Australian Industry Energy Transitions Initiative

Setting up industry for net zero

Phase 1 Highlights Report: current state and future possibilities

JUNE 2021

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The Australian Industry ETI's industry partners and supporters have contributed to the conclusions, findings and messages of this report. This report however does not necessarily reflect the position of each individual partner.

Partners: Australia Gas Infrastructure Group, APA Group, Aurecon, AustralianSuper, BHP, BlueScope Steel, BP Australia, Cbus, Fortescue Metals Group, Orica, National Australia Bank, Schneider Electric, Wesfarmers Chemicals, Energy & Fertilisers, and Woodside.

Supporters: Australian Industry Group and the Australian Industry Greenhouse Network.

Contributors: HSBC Australia and Rio Tinto.

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Executive summary

Emissions from Australia's industrial supply chains are considered 'hard-to-abate' because addressing them poses more technological and commercial challenges than encountered in other sectors of the economy.

This report presents findings and highlights from the first phase of the Australian Industry Energy Transitions Initiative (Australian Industry ETI). It reports the current state of factors influencing decarbonisation in heavy industry, and the future technical and economic opportunities available to move towards net zero emissions.

Timely action is needed for Australian industry to be positioned for competitiveness in a decarbonised global economy. Early uptake and effective integration of renewable electricity, electrification and green hydrogen can help achieve competitive costs for reliable decarbonised energy, and allow Australia to remain an energy and commodity export powerhouse.

The transition to net zero emissions presents risks but also opportunities for Australian exports in energy and emissions intensive supply chains. The supply chains of iron and steel, aluminium, other metals, chemicals and liquefied natural gas (LNG) make a critical contribution to Australia's economy. Collectively, these supply chains contribute 12.3% to Australia's GDP, generate exports worth over $160 billion per annum for the Australian economy and employ 2.9% of Australia's workforce. Clearly, there is impetus to ensure that transitions for these supply chains are managed effectively for the future prosperity of Australia.

Momentum and urgency for action towards net zero emissions is building. Many of Australia's largest trading partners including China, Japan, South Korea and the United States (US) have now made commitments to achieve net zero emissions by 2050 or 2060. Australian industry has much to gain from being leaders in the global net zero emissions transition, and an important role to play in decarbonising materials and the energy system at an international scale.

This report shows that existing and emerging decarbonisation solutions can address almost all emissions in Australian heavy industry supply chains by 2050.

Analysis to date has identified opportunities to address industrial 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 technologies are mature, available to be deployed and will be critical to driving down energy costs. For emerging technologies, further research and development is needed to provide proof of concept or demonstration at scale.

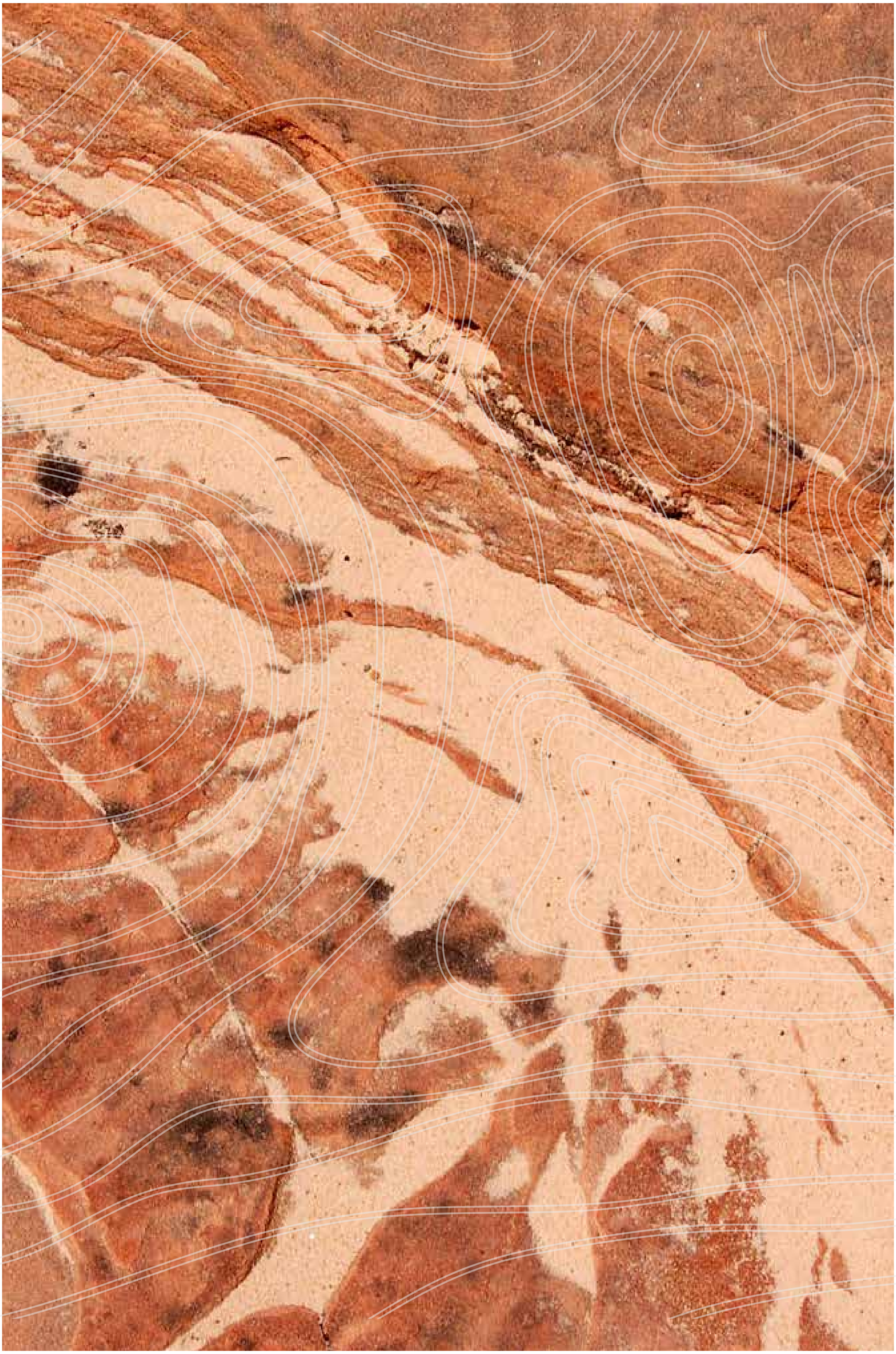
Renewable energy is already the cheapest form of new electricity generation and the initiative's research indicates that certain Australian industries could access variable electricity costs of $20 – 30/MWh by 2050, and potentially far sooner, by matching production to available renewable supply and avoiding costs of energy storage. In particular, hydrogen electrolysis is well-suited to variable energy supply, enabling favourable regions to flexibly produce green hydrogen for below $1.50/kg. This could help position Australian industry to be competitive in a globally decarbonised economy and support lower overall system costs for all electricity consumers.

The formation of clustered, industrial precincts is a key opportunity for Australian industry and governments in regions where hard-to-abate sectors are concentrated. The co-development of decarbonised energy systems alongside a concentration of demand, investment, ports, industry knowledge and skills, is an opportunity to empower regions and enable key industries to thrive. Existing industrial regions show exceptional promise for low cost, decarbonised energy, showing potential for further regional development.

Industrial companies in Australia are starting act, shifting from compliance and risk management to seeking opportunities. In addition, companies are setting more ambitious targets, aligning governance, increasing deployment of mature technologies and developing demonstrations of promising emerging technologies.

The transitions required for Australia to remain globally competitive are complex by nature, requiring significant investment, leadership and transformation of the energy system. Solutions are emerging to navigate this transition both globally and in Australia, but the transformational solutions needed to get to net zero emissions are more than a single organisation can achieve alone. Solutions must address the transition across and between supply chains, which requires collaboration across industry, government, finance and the energy sector, to enable simultaneous shifts on multiple fronts including corporate strategy, technology, policy, markets, investment and research.

These steps should not be underestimated and whilst commitment from industry to the long-term transition has been a step forward, there will be significant short-term challenges to navigate in the decarbonisation of existing operations and associated infrastructure.



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 by 2050.

The initiative focuses on five key industrial supply chains:

- iron and steel
- aluminium
- other metals (particularly copper, nickel and lithium)
- chemicals (particularly fertilisers and explosives)
- liquified natural gas (LNG).

The Australian Industry ETI is a valued platform convening Australian industry and business leaders to collectively address the challenges associated with mitigating the worst impacts of climate change.

Throughout 2020, the Australian Industry ETI brought together 14 industry and business partners, including: Australia Gas Infrastructure Group, APA Group, Aurecon, AustralianSuper, BHP, BlueScope Steel, BP Australia, Cbus, Fortescue Metals Group, Orica, National Australia Bank, Schneider Electric, Wesfarmers Chemicals, Energy & Fertilisers, and Woodside. The initiative's work has also benefited from the input of other participants including HSBC Australia and Rio Tinto. It is supported by the Australian Industry Group and the Australian Industry Greenhouse Network, with research partners including CSIRO and the Rocky Mountain Institute.

The Australian Industry ETI aims to position Australian industry to lead in the shift to net zero emissions supply chains by 2050 and help Australia build an economy that takes advantage of the transition. It works collaboratively with these companies to develop pathways towards net zero emissions by 2050, and identify actions to accelerate momentum towards this goal.

This report presents the findings and insights from Phase 1 of the initiative, 'Current state and future possibilities'. Through this phase, the Australian Industry ETI has carried out research, analysis, engagement and portfolio learning with a focus on understanding the current state of factors influencing decarbonisation in heavy industry, and the technical and economic opportunities that could drive action towards net zero emissions. Analysis in this report is supported by the Australian Industry Energy Transitions Initiative Phase 1 Technical Report (Butler et al. 2021), which can be referred to for more detailed research and findings.

This first phase of the initiative has looked at 'where we are now', and 'where do we ultimately need to be', by starting with the reference point of net zero emissions by 2050 as a goal for industry to accelerate towards. This reference point of net zero by 2050 then shapes the initiative's identification of technologies that are more likely to play a role in supply chain decarbonisation, both over the long term and throughout the transition if net zero emissions is to be achieved. While the technology opportunities identified in this report are representative of how industry could work towards the point of net zero emissions by 2050, there will be significant short-term challenges and uncertainties as existing operations and their associated infrastructure decarbonise.

In Phase 2, 'Promising pathways', the Australian Industry ETI will investigate the transition in more detail, identifying interim steps and how challenges can be navigated. The initiative will develop pathways to net zero for each supply chain and examine the challenges facing industry in the short term. Validated by industry partners, these pathways will help industry better understand the timing and regional dynamics of the transition, with a particular focus on Western Australia. Throughout this second phase, the Australian Industry ETI will continue to identify mutual interests for action and build the portfolio of implementation projects.

To produce this report, the Australian Industry ETI consulted with a diverse group of over a hundred cross-sectoral stakeholders and received support from global delivery partners, including the Energy Transitions Commission, Rocky Mountain Institute, CSIRO and the Australian Renewable Energy Agency (ARENA). These consultations were convened by ClimateWorks Australia and Climate-KIC Australia.

The Australian Industry ETI's industry partners have contributed to the conclusions, findings and messages of this report. This report, however, does not necessarily reflect the position of each individual partner.

1. Momentum is building towards net zero emissions

Australian Industry ETI is finding that companies in Australia and around the world are increasingly recognising the scale, urgency and complexity of the challenge to decarbonise.

Since launching in July 2020, the Australian Industry ETI's partners have come together to explore opportunities, understand challenges and identify areas of mutual interest. The initiative launched with an initial 11 partners, and has since grown to 14 as momentum builds in Australian industry towards action.

Even in the short period of time since launch, the economic urgency for climate action has increased, with a swathe of recent net zero emissions commitments from Australia's major trading partners. For example, China, Japan, South Korea and the US have all announced commitments to net zero by 2050 or 2060.

The European Union (EU) is also progressing plans for a carbon border adjustment mechanism, to apply an additional tax on imports from countries without an adequate compliance framework aligned to net zero emissions by 2050. The proposal passed the European Parliament in March 2021 with broad support, and it is intended to come into effect in January 2023. It will initially apply to energy-intensive industrial sectors including cement, steel, aluminium, chemicals and fertilisers, and will eventually be extended to all commodities and products (EU Parliament 2020). Japan and the US are also considering similar schemes in the coming decade (Bloomberg Tax 2021, Reuters 2021).

