale.				

Objective	No	Recommended action	Type of enabler			
			Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Accelerate development and demonstration of the emerging technologies needed for Australia to be a net zero emissions superpower	11	Prioritise funding and support for pilots and demonstrations that build capability and expertise to enable Australia to maintain and grow market share in existing industries, and expand into new industries where Australia has natural advantage	■			■
	12	Address common strategic risks and enable cost sharing by supporting supply chain partnerships and multi-stakeholder collaborations.	■	■		■
	13	Direct public funding towards development and demonstration activities, develop mechanisms to catalyse greater industry investment and better enable private finance and investment in early stage technologies.	■		■	■
Drive deployment of low carbon solutions across the economy, reduce barriers and support investment towards the transition to compete in a decarbonising global economy	14	Governments can ensure that their industry and climate policies enable efficient emissions reductions across the economy through mechanisms such as the Safeguard Mechanism while also committing to targeted measures to reduce barriers and support investment towards the transition.				■
	15	Develop early supply, demand and enabling infrastructure to scale net zero solutions through levers such as offtake commitments, government procurement contracts, aggregation of industry demand, feed-in tariffs, voluntary pledges, mandates and certification schemes for green products.	■	■	■	■
	16	Financial institutions should continue to focus their stewardship and engagement with industrial companies to align lending and investment to net zero emissions by leveraging credible pathways and benchmarks for industrial transition and reflecting lower risk of transition for aligned companies in lending and investment criteria.		■	■	

Objective	No	Recommended action	Type of enabler			
			Technology & infrastructure	Partnerships & collaboration	Finance & investment	Policy & regulation
Develop integrated net zero regions, supply chains and energy network solutions	17	Commitment from government to develop a number of coordinated net zero industrial precincts, designed to leverage shared infrastructure and draw in large scale renewable energy from renewable energy zones or equivalent.	■	■	■	■
	18	Energy market reforms, including through the National Energy Transformation Partnership, should give equal weight to energy efficiency, demand management, hydrogen production as a load balancing mechanism and customer owned storage to facilitate lower cost; special focus should be given to firming variable renewable energy for industrial processes.	■			■
	19	Build supply chain roadmaps for heavy industry to align suppliers, finance, consumers and decision -makers on the vision and milestones for the development of infrastructure, energy systems and technology solutions that support industrial decarbonisation.	■	■	■	■
	20	Build the circular economy through extensive build-out of scrap collection, processing, and recycling facilities in Australia; design products and services for circularity; and update business models to include data-driven, ‘product-as-a-service’ models.	■	■		■

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Glossary

A$	Australian dollars
ACCUs	Australian carbon credit units
ACCC	Australian Competition & Consumer Commission
AE	alkaline electrolysis
AEMO	Australian Energy Market Operator
ARENA	Australian Renewable Energy Agency
ASFI	Australian Sustainable Finance Institute
Australian Industry ETI	Australian Industry Energy Transitions Initiative
ASEAN	Association of Southeast Asian Nations
Bcm	billion cubic metres
BloombergNEF	Bloomberg New Energy Finance
bp	Formerly known as British Petroleum
CA100+	Climate Action 100 plus
CBAM	Carbon Border Adjustment Mechanism
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CCUS	carbon capture utilisation and storage
CEFC	The Clean Energy Finance Corporation
CER	Clean Energy Regulator
COAG	Council of Australian Governments
COP	Conference Of Parties
COP26	26th Conference Of Parties
CRCs	cooperative research centres
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAC	direct air capture
DISR/DISER	Department of Industry, Science and Resources
DRI-EAF	direct reduced iron–electric arc furnace
DRI-Melter-BOF	direct reduced iron–melter–basic oxygen furnace
DSR	demand side response
EAF	electric arc furnace
e-drives	electric drives
EU	European Union
EOI	Expression of Interest
EOR	enhanced oil recovery
ESG	environmental, social and governance
EPA	Environmental Protection Authority
FCEV	fuel cell electric vehicle

FFI	Fortescue Future Industries
FMG	Fortescue Metals Group
GDP	gross domestic product
GFANZ	Glasgow Financial Alliance for Net Zero
GGFRP	Global Gas Flaring Reduction Partnership
GJ	gigajoule
Gt	gigatonne
GTG	gas turbine generator
GW	gigawatt
H_2	hydrogen
HYBRIT	Hydrogen Breakthrough Ironmaking Technology Project
HBI	hot briquetted iron
ICT	Information, communication and technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISP	Integrated System Plan
kWh	kilowatt hour
kt	kilotonne
km	kilometre
LULUCF	land use, land use change and forestry
LDAR	leak detection and repair
LNG	liquified natural gas
MCi	Mineral Carbonation International
MCH	methylcyclohexane
MOU	Memorandum of Understanding
MRIWA	Minerals Research Institute of Western Australia
Mt	megatonne
$MtCO_2e$	megatonne of carbon dioxide equivalent
MWh	megawatt hour
N_2	Nitrogen
N2O	Nitrous Oxide
NAIF	Northern Australia Infrastructure Facility
NCIIP	Net Zero Industry and Innovation Program
NEM	National Energy Market
NERA	National Energy Resources Australia
NG	natural gas
NGFS	Network for Greening the Financial System
NDC	Nationally Determined Contributions
NSW	New South Wales
NWIS	North West Interconnected System
NZAOA	Net Zero Asset Owner Alliance
NZE	Net Zero Emissions
OEM	original equipment manufacturer
OECD	Organisation for Economic Co-operation and Development
O&M	operations & maintenance

PEM	proton exchange membrane
PFCs	perfluorocarbons
PJ	petajoule
PV	photovoltaic
R&D	research and development
RE	renewable energy
REIP	renewable energy industrial precinct
RET	Renewable Energy Target
RFP	Request For Proposal
RMI	Rocky Mountain Institute
ROI	Registration Of Interest
SA	South Australia
SDGs	Sustainable Development Goals
SDS	Sustainable Development Scenario
SMR	steam methane reforming
SWIS	South West Interconnected System
SAF	sustainable aviation fuel
TAS	Tasmania
TAFE	Technical and Further Education
TCFD	Task Force for Climate Related Financial Disclosures
TRL	technology readiness level
TWh	Terawatt hour
UK	United Kingdom
USA	United States of America
VIC	Victoria
VRE	variable renewable energy
WA	Western Australia
WEM	Wholesale Electricity Market
WOSP	Whole of System Plan

FURTHER INFORMATION

Rob Kelly
Program Director
rob.kelly@climateworkscentre.org

Anna Skarbek
CEO – Climateworks Centre
anna.skarbek@climateworkscentre.org

Chris Lee
CEO – Climate-KIC Australia
chris.lee@climate-kic.org.au

www.energytransitionsinitiative.org

Australian Industry Energy Transitions Initiative

An initiative jointly convened by Climateworks Centre and Climate-KIC Australia