International policy developments such as these signify major shifts towards the decarbonisation of the global economy, which will have repercussions for Australia's export markets and globally integrated supply chains. In this context, the Australian Industry ETI is finding that companies in Australia and around the world are increasingly recognising the scale and urgency of the challenge to decarbonise. At the same time, companies are grappling with the complex issues this raises: the need for significant investment, leadership and a transformation of the energy system, and substantial short-term challenges to navigate in the decarbonisation of existing operations and associated infrastructure.

These changes present risks for Australian exports in energy intensive supply chains. In a context of global decarbonisation modelling, scenarios that limit global warming to 1.5 degrees Celsius generally see demand for gas peaking and declining before 2050 (IPCC 2018, ETC 2020). Similar risks are present in iron ore supply chains, where by 2050 China's demand for Australian iron ore would shrink at least 50% under a China zero-carbon scenario (ETC and RMI 2019).

ClimateWorks' analysis on the climate change targets of 22 of Australia's biggest emitters within the resources sector found all 22 companies are taking steps to decarbonise their operations, with half committed to reducing their operational emissions in line with net zero emissions by 2050. However, collective actions to address emissions through the supply chain, such as through scope 3 emissions, fall well short of a net zero by 2050 goal (ClimateWorks Australia 2020).

In Australian Industry ETI consultations, industry partners discussed a need for Australian industry leadership in a context of technological development, shifts in societal expectations, international commitments and global policy shifts. From these consultations, it is clear that action is needed now, and effort must be applied to address the longer-term opportunities and challenges. Efforts will need to be coordinated across industrial companies, governments, finance and investment to accelerate action towards net zero supply chains by 2050.

Workshops and conversations with the initiative's 14 industry partners have shown that these companies have increased their focus and activity on net zero supply chains over the past 12–18 months. There has been a shift from a compliance and reporting approach to target setting, a culture and strategy shift, exploratory projects and initiatives, funding announcements, net zero policy commitments and appointments of senior executives focussed on this issue. In a short time, there has been a step change in industry attitudes to the changes needed and the benefits of collaboration to find solutions. This is discussed further in Part 6 of this report.

However, without effective, timely efforts, there is a risk that Australia will not keep pace with the global transition to net zero emissions. The Australian Industry ETI's work to date indicates that Australia can continue to be a globally competitive export economy based on energy and commodities if it capitalises on the increasing global demand for low-carbon technologies and energy exports (such as green hydrogen and steel), and rapidly deploys existing technology solutions. This is discussed in further detail in Part 2 of this report.

2. Further action is needed in Australia

Australia can continue to be an energy and commodity export powerhouse, provided there is timely action that positions Australian industry for competitiveness in a decarbonised global economy.

The five supply chains included in the Australian Industry ETI make a critical contribution to Australia's economy. Collectively, these supply chains contribute 12.3% to Australia's GDP, generate exports worth over $160 billion per annum and employ 2.9% of Australia's workforce. Their economic contribution is particularly evident in regional areas with a strong focus on these supply chains (or components of them). For example:

- in the Pilbara, Western Australia – iron ore mining represents a 45.6% share of direct employment in the region, and
- in Gladstone, Queensland – alumina, aluminium, LNG and chemicals represent a 11.3% share of direct employment.

As discussed in Part 1, the global trading context for these supply chains is shifting. Major trading partners and competitors such as China, Japan, South Korea and the US's recent net zero commitments, and increasing momentum towards carbon border adjustment mechanisms, create an enormous pull for industry action. These countries are the destination of $246 billion of our $382 billion exports of goods, and are particularly significant for the Australian Industry ETI supply chains.

Figure 1 illustrates the movement of key industrial supply chains exports, highlighting countries with net zero by 2050 commitments and/or those considering carbon border adjustments.

In global analysis of the transition to net zero emissions, studies show that energy and materials will be needed at a comparable scale to those today, but the types of energy and materials will change, with electricity (directly

FIGURE 01: Global policy context and Australian exports

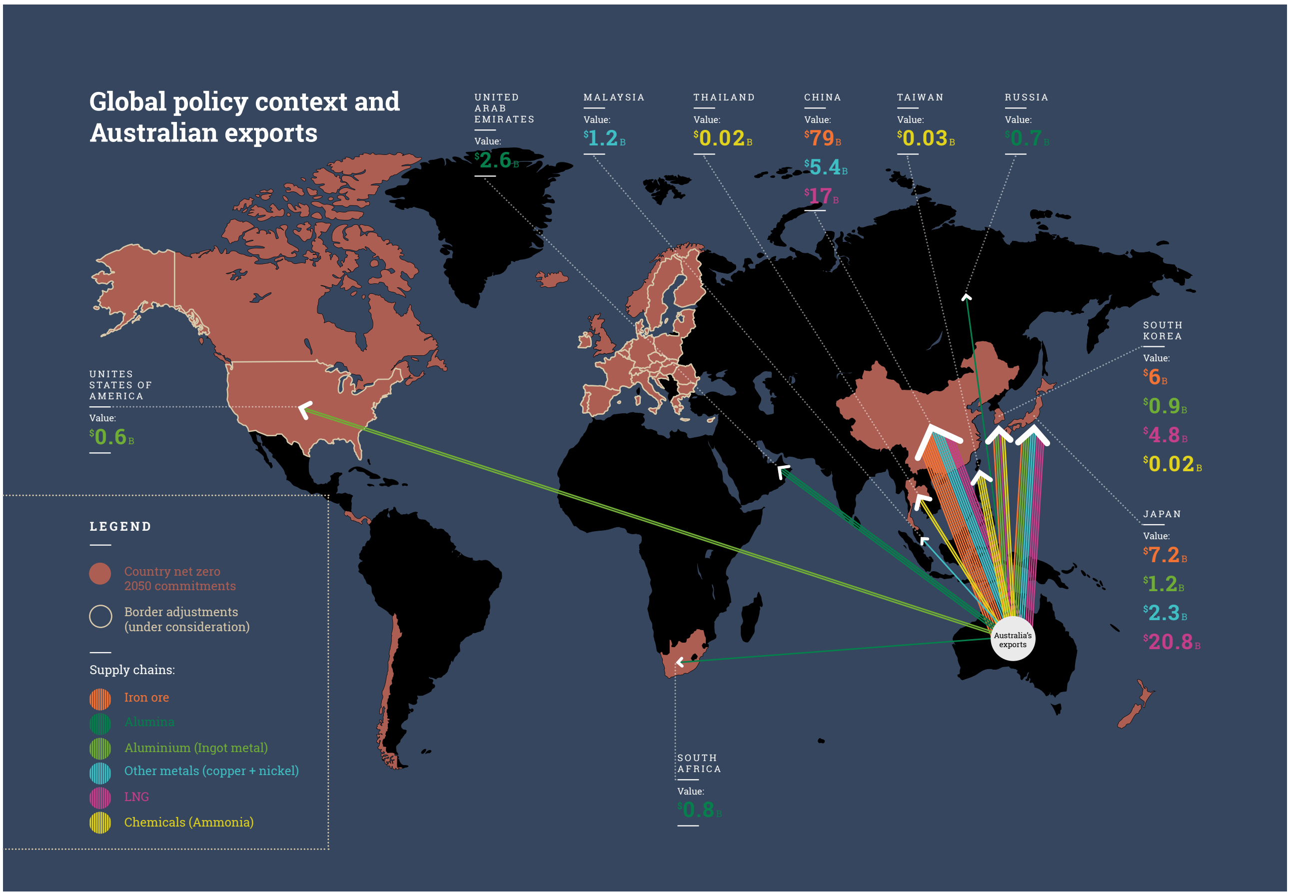


Image source: ClimateWorks Australia; data source: DISER 2020 or through hydrogen and ammonia) becoming the dominant energy vector (ETC 2020). Australia's natural assets in mineral resources, wind, solar, land and strong industry capability, put it in a good position to make the most of the global net zero opportunity, provided decarbonisation occurs in a timely and effective way.

Australia is well placed relative to other countries for large scale deployment of renewable energy, as it has huge endowments of renewable energy resources.

Analysis by Bloomberg NEF suggests that China, Japan and South Korea all have insufficient solar and wind resources to supply 50% of electricity and 100% of hydrogen from renewable energy (BNEF 2020). With solar and wind now the lowest cost form of new electricity generation, global competitiveness for the production of electricity will shift towards countries with the greatest wind and solar resources, as it once did for countries with abundant coal, oil and gas. Fortunately, Australia has some of the most enviable resources in the world: the energy falling on a solar farm covering 50 square kilometres would be sufficient to meet all of Australia's electricity needs due to the high irradiation of solar energy in Australia (Geoscience Australia 2020). Australia benefits from both abundant solar radiation and strong onshore winds. Four million square kilometres were recently assessed as having both these resources in coexistence (Grattan 2020).

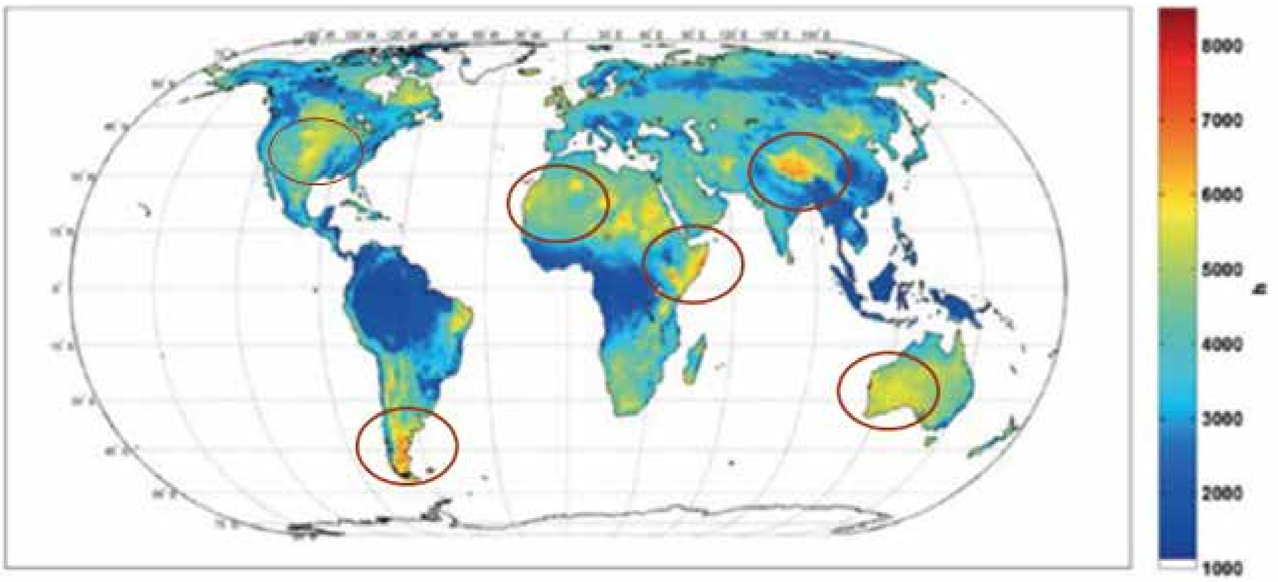
This creates the potential to combine wind and solar PV generation in relative proximity – a key advantage, as it partially addresses issues of natural variation in generation profiles of individual renewable resources. Regions with these resources derive benefits from having these sources of energy available at different times of the day, improving the reliability of energy delivered and reducing (but not eliminating) the need for energy storage at significant additional costs to provide system stability.

Figure 2 shows the combined solar and wind resources globally, illustrating that parts of Australia are among only a few regions globally that stand out as renewables 'hot spots'. In these regions, renewable energy becomes even more cost effective, as plants are able to generate nearer to their capacity limits, therefore yielding more units of energy per unit of capacity – the main cost of deployment.

However, these advantages will only be valuable for Australian industry if developed in an effective and timely way. There are a number of other regions such as central China, southern Chile, northern Africa and central United States that may have similar opportunities to develop advantages in the deployment of low-cost renewable energy.

Globally, momentum to address emissions is increasing, with an accelerating number of commitments to demonstrate and deploy both mature and emerging technologies, in addition to research and development. Government action through regulatory and policy instruments is mobilising huge amounts of investment in the transition to net zero. For example, the EU's Green Deal includes investment of over €1 trillion by 2030, and South Korea's Green New Deal includes investment of US$61.9 billion by 2025. New projects are being announced at a rapid pace, with the pipeline of announced GW-scale green hydrogen projects growing

FIGURE 02: Combined solar and wind resources showing how availability of wind and solar differ significantly by region



Source: IEA (2017) Renewable Energy for industry (Adapted and based on Fasihi, Bogdanov and Breyer (2016). Techno-Economic Assessment of Power-to-Liquids (P+L) Fuel Production and Global Trading Based on Hybrid PV-Wind Power Plants) globally from 50GW to 137.8GW in just four months from December 2020 (Recharge 2020). Momentum is building across the industrial sector, from the HYBRIT project in Sweden piloting fossil free steel, to ELYSIS in Canada which has been built to trial zero emissions smelting of aluminium at a commercial scale.

Throughout the Australian Industry ETI's consultations, the initiative has perceived a real hunger from stakeholders for home-grown collaborative pilots and demonstration projects (similar to those overseas) for learning and showing what is possible, while also learning from international projects and developments. To maintain a leadership role in the energy and metals industries, Australia will need to keep pace with our international peers.

Navigating a net zero transition by 2050, within the Australian industry sector and national context, presents challenges for companies.

A few years ago, commitments to achieve net zero emissions in the industrial sector were only beginning to emerge. This mindset has now shifted and industry is recognising that significant changes will be required to reach net zero by 2050. Industry and business partners of the Australian Industry ETI have seen this shift occur in their own companies, and this is discussed further in Part 6.

While this shift has been developing in the hard-to-abate industries, infrastructure investment into these sectors has continued, resulting in significant capital investment into existing operations. In the year 2020 alone, over 35 billion of CAPEX was invested by the mining sector in Australia (ABS 2021). The value of these investments and the ability to repurpose or retrofit infrastructure should be factored into planning for industrial decarbonisation, reducing the risk of stranded assets on pathways to net zero emissions supply chains. These steps should not be underestimated. While commitment from industry to the long-term transition has been a step forward, there will be significant short-term challenges to navigate in the decarbonisation of existing operations and associated infrastructure.

Where globally we are seeing huge investments in the transition to net zero, companies in Australia are still grappling with when and how to move forward. The simultaneous, cross-sectoral shifts required for the implementation of certain technologies is a complex challenge for industry partners who have acknowledged the difficulties of working in isolation. To achieve net zero emissions in heavy industry supply chains in Australia, decarbonisation needs to occur across the energy system, individual company operations and companies' customers and suppliers. Effective decarbonisation strategies therefore need to consider coordination and alignment between these different levels.

Without accelerating simultaneous, cross-sectoral shifts at scale, Australia is at risk of falling behind despite our significant natural assets in minerals and renewable energy resources, and strengths in industrial production. Planning for these shifts should also acknowledge the Australian national context, with local elements such as high labour costs and an uncertain policy environment factoring into investor decision making. For Australia to keep up and capture more value in the mineral and resources sectors as the world decarbonises, industry partners have identified a vital need to leverage mutual interests and synergies that exist within and across supply chains, between different stakeholders (including industry, government, research), as well as communities in regional areas.

Australian industry is beginning to work through this complexity to find pathways and actions towards net zero emissions, through platforms such as the Australian Industry ETI. Industry and business partners of this initiative represent a critical mass of the Australian economy, and those listed on the ASX100 have a combined total market capitalisation of over $400 billion, representing approximately 20% of the value of the index (Market Index 2021), and have over one hundred thousand employees in Australia. Therefore, this group collectively represents significant resources and capabilities with which to navigate these challenges.

The transitions required in heavy industry for Australia to remain globally competitive are complex by nature, requiring significant investment, leadership, coordination, alignment and transformation of the energy system. The Australian Industry ETI recognises that the ongoing challenge of industrial decarbonisation will need to be discussed alongside the transformational changes, investment and leadership required to achieved it, and is excited to be taking the first steps in this journey by identifying the technologies that will shape industries acceleration to net zero emissions by 2050.

3. Existing and emerging solutions can address industrial emissions

The Australian Industry ETI's analysis indicates that existing and emerging solutions can address almost all emissions in Australian heavy industry supply chains by 2050.

Given the size and diversity of emissions sources in the supply chains investigated by the Australian Industry ETI, a range of decarbonisation strategies will be necessary to achieve net zero emissions.

Across all five supply chains, the net zero emissions transition can be conceptualised into four pillars of industrial decarbonisation (Figure 3).[1] Broadly, they can be summarised as follows:

Pillar 1 Material, energy and service efficiency
Reducing the overall burden of energy and emissions to be addressed through materials, energy and process efficiencies, along with recycling.

Pillar 2 Zero emissions energy and feedstock supply
Expanding production and supply of zero emissions energy and feedstocks, including renewable electricity.

Pillar 3 Electrification and other fuel switching
Switching fossil fuel-based processes to electricity or zero emissions alternatives.

Pillar 4a Non-energy emissions abatement
Eliminating non-energy emissions from industrial processes, leakages and operational venting and flaring.

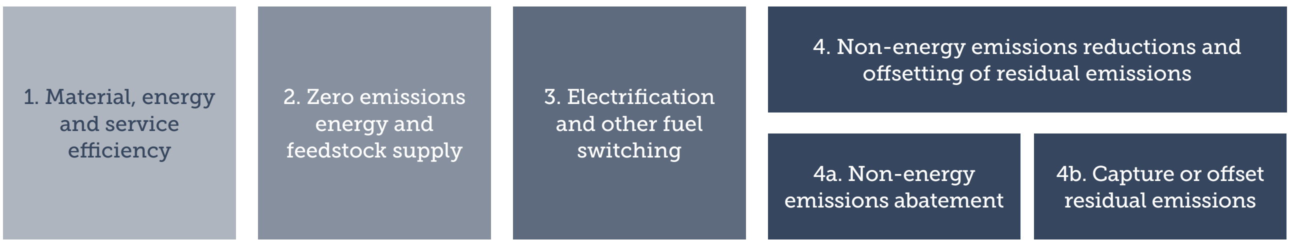
Pillar 4b Capture or offset of residual emissions
Deploying CCUS, negative emissions technologies or other mechanisms to reduce or offset residual supply chain emissions.

Although not strictly designed as such, the pillars can be thought of as roughly sequential, increasing in difficulty (that is declining in technological or commercial maturity) from Pillar 1 through to Pillar 4. For example, near-term material and energy efficiency improvements (Pillar 1) can often be achieved through uptake of best available technologies without relying on considerable breakthroughs, in many cases delivering economic value through short payback periods. Similarly, the technologies already exist to produce zero-emissions energy and feedstocks (Pillar 2), although there are other commercial and scale challenges to overcome. The technological availability and commercial viability of technologies in Pillars 3 and 4a can vary widely depending on supply chain, with Pillar 4b providing a 'balancing' function to achieve net zero in the event that other pillars were unable to eliminate emissions.

Within each of these avenues to emissions reductions, there are a range of technological options available to decarbonise industry. Each option is different in terms of: the scale of emissions that it is able to abate; its technological maturity; and cost competitiveness compared to incumbent processes and other abatement options.

Table 1 provides an overview of the potential for different technological solutions to drive emissions reductions across the five focus supply chains, categorised by the four decarbonisation pillars. The Australian Industry ETI's research and analysis suggests that these existing and emerging technologies can eliminate more than 85% of emissions in each of the focus supply chains.

Figure 03: Key pillars of a net zero emissions transition



1 This is a variation on the 'four pillars approach' used by ClimateWorks Australia (2019), to allow more detailed exploration of key challenges facing the Australian Industry ETI supply chains. The main changes include expanding Pillar 2 to include the supply of other zero emissions fuels and feed stocks alongside decarbonised electricity, and separating Pillar 4 into two parts to distinguish between non-energy emissions abatement and the capture or offset of emissions generated.

This table provides a general summary, with detailed analysis and discussion of specific technologies available in the Australian Industry ETI Phase 1 Technical Report, Section 3 – Supply chain detail (Butler et al. 2021).

The initiative's research and analysis identified potential technologies that could eliminate the vast majority of emissions in each of the focus supply chains.

TABLE 01: Potential of technological solutions to emissions reductions across the five focus supply chains

		Iron and steel	Aluminium	Other metals	Chemicals	LNG
Pillar 1: Material, energy and service efficiency	Material efficiency	There are multiple measures to optimise mine sites and plants which, alongside uptake of best available technologies can drive significant reductions in material and energy use. Increased recycling is another major opportunity, particularly for metals supply chains, with impacts throughout multiple processes. Downstream efficiencies or demand reductions also greatly impact supply chain energy use and emissions. For example, downstream energy efficiency and electrification could reduce and potentially replace gas use in certain sectors.				
	Energy efficiency					
Pillar 2: Zero emissions energy and feedstocks supply **Pillar 3: Electrification and other fuel switching**	Zero emissions electricity	Iron ore haulage Decarbonise existing electricity use EAF run on scrap or DRI Green hydrogen production* Ore electrolysis*	Decarbonise existing electricity use (smelting) Process heat for alumina refining*	Decarbonise existing electricity use (comminution) Additional electrification opportunities	Green hydrogen production Electrified process heat	Electrified liquefaction
	Other zero emissions fuels	Iron ore haulage	Process heat for alumina refining*	Process heat in metals refining*		Blue hydrogen production
Pillar 4a: Non-energy emissions abatement	Process improvements		Inert anode for smelting*		Nitrous oxide abatement	Reduction in venting, flaring and leaks
	Zero emissions feedstocks	Green hydrogen use in DRI-EAF process*			Green hydrogen use in ammonia production	Blue hydrogen production
Pillar 4b: Capture or offset residual emissions	CCS of process emissions	BF-BOF with CCS*			CCS of SMR emissions	CCS of reservoir gas
	Negative emissions technologies	Mineral carbonation (waste rock)*	Mineral carbonation (mine tailings)*	Mineral carbonation (waste rock)*	CO_2 feedstock from NETs*	

* These technologies are currently classified as having a technology readiness level (TRL) of 1-6 and require further research, development and demonstration (ARENA 2019).
BF: blast furnace; BOF: basic oxygen furnace; CSS: carbon capture and storage; DRI: direct reduced iron; EAF: electric arc furnace; LNG: liquified natural gas; NETs: negative emission technologies; SMR; steam methane reforming.

(light grey)	Immaterial or uncertain role	(beige)	Potential role in transition to zero or near-zero emissions options	(grey-green)	Important role in near term abatement but insufficient for net zero emissions	(dark green)	Long term, zero or near-zero emissions potential

Encouragingly, the Australian Industry ETI analysis has found that most of these technologies are mature and available for deployment now, while other major solutions such as green hydrogen for DRI-EAF steel production have been demonstrated and are expected to be available for commercial production by 2035, having already been demonstrated at a pilot scale.

In the five focus supply chains, deployment of mature and demonstrated technologies can achieve more than 85% emissions reductions, as shown in Table 2. This means that the technical capability exists to enable deep decarbonisation, and that barriers to uptake are more related to economic, policy, capital or other system-wide factors.

Accelerated demonstration and deployment of these technological solutions can help build the necessary system conditions and drive costs down in the near term through learning rates and economies of scale. Continued deployment of opportunities such as material and energy efficiency can also improve competitiveness in the short term, lowering energy and other input costs. The proliferation of digitalisation technology has the potential to transform global energy supply. This is due to the impacts on both demand and supply and global investment in digital technology, infrastructure and software increasing by over 20% per year since 2014 (IEA 2017a).

For those emerging technologies that could address residual emissions in the supply chains, there is a greater short term need for research and development to provide proof of concept or demonstration at scale.

An overview of zero emissions opportunities for each supply chain is provided in Table 2, including maturity of the technologies and residual emissions areas (Technical Report, Section 2.1 – Summary findings).

3.1 Technical challenges to navigate in industrial decarbonisation

Technological solutions are not deployable in isolation. To deploy solutions at the scale required, it will be necessary to navigate multiple critical dimensions, complexities and uncertainties.

Australian Industry ETI analysis and partner workshops have helped to create a shared understanding that there are multiple critical dimensions, complexities and uncertainties that need to be understood and addressed to enable the transition to net zero emissions.

Industrial supply chains are considered 'hard-to-abate' because addressing emissions within those supply chains poses more technological and commercial challenges than other sectors of the economy. A range of the solutions under the four pillars are mature and well established (for example, energy efficiency measures, solar and wind power, as well as batteries and electrification to a degree). However, in industrial supply chains, challenges exist for solutions that are at the early stages of commercialisation, as well as for the challenge of integrating emerging and established technologies into large scale industrial systems.

The Australian Industry ETI has identified that many of the challenges of integrating these solutions can be characterised as 'chicken and egg' problems, where the deployment of a solution depends on developing demand, supply, distribution and networks before they can be implemented at scale, but for which scale can only be reached through effective initial deployment. The development of an integrated hydrogen system is a prime example of this 'chicken and egg' problem where a market's development requires a source of supply, demand and the infrastructure and networks required to connect the two before commercial projects can be realised.

These challenges often mean that the transformational solutions needed to get to net zero emissions are more than a single organisation can achieve alone, or even in a joint venture. Solutions must address the transition across and between supply chains, requiring collaboration across industry, government, finance and the energy sector. These transitions are complex by nature but solutions are emerging to navigate this transition both globally and in Australia.

The next parts of this report (Part 4 and Part 5) break down some of this complexity. Part 4 looks at some key areas for decarbonising industry, including modelling on cost competitiveness of technologies over time. Part 5 builds on this by looking at the essential role of industry to support decarbonisation, and the potential to accelerate cost reductions through a precinct or hub approach.

TABLE 02: Major abatement opportunities, technological and commercial readiness, and residual emissions in the Australian Industry ETI supply chains

Supply chain	Major abatement opportunities (blue shading indicates commercial readiness)[2]	Abatement potential from 'Demonstration' and 'Deployment' technologies	Residual emissions areas (TRL<7)
Iron and steel	Uptake of best available technologies and process optimisation Renewable electricity for currently electrified processes Green hydrogen for DRI-EAF steel production Battery-electric or fuel-cell powered trucks Breakthrough technologies for ore electrolysis CCS for blast furnace steel production	~95%	Emissions from the use of explosives in iron ore mining
Aluminium	Uptake of best available technologies and process optimisation Electrification or other fuel switching for low temp heat in alumina refining Other fuel switching (biomass or hydrogen) for high-heat in alumina refining Renewable electricity for currently electrified processes (particularly smelting) Electrification or concentrated solar thermal for high temp heat in alumina refining Carbon anode alternatives	~92%	Carbon anode use, pending commercial viability of alternative technologies
Other metals	Uptake of best available technologies and process optimisation Renewable electricity for currently electrified processes Additional electrification of mine site operations Electrification or other fuel switching (biomass or hydrogen) for high-heat applications in metals processing	~100%	None or immaterial
Chemicals	Uptake of best available technologies and process optimisation Renewable electrolysis for hydrogen production Electrification of process heat CCS for SMR hydrogen production Nitrous oxide abatement CO_2 feedstock from negative emissions technologies (to offset eventual emissions released from urea-based fertilisers)	~85%	Residual nitrous oxide emissions Emissions from application of urea-based fertilisers, in the absence of using CO_2 feedstock from negative emissions technologies
LNG	CCS for reservoir gas Leak detection and removal Operational improvements to eliminate venting and flaring Renewable-powered electric liquefaction	>90%	Operational emissions unable to be captured and stored Scope 3 emissions from use of exported LNG (not included within scope but a significant issue for the supply chain)

DRI: direct reduced iron; EAF: electric arc furnace; CSS: carbon capture and storage; LNG: liquified natural gas; SMR; steam methane reforming; TRL: technology readiness level.

Research and development TRL 1-6, pre-commercial stage	**Demonstration** TRL 7-9, pilot or commercial scale-up stage	**Deployment** TRL 9, supported or competitive commercial

2 Commercial readiness categories are based on Figure 2 of ARENA's 'Commercial Readiness Index' (ARENA 2014)

4. Decarbonisation of the energy system empowers Australian industry

The initiative's research shows that certain Australian industries could access variable electricity costs of $20-30/MWh by 2050, and potentially far sooner, by matching production to available renewable supply and avoiding costs of energy storage. This would enable favourable regions to flexibly produce green hydrogen for below $1.50/kg.

The Australian Industry ETI has found that decarbonised electricity will make or break the transition to net zero emissions by 2050 for Australian Industry. Electricity is a large source of current industrial energy use (and emissions) and decarbonisation of electricity also offers significant opportunities for 1) electrification of processes currently based on fossil fuels; and 2) producing zero emissions green hydrogen.

As shown in Table 3, across the five supply chains within the focus of the Australian Industry ETI, decarbonisation of energy will be the central element, potentially decarbonising 65–100% of the emissions of each of these supply chains.

TABLE 03: The role of zero emissions electricity or hydrogen in supply chain decarbonisation

Supply chain	Plausible role of zero emissions energy and feedstocks in net zero transition		Estimated emissions reduction potential by 2050 from energy solutions only
	Electricity	Hydrogen	
Iron and steel	Trolley assist Battery-electric trucks Electric arc furnace Electrolytic steel production	Hydrogen fuel-cell trucks Direct reduced iron production Hydrogen injection in Blast Furnace	~95%
Aluminium	Trolley assist Battery-electric trucks Process heat in alumina refining	Hydrogen fuel-cell trucks Process heat in alumina refining	~92%
Other metals	Trolley assist Battery-electric trucks Renewable-powered mine operations Process heat	Hydrogen fuel-cell trucks	~100%
Chemicals	Process heat	Hydrogen produced via renewable electrolysis[3]	~65%
LNG	Electrified liquefaction	Uncertain role for hydrogen in reducing LNG production emissions[4]	~65%

Source: Australian Industry ETI Phase 1 Technical Report, Section 2.4 – Pillars of decarbonisation, Pillar 3 (Butler et al. 2021)

3 Switch from gas-based steam methane reforming in the production of hydrogen feedstock for ammonia.

4 This refers specifically to the use of hydrogen in the LNG supply chain. The potential near-term role for the use of gas with CCS (>90% capture to produce low emissions hydrogen is covered elsewhere in this report.

4.1 Decarbonising electricity

The availability of cost competitive decarbonised energy will be critical to ensure the ongoing competitiveness of industry in a decarbonised global economy, particularly in trade-exposed industries.

Renewable energy is already the cheapest form of new electricity generation on a levelised cost basis in Australia relative to all new sources of electricity generation, as set out in Figure 4 (Technical Report, Section 4.1 – Electricity generation). These costs can be expected to continue to decrease, although greater penetrations of electricity will require mechanisms to balance the load and variable supply of these energy generation technologies.

Firmed renewable energy generation is expected to become the lowest cost-form of new electricity generation, enabling net zero production to become cost competitive with current production processes.

In the past decade there have been massive renewable energy technology cost reductions, such as solar (–82%) and wind (–40%) (IRENA 2020). This has been alongside an 89% cost reduction in battery storage (BloombergNEF 2020a). By 2030, the cost of solar and wind is expected to be lower than all other forms of electricity generation, even considering the costs of storage, as shown in Figure 4.

This relative cost advantage is expected without considering a cost of carbon or a risk premium on investment in fossil fuel generation.

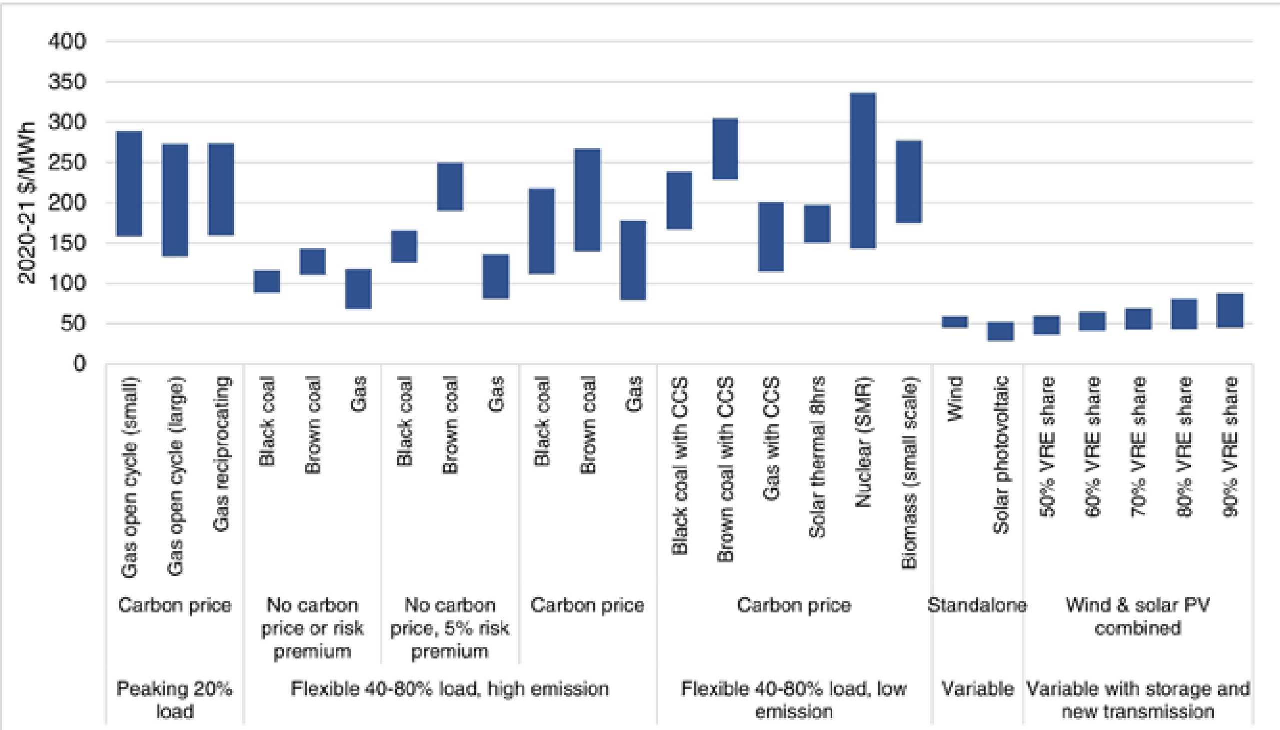
4.2 Green hydrogen production

Hydrogen costs are expected to continue to fall, driven by cheap renewable electricity.

Rapid reduction in the cost of technologies is not isolated to renewable electricity generation from solar PV and wind. Low cost renewable electricity, alongside reductions in electrolyser costs, is expected to facilitate a similar outlook for the costs of green hydrogen production.

As shown in Figure 5, electrolysis using variable renewable electricity is expected to be the lowest cost future hydrogen production route, which could lead to favourable regions producing green hydrogen for below \$1.50/kg by 2050 (Technical Report, Section 4.2 – Hydrogen). This is well under the \$2/kg stretch goal for

FIGURE 04: Calculated Levelised Cost of Energy by technology and category for 2030



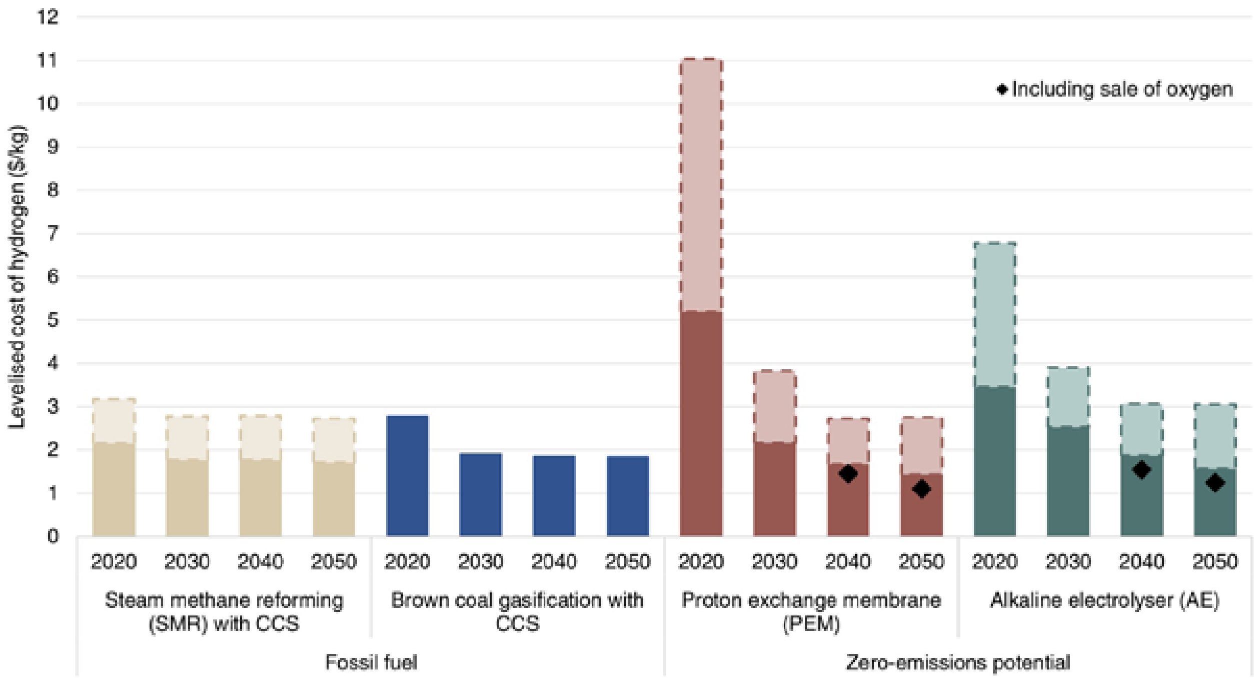
Source: CSIRO 2020

hydrogen production under the Technology Investment Roadmap (Australian Government 2020), which could be passed between 2035 and 2040. For SMR hydrogen with 90% capture of CO_2, this $2/kg is already within reach if produced with low cost gas, although this does not eliminate emissions entirely. Key drivers of the transition for green hydrogen are expected reductions in variable renewable electricity costs and lower electrolyser capital costs resulting from global deployment at scale.

Further development and integration of the hydrogen supply chain could unlock even lower costs. For example, selling oxygen (which is an important input in steelmaking, metals refining, chemicals production and numerous other industries) could drive overall costs of green hydrogen towards $1.10/kg (Technical Report, Section 4.2 – Hydrogen).

The main driver of green hydrogen production costs in the near term will be capital costs of electrolysers, which will be driven by global developments. Over time, electricity price becomes the dominant factor. There is considerable uncertainty regarding the future outlook for these cost components, and other emerging research suggests that even lower green hydrogen production costs could be achieved in regions such as Australia, and potentially far sooner (ETC 2021). These more optimistic scenarios are based on economies of scale from global expansion of electrolyser capacity, as well as additional learning benefits for variable renewable energy needed for hydrogen development. While not reflected in the analysis presented above, this potential upside will be included in the pathways modelled throughout Phase 2 of the Australian Industry ETI.

FIGURE 05: Projected costs of hydrogen production routes, 2020-2050 (Source: CSIRO 2021)[5]



The dotted boxes display the range of costs for a particular production method. For SMR, the lower and upper bounds are based on a gas price of $3/GJ and $9/GJ respectively. For PEM and AE, the scenarios comprising a lower and upper bound vary over time. In 2050, the lowest production costs for PEM and AE are both based on capital costs of $206/kw, performance of 43 kWh/kgH2 and variable renewable electricity costs $19.9/MWh (representing the cost of solar PV without storage at the Leigh Creek, SA Renewable Energy Zone). Under these assumptions, PEM electrolysis reaches a low of $1.42/kg in 2050, while AE reaches $1.56/kg, with operating expenses, stack lifetimes and stack replacement costs driving the differences. Detailed assumptions and further results are available in Appendix B of the Technical Report. The black markers in 2040 and 2050 show the impact of selling oxygen as a byproduct of the electrolysis process, which is dependent on the presence of a local buyer.

5 Large drop in 2030 costs is due to the Hydrogen Energy Supply Chain (HESC) project coming online. Sudden changes at 2025 and 2028 are due to plants coming online, reducing capital costs due to learning rates. SMR with CCS is cheapest for now, assuming a stranded gas asset with a gas price of just over $3/GJ.

4.3 Decarbonising industrial processes

At an electricity price of \$35/MWh in 2050, hydrogen direct reduced iron would serve as the cheapest decarbonised steelmaking route, while CCS and bioenergy could assist the transition (Technical Report, Section 4.4 – The importance of regional energy and industry integration, Box 2).

The combination of low-cost renewables and hydrogen also facilitate green steel production using hydrogen for direct reduction (H2-DRI) of iron, as an alternative process to coking coal.

The H2-DRI process relies on electricity-intensive production of hydrogen for fuel and so will be sensitive to the costs of electricity. Reductions in the costs associated with renewable electricity generation and hydrogen production would lead to potential parity of production costs through this steelmaking route in the coming decades, compared to traditional Blast Furnace-Basic Oxygen Furnace (BF-BOF), as shown in Figure 6.

In the interim, development of DRI facilities using a transition fuel such as natural gas and biogas for direct reduction of steel (NG-DRI and BioNG-DRI) with Electric Arc Furnace (EAF) may provide a transitional option to move towards direct reduction technology. In the long term, these opportunities are limited by the likely finite supply of bioenergy feedstock and relative competitiveness of their technologies compared to the falling future costs of hydrogen DRI.

Declining costs of green hydrogen would see zero emissions ammonia become cheaper than conventional production by 2050.

Research and analysis for the Australian Industry ETI shows that the reduction in the cost of renewable energy and hydrogen can also lead to the potential for significant cost reductions in the production of green ammonia. Ammonia is one of the most commonly produced chemical outputs, essential for the production of fertilisers and explosives used in mining.

Green ammonia differs from traditional routes of manufacture as it uses green hydrogen as the main industrial input, rather than methane (a greenhouse gas that leads to the production of CO_2 through the process).

The analysis shows that the green hydrogen route would become the lowest cost source of production of ammonia by 2050, if electricity can be delivered with a cost of electricity below \$35/MWh (Figure 7 below, and Technical Report, Section 4.4 – The importance of regional energy and industry integration, Box 2). Other processes such as CCS or the use of biomass in production could hold the key to lower cost, decarbonised production in the near term.

FIGURE 06: Cost projection of steelmaking by different routes (\$/tonne steel) (RMI 2021)

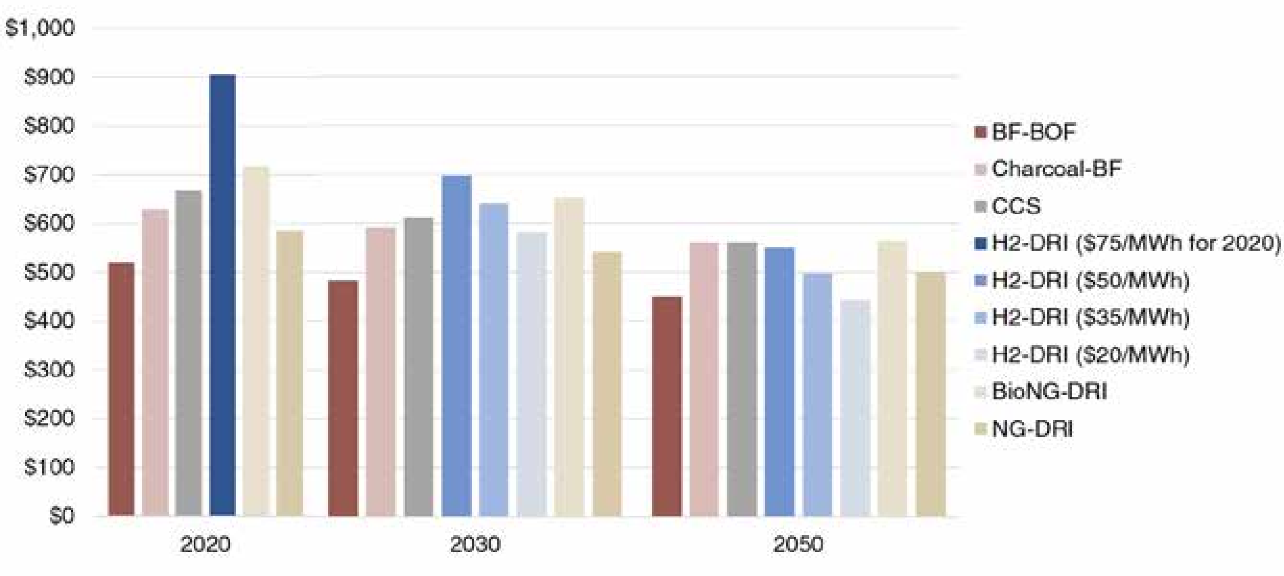
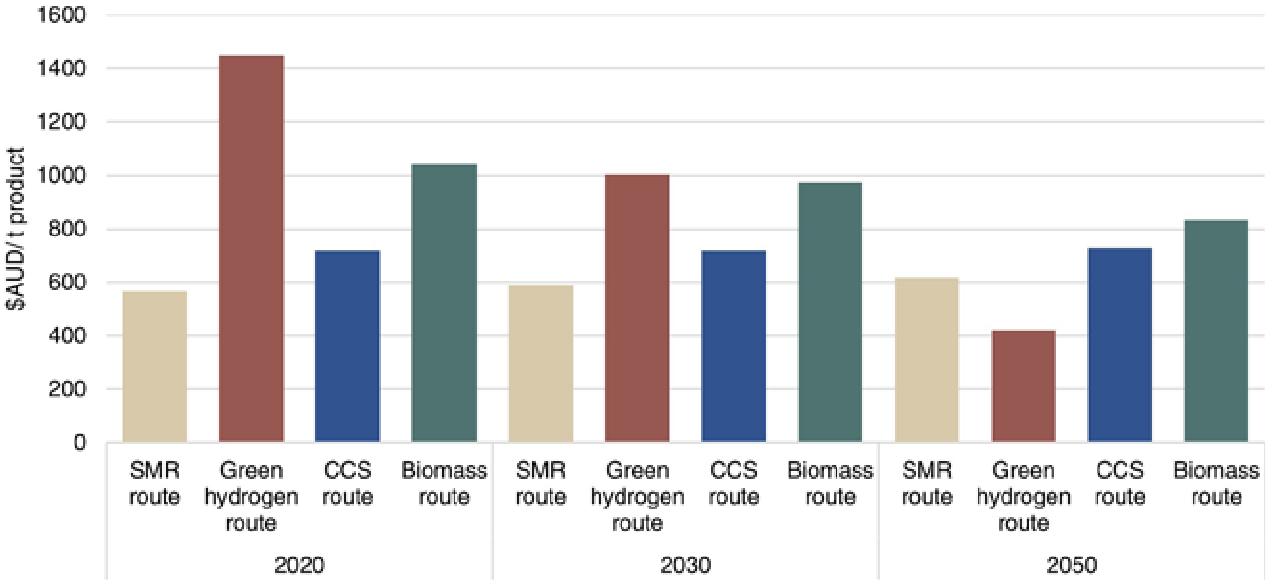


FIGURE 07: Cost of ammonia production using SMR, green hydrogen, CCS and biomass (RMI 2021)[6]



The range of possibilities for the decarbonisation of mining haulage are narrowing to two clear pathways.

Haulage is one of the most energy and emissions intensive processes in mining industries, based predominantly on the use of diesel. It is also challenging to decarbonise due to the size and capacity required for the vehicles, and the operational requirements of a mine site. Key options being investigated include battery-electric vehicles and hydrogen fuel cell vehicles.

The size and weight of batteries required is the main challenge for the battery-electric route, although improved technology costs and performance (eMining 2019) are leading to some mining companies considering battery-electric haulage central to their decarbonisation strategies. In addition, companies are investigating a range of options to power the vehicles and recharge batteries, including trolley assist infrastructure, and dynamic or fast charging while in use. There are additional site planning and infrastructure costs of charging systems, however these may be offset by improved vehicle efficiency, reduced fuel costs and maintenance.

Haulage using hydrogen power could be relatively cost effective against fossil fuel alternatives if delivered below $8/kg, indicated through analysis of relative emissions intensities and costs of haulage (Technical Report, Section 4.4 – The importance of regional energy and industry integration, Box 2). Given expectations that green hydrogen could be produced for far less than this in the future, the challenge becomes the shorter-term commercialisation of the technology, and development of the hydrogen supply chain. Widespread uptake of fuel cell vehicles in haulage could drive hydrogen cost reductions while eliminating emissions from this source. The analysis presents the cost of haulage for a given cost of *delivered* hydrogen fuel, rather than the costs of production. Reducing the costs of the transport and distribution of hydrogen will therefore reduce the overall costs of deploying this technology.

Aluminium smelting can be largely decarbonised through renewable electricity.

Almost all emissions from the Australian aluminium supply chain are from alumina refining (41%) and aluminium smelting (58%). Aluminium smelting is already an electrified process, so energy emissions are dependent on the emissions intensity of the electricity source. Aluminium production requires a relatively constant load of electricity as pot lines can solidify if left without a current for too long, rendering the plant inoperable in extreme cases. Given the energy-intensive nature of aluminium smelting and the need for reliable energy supply, aluminium smelters in Australia are currently entirely dependent on grid electricity. The need for firmed electricity supply also means that renewable energy from solar and wind would require firming through battery storage or large-scale demand response.

The historical competitiveness of Australian production in this sector was historically built on low-cost contracts with coal-based electricity providers. The transition to decarbonised grid electricity presents a long-term opportunity as a pathway for affordable and decarbonised grid energy emerges, although the sector faces considerable commercial challenges in the interim.

6 Using high natural gas price in east Australia
- Natural gas price: $9/GJ in 2020, $10/GJ in 2030, $11/GJ in 2050
- Electricity price: $75/MWh in 2020, $55/MWh in 2030, $35/MWh in 2050.

Current emissions in alumina refining relate to heat for the Bayer process which is currently based on the use of fossil fuels, particularly gas. As such, finding zero emissions alternatives for process heat is the primary challenge for alumina production. Research and development into electrification of some parts of the Bayer process is showing promise and is a focus of the sector, in addition to investigation into alternative heat sources such as solar thermal or hydrogen.

4.4 Bringing it all together

Integrating large scale renewable energy supply, hydrogen and industrial production could minimise the need for energy storage and infrastructure, reducing the system costs of energy.

Intermittent renewables such as solar and wind have become the lowest cost form of new generation and costs will continue to fall as these technologies improve further. However, the need for battery and other storage mechanisms that are required to provide reliability with high penetration of variable renewable energy means that energy costs would remain relatively higher in this scenario.

Under a business-as-usual scenario where there are no further incentives for renewables, solar and wind could be expected to provide around 90% of electricity generation in 2050 based on modelling by CSIRO (CSIRO 2020, Technical Report, Section 4.4 – The critical role of regional energy and industry integration).

When including the need for storage to ensure reliability of electricity supply, the costs of energy would be expected to range from $50 – $90/MWh under scenarios modelled (shown in Table 4 below). If efforts are made to decarbonise the electricity entirely, further storage would be needed, driving costs up to the high end of this range.

There is incredible promise in the use of demand response from hydrogen and other industrial production alongside vehicle-to-grid or bi-directional charging to substantially reduce the costs of energy by reducing the need for additional storage alongside renewable energy generation. Analysis for the Australian Industry ETI quantifies the potential of these measures to reduce electricity costs to $20 – $30/MWh by 2050, substantially below current costs of energy and potentially driving competitiveness of industry where electricity and electricity derived fuels such as hydrogen are central to decarbonised production.

A net-zero emissions economy will require a vastly different and far larger electricity system compared to today. With electrification of industry alongside large scale production of hydrogen from electricity, that would need three to four times as much electricity generation than at present according to some analysis (ETC 2020). If Australia was to realise the opportunity of being a major exporter of hydrogen as outlined in the most optimistic scenarios of National Hydrogen Strategy, it would require a total electricity load five times greater than the current size of the National Electricity Market (Deloitte 2019).

Having considered key areas for decarbonisation in industry, Part 5 looks at the essential role of industry in taking up these technologies, and the potential to use industrial precinct synergies to further reduce costs of energy.

TABLE 04: Energy system scenario modelling

Electricity system scenarios	Renewables share (2050)	Flexibility of demand	Storage requirements	Cost outcome (2050)
(1) Likely BAU outcome	90%	Low	Proportionally moderate storage to balance supply and demand	Lower end of $50-$90/MWh
(2) Net zero emissions policy with electricity system leading	100%	Low	Proportionally larger storage required to balance supply and demand	Mid to higher end of $50-$90/MWh
(3) Scenario 1 with electric vehicles supporting grid balancing	90%	Medium-high	Minimal additional stationary storage required	$30-$60/MWh
(4) National Hydrogen Strategy high hydrogen demand case[7]	100%	High	Proportionally lower storage of any source required	$20-$30/MWh for hydrogen industry $40-$60/MWh for other consumers

Source: Technical Report, Section 4.4 – The critical role of regional energy and industry integration

7 COAG Energy Council Hydrogen Working Group (2019)

5. Industry can shape a decarbonised energy system

Industry has an important role in decarbonising the energy system. Industry's early uptake and integration of renewable electricity, electrification and green hydrogen can help Australia achieve competitive costs for reliable decarbonised energy.

The transformation of the energy system to deliver low cost, decarbonised, reliable energy is central to decarbonising industry and supporting long term competitiveness of the sector. The manner and pace of this transformation is likely to make or break Australian industry's pathway to net zero production.

Industry has a key role to play in decarbonising the energy system. The Australian Industry ETI analysis and consultations suggest the need for deliberate, coordinated effort by all stakeholders across supply chains to accelerate the carbon transition, catalyse the associated technology and market developments and to fully realise the wide-ranging economic potential. Early industry deployment and integration of decarbonised energy can help to begin the cycle of cost reductions that come with deployment at scale. Additionally, integrating decarbonised energy systems with industrial demand through demand response and green hydrogen networks can firm electricity production. This integration can also reduce the need for energy storage and lower overall system costs of energy, which is vital for industry's long-term competitiveness.

In regards to the energy transition in industry, strategic industrial deployment and co-location of renewable energy technologies can rapidly bring down the cost of decarbonised electricity whilst creating jobs and regional growth, such as by speeding up the development of a world-leading green hydrogen industry in Australia.

Importantly, the Australian Industry ETI modelling and consultations indicate the need for coordinated effort beyond industrial companies. Companies working with government and investors can enable effective deployment of renewable energy technologies in a way individual companies could not.

5.1 Industrial regions or clusters

With energy costs critical to the ability of heavy industry to decarbonise while retaining competitiveness, any efforts to reduce costs will be valuable. Preliminary research as part of the Australian Industry ETI shows incredible promise in the longer term for the potential to manage grid reliability by co-locating industry alongside large-scale hydrogen production and renewable electricity generation to reduce networks and infrastructure costs. Enabling future vehicle-to-grid charging can also contribute to managing the reliability of electricity supply, reducing the need for investment in large scale storage.

Green hydrogen production requires a lot of electricity and can ramp up and down production very easily in response to the availability of renewable energy. The Australian Industry ETI sees the potential for hydrogen production to be used to balance load with much lower storage requirements, driving costs of electricity produced down towards the variable energy costs, in the range of $20 – 30/MWh in 2050 (Technical Report, Section 4.4 – The critical role of regional energy and industry integration).

A precinct or hub approach to supplying energy for manufacturing could therefore be a crucial element allowing for the competitive decarbonisation of industry.

Existing industrial regions show exceptional promise for low cost, decarbonised energy – and potential for further regional development.

Fortunately, many existing industrial regions are potential candidates for the development of precincts or hubs for net zero emissions industry. These candidates have very low variable costs of energy generated from renewables as they are located near promising wind and solar resources. Many of these regions can also capitalise on other important resources such as access to port capacity, existing infrastructure such as gas networks, suitably zoned land and a skilled workforce.

Regions such as the Pilbara in North-West Western Australia, home to the production of iron ore, LNG and fertilisers, show great promise due to the low costs of variable energy production. This region is already seeing plans for major renewable energy developments, with the Asian Renewable Energy Hub (AREH) planning up to 26GW of solar and wind generation powering local industry as well as hydrogen production for local use and export (AREH 2020).

Other regions with existing industrial activities alongside the potential for large scale, low cost renewable energy can be found across Australia, including Kwinana in Western Australia, Whyalla in South Australia, Portland in Victoria, Port Kembla and Hunter Valley in New South Wales and Gladstone in Queensland. State and territory governments are increasingly looking at how they can support this transition and attract new industries to these regions, particularly as they focus on COVID-19 economic recovery. This includes through their renewable energy policy and incentives, initiatives to attract new industries (such as renewable hydrogen strategies) and place-based support in planning, land-assembly and promotion.

Much more work is needed to demonstrate the feasibility of these regions for the development of industrial precincts and hubs driven by renewable energy and hydrogen. This effort will need to focus on development of shared infrastructure for energy generation, transmission and distribution including new hydrogen networks as well as the less tangible social infrastructure of the regions. These projects will also need to ensure community and stakeholder support, particularly where native title or heritage values exist.

These changes and the resulting benefits to the energy system can only come if deployment begins at scale and incentives are designed to drive the benefits of demand response for local manufacturing precincts. This will need policy, regulation, coordination with government and investment.

The analysis of key industrial regions will be a focus of Phase 2 of the Australian Industry ETI.

Large scale deployment could drive the cost competitiveness of clean energy technologies much sooner than 2050.

While there are challenges in enabling the transition, this analysis has a number of levels of conservatism, suggesting future developments could lead to achieving the transition much sooner than 2050.

With the right incentives, technology often outperforms the best expectations of even the most informed analysts, as long as deployment is driven early to achieve positive feedback loops of continued learning effects. The International Energy Agency's (IEA) forecasts on the deployment of solar PV are a great example. In 2010, the IEA forecast that cumulative solar installations would be around 550 GW in 2035 (IEA 2010); that capacity was actually reached last year, 15 years earlier than expected (IRENA 2020).

For every doubling of total deployed renewable energy capacity, rates of improvement have been observed in renewable energy technologies. The analysis on future energy costs presented in this study have been based on these rates of improvement, however if deployment is achieved at a faster rate, lower costs of energy can be achieved even sooner. The learning rates account for incremental improvements only, rather than anticipating future breakthroughs or disruptive technology. Other breakthrough technologies are possible – for example, in China, the technologies such as alkali for hydrogen shows promise.

Record low costs of delivered renewable electricity are being broken with regularity. Recently, Portugal held a solar power auction in which power plant developers submitted different bids for the price they could offer

TABLE 05: Estimated variable renewable energy costs for Renewable Energy Zones in proximity to industrial regions, 2020 and 2050

State	Industrial region	Nearest Renewable Energy Zone	Variable renewable energy cost*: lowest cost / combined wind and solar cost	
			2020 ($/MWh)	2050 ($/MWh)
WA	Pilbara	WA North	$47 / $55	$21 / $35
WA	Kwinana	WA South	$51 / $56	$23 / $37
SA	Whyalla	Northern SA	$50 / $59	$22 / $40
VIC	Portland	South West Victoria	$59 / $65	$31 / $40
NSW	Port Kembla	Tumut	$63 / $64	$28 / $42
NSW	Hunter Valley	New England	$57 / $63	$26 / $42
QLD	Gladstone	Fitzroy/Wide Bay	$49 / $58	$22 / $39

*Based on GenCost data and the solar PV and wind capacity factor published by AEMO for the nearest Renewable Energy Zone. 'Lowest cost' represents solar PV in all regions except South West Victoria 2020 (where wind is currently lower cost). 'Combined wind and solar cost' represents the average cost of wind and solar PV at combined capacity factors in each region, assuming a simplified 50:50 split. In practice, the cost-optimised share of wind and solar generation would be determined by the relative quality of each resource in different regions.

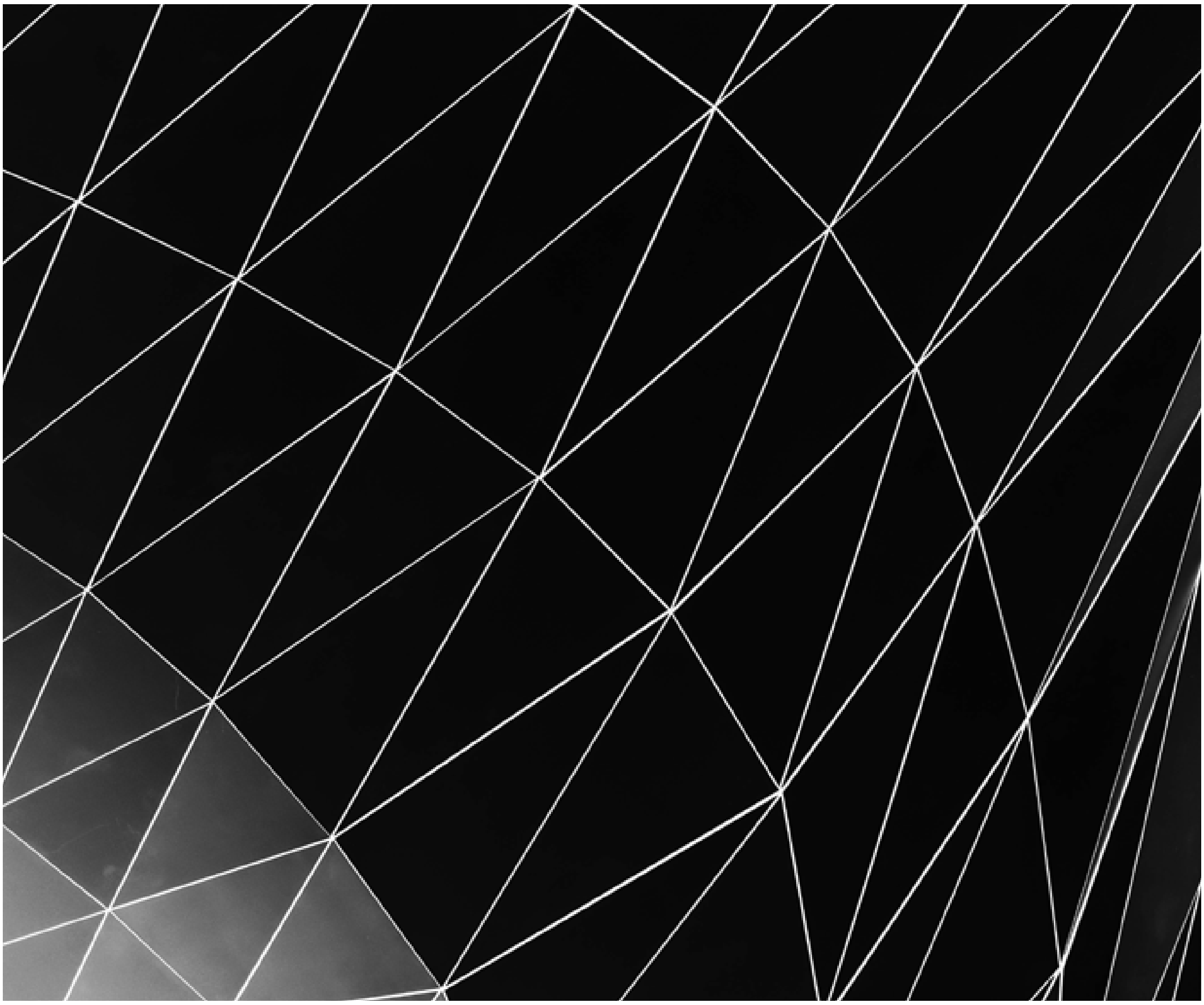
Source: Technical Report, Section 4.4 – The critical role of regional energy and industry integration (Butler et al. 2021).

electricity under a new contract. One of the bids broke the world record for the lowest solar power price at US$13 per MWh (Cleantechnica 2020). This is already below the variable costs of some forecasts of renewable energy generation assumed in this study by 2050, highlighting the conservatism in forecasts and also the future potential for further cost reductions suggesting there is a long way to go before reaching the floor of the cost of renewable energy.

Industry consultation through Phase 1 of the Australian Industry ETI has uncovered a similar sense among industry that hydrogen technologies may be on a similar path to rapid deployment and corresponding cost reductions in the coming decade. This is because, like solar, green hydrogen production through processes such as polymer electrolyte membrane (PEM) hydrolysis is a modular technology that can be deployed through similar processes at small or large scale, with each new deployment providing an opportunity to learn and improve through the various stages of manufacturing, installation and operation.

There are clear synergies and positive feedback loops involving green hydrogen production, renewables and hydrogen use. Deployment of renewable energy leads to cheaper overall energy costs as innovation and cost reductions are achieved through deployment. This in turn reduces the costs of green hydrogen production. The decreasing costs of the deployment of hydrogen production then facilitates the deployment of green steel, green ammonia and green manufacturing hubs, offering opportunities to learn from their deployment and also reinforcing the need for further scale of renewable energy and hydrogen deployment. These processes necessitate more renewable energy supply and facilitates demand response which will lead to even greater reductions in the cost of overall energy supply and cheaper hydrogen. This positive feedback will continue as long as Australia remains on the forefront of these industries and is able to capitalise on increasing global demand.

While today some green processes appear to be competitive only in the long term, effective large-scale deployment in the short term could drive the improvements to reach cost parity much sooner than would be expected, as we have seen from the experience of solar and wind.



6. Australian Industry ETI partners gain momentum

Australian Industry ETI partners are moving on the challenges and opportunities that a global net zero market creates.

Australian Industry ETI convened a series of workshops and one-on-one conversations with industry partners to hear their latest perspectives on the progress towards net zero supply chains and what will be required to get there.

Partners are shifting focus from compliance to strategy.

Industry and business partners shared how they are starting to move to action, and that over the past 12–18 months, there has been a shift from a 'defensive' compliance and reporting approach to target setting, a culture and strategy shift, exploratory projects and initiatives. Partners are seeking to take up opportunities and address the challenges that a global net zero market creates, and have been encouraged to see that their peers, like them, have also been making this shift.

A selection of perspectives shared by industry partners:

> *'across all sectors the narrative of climate change and sustainability was once a discrete workstream. It's now core strategy.'*

> *'The tone from the top has changed in recent years and is changing... leading to a change in culture… we are right in middle of the journey'*

> *'focus has been on setting targets and creating a mandate to focus on emissions'*

> *There is a 'universal theme of a shift from tactical operational thinking to strategic thinking, consistent with everything we are seeing in the media every day. Interesting [that we are] actually getting traction at strategic level. Heartening to hear.'*

> *'There has been a shift to corporate strategy from reporting, focus on risk and opportunity'*

Different companies do, of course, have different approaches. For some, 'medium term targets (versus long term) are useful [as this] allows more flexibility'. For others 'it's not a wait and see culture' as they announce bold strategies. While all partners have increased ambition on climate targets, organisational culture came up several times in relation to the setting of aspirational net zero targets. For some, concrete near term goals and actions are more aligned to their way of operating. That is, they are not comfortable with having long term targets 'out there without really knowing [the] definitive pathway'.

Many industry and business partner companies in the workshops and interviews talked about being at various stages of re-aligning their organisation, governance and business strategies to their net zero targets as a near term priority. Defining medium-term targets and plans for the transition is a key focus and a genuine challenge with emerging questions.

> *'company culture is on board with the target and wanting to back it up with a plan'*

> *'[We have] a plan for each asset, a decarbonisation plan for each. We are currently in the throes of doing this. First plans will be developed by the end of the year.*

> *We are having 'difficulty around plans – and how they survive contact with the reality'*

> *'How to upskill people from team to board level on climate change?'*

> *'Is there alignment between rhetoric and action at the top?'*

Companies are keen to learn from the experience of others to build momentum. This prioritisation of collaboration will be essential to working across the relevant stakeholders as parfait of an effort to decarbonise the energy system.

> *'I am curious how others are moving from setting targets to strategy and implementation'*

> *'How best to tap into the knowledge and desire of people across the organisation?'*

Capital expenditure plans are being seen by investors and other stakeholders as an indicator of companies translating talk into action.

> *'investors asking "so what" after targets'*

> *'is it in the capital plan or is it just BS?'*

> *Investors are positing that it's 'not just about targets… do they [industrial companies] have right strategies, governance?'*

There is an awareness of the shift now needed to move from aspirational targets to tangible action in industrial transitions. Examples from other markets show us that simultaneous, aligned action is needed in corporate leadership, government policy and support, and the flow of money to decarbonisation and transition efforts.

Partners of the Australian Industry ETI are taking steps with target setting, exploratory projects, initiatives and strategies and seeking to take up the opportunities that a net zero market creates.

Examples of publicly announced targets, projects, initiatives and strategies from industry and business partners on net zero include:

- Fortescue and Andrew Forrest's vision for green steel, hydrogen and net zero operations by 2040
- BHP's USD$400M investment fund, pathway to net zero operational emissions work and moves to tie climate performance to executive remuneration
- Orica's emissions reductions target of 40% by 2030
- BlueScope Steel's 12% reduction in its GHG emissions intensity by 2030
- Wesfarmers Chemical, Energy and Fertilisers aspiration to achieve net zero Scope 1 and 2 emissions by 2050
- APA Group's ambition to achieve net zero operations (scope 1 and 2) emissions by 2050, and pilot project to convert 43km of the Parmelia Gas Pipeline to hydrogen ready transmission
- AGIG, through AGN, playing a leading role in Australia's first renewable hydrogen pilot plant
- Cbus 1% allocated climate investment opportunities to support climate transition
- BHP, Woodside and others' involvement in ARENA bids for renewable hydrogen projects
- BP and Woodside's net zero ambition by 2050.

Investors are taking a proactive role and adopting a long-term mindset.

The Australian Industry ETI's consultations showed institutional investors and banks are taking a proactive role in supporting industrial companies to achieve net zero emissions. Partner investors (Cbus, AustralianSuper and NAB) are focused both on customer returns (their member's wealth) and long-term viability of companies in their portfolios. Investors and lenders have set their own targets (resulting from their analysis as well as member and shareholder pressure), formed collaborations to advocate for policy shifts in company policy and are maturing their approaches to assess viability, support change and take up opportunities. Partner investors identify that the shareholder role is an important one and is likely to continue to grow.

The investors consulted are looking to be supportive, rather than interventional at this stage. Discussions suggested that investors would 'not take a big stick approach' in their engagement. Institutional investors talk about not divesting (that is, they are maintaining their portfolio approach) but rather favouring investment in best category companies and providing hard-to-abate sectors with capital and support in transition. Investors are managing investment risk to deliver the best return for their members. They are looking at the company strategies, capital investments and governance.

> *'This is not just about targets being in place in companies – do they have right strategies, governance etc'*

> *'We are prioritising these hard to abate sectors in engagement activities'*

> *'What does industry need from us as a shareholder to help support the transition?'*

> *'Lenders sometimes take a "policy first" approach to lending, it reflects a long-term perspective'*

Investors have formed several groups and collaborations to advocate for shifts in company policy. For example, Asset Owners Alliance, Climate Action 100+ and the Investor Group on Climate Change among others. These groups pose an interesting example of where and how companies might cooperate.

Investors and lenders in Australian Industry ETI consultations discussed how they are evolving and maturing their methods and approaches in managing climate risk and opportunities. This includes marrying up investment with 1.5 degrees Celsuis scenarios, setting targets, creating sustainability linked loans and other products, setting baselines on asset classes, signing up to principles of responsible lending, educating board members and investment managers, looking at the robustness of investments by sector over several scenarios (for example, with / without carbon price) and looking at the risks of holding assets over the long term. Investors are also looking to invest in the right emerging areas, for instance allocating a percentage of funds to pursue new opportunities in response to climate change. The focus is on using these investments as a 'learning tool, building knowledge and comfort with particular sectors then rolling these over into the larger fund'.

Investors are signalling to the boards of the companies they invest in, the need to take emissions reduction seriously. This is across banks, investment companies and industry. Shareholders are influencing corporate leaders through questions, agitation and in formal approaches. Shareholder resolutions 'signal to the board they need an active role in this area'.

There is potential for industry and investors to work more closely to accelerate change as both are focused on how to turn targets into real action. The Australian Industry ETI workshops attended by industry partners and panellists from the Australian finance community revealed an enthusiasm for more opportunities to sit down together and align understanding of sector transition pathways to net zero. The investment and finance representatives also stressed the importance of policy and regulatory settings to support market certainty and enable rapid decarbonisation of supply chains.

There remains significant uncertainty in navigating the transition to Paris-aligned futures.

While momentum is building towards the net zero emissions transition, there remains significant uncertainty to navigate for businesses. This is because of the huge range of factors that will ultimately impact on the transition such as social, geopolitical and other environmental factors that affect the future. This is exemplified by the impact of large-scale disruptions such as the COVID-19 pandemic and the shift this has caused to remote working, changes in transport practices and systems that will be very hard to predict even after the end of the pandemic.

The recent net zero commitments from China, Japan and South Korea, the US positioning itself as a global leader on climate action under the Biden administration, and the new European green deal signify major shifts towards the decarbonisation of the global economy and Australia's export markets. The consultation found that these trends were having an impact on companies' thinking but there is still uncertainty on the timing and impact of changes.

> *'interesting to understand the challenge organisations have, given customers in other parts of the world'*

> *'China, Japan, Korea – how will markets change... when will preferences change? When to move down here in Australia?'*

> *'Global regulations and standards around green and low carbon products for example, in the EU, will further impact domestic production and competitiveness'*

> *'Carbon border abatement requirements will be big driver'*

Some companies are approaching the global policy shifts as an opportunity to develop products and services for those markets, a new source of value.

> *'China announcement allows scope 3 discussions with Chinese customers – an opportunity to value add, by producing iron ore differently – and giving China the product they need to achieve that'*

As part of Phase 2 of the Australian Industry ETI, companies will have the opportunity to explore this uncertainty through the development of multiple scenarios on the potential transition to net zero emissions, understanding the factors that could lead to potentially favourable and unfavourable outcomes.

7. Coordinated and simultaneous action is needed

Although some companies are taking bold steps, industry recognises that decarbonising the energy system, their operations and supply chains is not something that can be achieved by individual companies on their own.

While some Australian companies are pursuing ambitious projects and strategies, single organisation projects and disconnected bi-lateral efforts will be insufficient to overcome the complex system level challenges and uncertainties associated with industrial decarbonisation.

The scale and pace of decarbonisation needed for Australian industry to be and remain global leaders in many sectors requires a dramatic increase in the number of projects and initiatives, their scale, and the connections and coordination between them. This is especially true when it comes to transformation of the energy system, where common infrastructure will benefit multiple companies and create system-wide benefits. It's also true where a step change is needed in supply chains and where Australia has the potential to move up the value chain and capture more value, for example in the production of green metals and other products.

The Australian Industry ETI interviews and consultations identified a number of examples where there is an interest in higher levels of coordination, and private-public collaborations for the common good, including:

- decarbonisation infrastructure, for example Pilbara gas, electricity networks
- development of hydrogen hubs including domestic demand
- low emissions material movement, for example, alternative fuel heavy vehicles, shipping, rail
- carbon capture and storage (CCS), development of business cases for carbon capture and utilisation (CCU) and carbon carbon capture use and storage (CCUS) hubs.

There is a need not only for industry to come together but also the need for a broader set of stakeholders to coordinate and collaborate. Stakeholders such as those from technology development, policy and regulation, market development, knowledge and research as well as investment and finance. Even the burden of industry leadership is something that could be shared. As an industry partner has pointed out 'individual companies often don't want to take a leadership role because they will be shot down'.

Simultaneous shifts are needed to transition to net zero emissions on multiple fronts including corporate strategy, technology, policy, markets and investment.

Achieving net zero emission supply chains will require decarbonisation of the broader energy system as well as the operations of individual companies along with those of their customers and suppliers. This will include consideration of scope 1, scope 2 and scope 3 emissions and points to the need to shift the way of doing things at a whole-of-system level.

The Australian Industry ETI has worked with industry partners and other key stakeholders to build an understanding of a whole-of-system transition by taking a socio-technical systems approach. The objective of this analysis was to identify the underlying structures and dominant thinking with regards to transitioning from the current state towards net zero across multiple dimensions. This required looking beyond just technology and economics so the dimensions included corporate strategy and leadership, policy and regulation, industry structure, knowledge and research, as well as technology, market, investment and finance.

BOX 01:

Case study – Iron and steel current state transition dynamics

To exemplify the multi-dimensionality of the transition, this case study summarises the current state dynamics for transition of one supply chain: iron and steel.

Technology. Today's dominant thinking is that the most promising approach to producing green steel in the medium to long term is via hydrogen direct reduction injection (H2 DRI) combined with electric arc furnace (EAF). This replaces coking coal with clean hydrogen in the reduction step and employs renewable electricity in EAF to produce molten steel. Some key determinants of these technological shifts are affordable renewable energy, natural gas (possible intermediate fuel), clean hydrogen as well as getting the timing right for steel plant upgrades. These plants typically represent sunk costs in the hundreds of millions of dollars, with a life span of two to three decades.

Corporate strategy and leadership. Many companies in the iron and steel supply chain are beginning to align to the goals of the Paris Agreement and net zero emissions. The global shift to net zero targets, especially in key Australian export markets such as China, Korea and Japan, is being seen as a key risk to business as usual with uncertainty around the timing and impact on Australian business. While there are examples of companies in Australia emerging as visionaries in the move to green steel, for example Fortescue Metals Group and GFG, many companies in Australia are still grappling with when and how to move forward with the transition due to the high capital cost of the transition and the perceived risks to early adoption in light of considerable market and technical uncertainty.

Policy and regulation. Stakeholders noted that there are currently insufficient policy and regulatory drivers for the transition. The federal government's Technology Investment Roadmap (Australian Government 2020) is seen to support the green metals and hydrogen objectives though so far lacks the detail and policy mechanisms needed to drive the transition. Industry sees government having an important role to play in the energy system transition by supporting availability and affordability of renewable energy, hydrogen or gas as a transition fuel and development of the shared infrastructure needed to support them. State government local content procurement policies can provide support to transition to new products. Procurement policies can provide incentives for the production of some green steel products, which can lead to a green premium over low-cost, high emissions products. However, these policies would only support certain steel products, where customers are able to specify sustainable materials. As part of consultation, some industry partners have expressed interest in market support for green steel, such as that proposed by the EU in the form of border tax adjustments. Regional jobs are an important motivation for policy and may be significant in government playing a more proactive role in supporting the shift to green steel or similar products.

Market perspectives. Market competitiveness is front and centre of concerns for many players given the global market exposure for their products. Global overcapacity of steel production and price pressure from cheap imports are seen as near-term challenges for producing green steel that is more costly. There is also uncertainty around the demand and possible price premiums for green steel as well as eventual market support mechanisms. The transition also presents challenges further down the supply chain, such as the risks to iron ore demand over the coming decade that have been raised by some analysts (for example, Credit Suisse 2020). Australian hematite ores in particular could be impacted by shifts to demand and consumer preferences in China, Japan and Korea. This is starting to challenge the general long-held view that the global demand for Australian hematite iron ore was likely to continue on a similar trajectory for many years to come. It is worth noting that there is also a growing interest in magnetite ore due to its suitability to hydrogen-based steel making.

Industry structure. Australia is the leading global iron ore producer while producing only 0.3% of the world's steel. Discussions with industry partners of the Australian Industry ETI have identified two very different pathways for Australia in a transition: a) central role in supporting emissions reductions downstream (offshore, scope 3 for Australian industry) with suitable iron ore products for hydrogen-based steel making for example, magnetite or b) use our world leading renewable solar and wind resources to develop a home grown green iron or green steel industry. Availability and affordability of natural gas as a transition fuel, renewable electricity and clean hydrogen will all be key determinants of Australia's ability to transition and play a bigger role in green steel beyond iron ore exports. Some iron and steel companies in Australia are exploring opportunities to vertically integrate energy supply, perhaps as a means to de-risk on the side of supply and price.

Knowledge and research. There is recognition that the shift to green steel will require new technical knowledge and skills with some sounding the alarm of a potential risk that there could be a future shortage of these skills in Australia. There is a strong belief in the value of demonstrations for learning and showing what is possible and growing interest from the research community to collaborate on such endeavours, something illustrated by the broad support for the current Heavy Industry Low-carbon Transition CRC (HILT CRC) proposal. There is optimism that public funding for research in this area will increase and support private R&D to ensure that Australia has its foot in the global innovation race for leadership in renewable energy and green metals.

Investment and finance: A critical dimension for the transition with shareholders becoming increasingly vocal about the importance of aligning to Paris and net zero. There has not yet been a clear view that the cost of capital/finance in Australia is changing for climate-exposed investments in iron and steel though some have noted that the cost of capital is decreasing for green projects in the European Union. Some companies are making significant investments here in Australia in the green shift and leveraging the small amounts of public funding to make this happen (for example, Whyalla Transformation in South Australia). Questions have been raised about governments' appetite and interest to use public money more broadly to de-risk the huge investments needed for the transition to green steel, as is being seen in other countries, most notably in Europe.

Conclusion and next steps

The Australian Industry ETI will continue to bring companies together to collectively advance pathways and collaborate on tangible action towards net zero emissions in heavy industry supply chains by 2050, given the importance of the opportunities and challenges that this transition poses for Australian industry.

The long-term potential for decarbonisation is promising, with existing and emerging solutions able to address almost all supply chain emissions. Costs of these technologies are falling and if effectively deployed and integrated with industrial systems they can help Australia achieve competitive costs for reliable decarbonised energy.

Industry has an important role in this, and the early uptake and effective integration of renewable electricity, electrification and green hydrogen could help build an Australian industrial-scale green hydrogen industry. Some industries could access electricity costs of \$20 – 30/MWh by 2050, and potentially far sooner, by matching production to variable renewable supply and avoiding costs of energy storage. This could help decarbonise particular industrial processes, enable favourable regions to produce green hydrogen for below \$1.50/kg, enhance Australian industry competitiveness in a globally decarbonised economy and support lower overall system costs for all electricity consumers.

However, these transitions will not occur without effective planning, coordination, demonstration and early deployment. The transition to net zero emissions will be complex, requiring simultaneous shifts on multiple fronts including corporate strategy, technology, policy, markets and investment. There will be significant short-term challenges to navigate in the decarbonisation of existing operations and associated infrastructure.

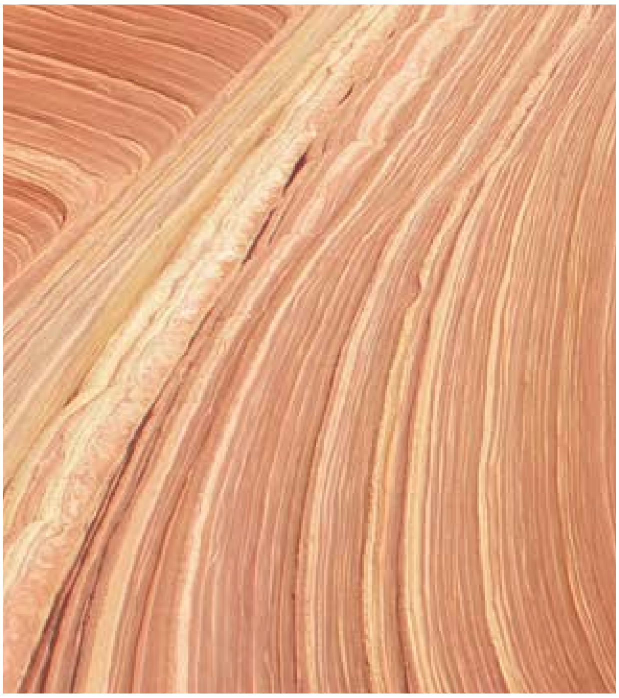
The work of the Australian Industry ETI is focused on addressing these challenges. Throughout the first phase, industry partners have come together to identify the most promising pathways to decarbonisation, build a collective understanding of the opportunities and challenges, share knowledge, and together develop projects of mutual interest.

> *'Companies know where they need to be and are tackling the "how" together in the ETI forum – pragmatic, transparent conversations.'*
>
> *Australian Industry ETI Steering Group Member*

In 'Phase 2: Promising pathways' the Australian Industry ETI will continue to foster cross industry learning and collaboration that supports action towards net zero supply chains by:

- developing pathways to net zero emissions, backed by rigorous technological and economic analysis of opportunities in each supply chain and validated by industry, including an analysis of energy systems capable of providing low-cost, reliable, net zero emissions energy
- developing an understanding of the practical challenges of deploying zero emissions technologies in the short, medium and long term, taking into consideration existing operations and assets
- identifying and catalysing actions and projects in areas of mutual interest, with an initial focus on industrial regions in WA and NSW, and
- broad network engagement to support collaborative efforts with supply chain companies, the energy sector, industry bodies, state and federal government and the broader innovation ecosystem.

The Australian Industry ETI's efforts will continue to be focused on accelerating action towards net zero emissions by 2050. It is a challenging path, but one that provides opportunities to position Australian industry to thrive in a decarbonised global economy.



Glossary

BF	blast furnace
BioNG-DRI-EAF	biomethane based natural gas direct reduced iron electric arc furnace
BOF	basic oxygen furnace
CCUS	carbon capture, utilisation and storage
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CO_2	carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAC	direct air capture
DRI	direct reduced iron
EAF	electric arc furnace
ETI	Australian Industry Energy Transitions Initiative
ETC	Energy Transitions Commission
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
H_2	hydrogen
HESC	Hydrogen Energy Supply Chain
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCOE	levelised cost of electricity
LNG	liquefied natural gas
NG-DRI-EAF	natural gas direct reduced iron electric arc furnace
Other metals	copper, lithium, nickel and zinc
PEM	proton exchange membrane
PV	photovoltaic
R&D	research and development
RMI	Rocky Mountain Institute
SMR	steam methane reforming
TRL	technology readiness level
US	United States
USD	United States dollar

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Australian Industry
Energy Transitions
Initiative

An initiative jointly convened by ClimateWorks Australia
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