Minerals Council of Australia

AUSTRALIA'S EMERGING HYDROGEN AND AMMONIA INDUSTRY

THE POTENTIAL ROLE OF AUSTRALIAN RESOURCES

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ACKNOWLEDGEMENT OF COUNTRY

The MCA acknowledges and pays its respects to past, present and emerging Traditional Custodians and Elders and the continuation of cultural, spiritual and educational practices of First Nations peoples.

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Mr Cronshaw also spent 36 years working with the Australian Federal Government on energy policy, including reducing greenhouse gas emissions, energy efficiency, renewables targets, oil and gas security and energy technology.

FOREWORD BY TANIA CONSTABLE

Australia can be a major global provider of clean hydrogen.

It can also be a leader in clean ammonia, a product that shares hydrogen's game-changing potential in the global task to deliver net zero emissions by 2050.

With substantial carbon capture, utilisation and storage (CCUS) sites in Victoria and Queensland, competitive and accessible coal reserves, natural gas and significant renewable energy generation capacity, Australia is well placed to meet growing international and domestic demand for this important fuel.

Australia continues to work with its partners on leading-edge energy innovation. With Japan, a significant investor in research, development and deployment, Australian industry is working to deliver long term supplies of clean hydrogen and ammonia, such as through the Hydrogen Energy Supply Chain (HESC) project in Victoria, utilising gasified brown coal.

At the same time, Australia is investing in the development of CCUS sites which will be vital in creating a zero emissions fuel, such as the Carbon Transport and Storage Company's project in the Surat Basin, and the CarbonNet infrastructure and storage project in Victoria.

Large-scale hydrogen and ammonia are expensive today, but ingenuity and hard-work can deliver a competitive product to meet a pressing demand.

Clean hydrogen plays a significant role in most scenarios under which the globe decarbonises by 2050. The International Energy Agency suggests clean hydrogen production will need to double by 2030 and increase six-fold by 2050 to meet this target. This is an increase from current annual production levels of around 90 million tonnes (Mt) to more than 530 Mt.

Australia can be a low cost source of clean hydrogen and ammonia. Ammonia in particular offers real prospects for decarbonising global shipping fleets, fertiliser production and electricity generation. This will require development of new pipeline and storage infrastructure including at ports.

To realise this potential, federal and state governments need to focus on removing regulatory barriers, including expediting approval processes for associated infrastructure like pipelines, hydrogen fuel stations and ammonia storage.

The Australian resources sector will play a critical role in delivering the resources required for global decarbonisation. More than just hydrogen and ammonia, this also includes various minerals that form the basis of new storage technologies and electrolysers. As part of this, federal and state governments should be considering how best to develop down-stream processing for lithium, cobalt, nickel and the range of rare earths.

This report shows it is clear the emerging clean hydrogen and ammonia opportunity is substantial for Australia and Australian mining.

Tania Constable

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1 INTRODUCTION

The global trend towards ambitions of net zero emissions of greenhouse gases by mid-century continues to gather momentum. While countries are adopting differing policy approaches, there are often important common features to the strategies employed.

Many countries are seeking to rapidly decarbonise the power sector, essentially through massive deployments of new renewable technologies. In addition, electricity use is being extended quickly into sectors such as transport, via electric vehicles, and low temperature heating, via heat pumps. In this manner, electricity increases its share of total final energy consumption from 20 per cent to half, or even higher shares in some regions.

Currently, natural gas (methane, CH_4) provides a high share of total final consumption in many countries, and a high share of seasonal flexibility, meeting seasonal heating demands plus flexibility in the power sector. Coal plays a similar role, especially in Asia. However, in the longer term, the continued use of gas and coal will require widespread, effective and efficient carbon capture, use and storage (CCUS) for climate sustainability.

Moreover, while decarbonised electricity can rapidly scale up to meet a large share of current energy needs, especially given supportive policy frameworks, there will remain industrial activities that are difficult to address. These include aviation, shipping, heavy-duty transport, and raw material production, such as steel, aluminium, cement, and chemicals, notwithstanding technologies such as electric arc steel making, displacing some metallurgical coal enabled reduction with electricity.

One widely proposed solution to address these issues is the production and use of hydrogen (H_2) using low carbon emission technologies, and its potential conversion to ammonia (NH_3).

Hydrogen can be produced using existing technologies, from natural gas or coal, with high levels of effective and efficient carbon capture and storage to be low carbon.

Hydrogen can also be produced in large quantities from electrolysis, where several mature technologies exist, using dedicated or excess renewable electricity or nuclear power, with no carbon emissions at the point of production and use.

Biomass could also be used in this way to produce hydrogen, likely in more decentralised facilities.

Hydrogen could supplement, and then replace, natural gas for uses such as heating and cooling, delivering flexibility to energy systems. It could be introduced into existing gas distribution systems at low shares, displacing fossil sourced methane, and providing an early opportunity to develop hydrogen production and sales. However, more widespread use of hydrogen in this fashion, at higher shares in the pipeline mix, would require extensive investments in new infrastructure. Co-firing of existing coal or gas fired power plants with hydrogen or hydrogen based fuels such as ammonia, enables these existing plants to contribute to electricity security, while lowering emissions quickly.

The high energy density of hydrogen per kilogram makes it potentially very useful for aviation use, and other transport applications, including buses, trucks, and shipping, used directly or through high efficiency fuel cells. Hydrogen can be used as a feedstock for chemical production, converted to ammonia for fertilisers, and as a reductant in steel making, or alumina production. Hydrogen can be exported from Australia in liquid form (trial shipments began in January 2022), or can be converted to hydrogen containing compounds notably ammonia.

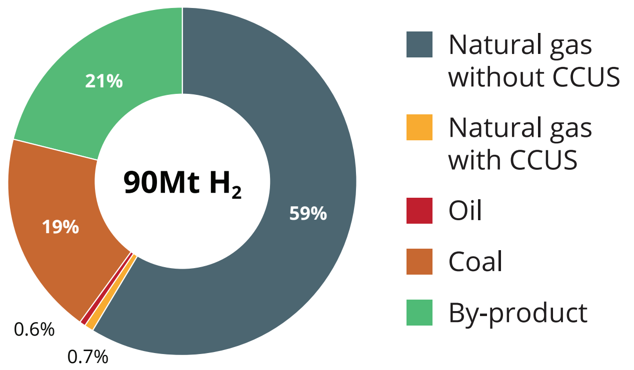
Ammonia is much easier to transport, offering the prospect of exports of Australian produced hydrogen to, for example, East Asian markets. A major trial of ammonia co-firing of coal-fired power plants is already underway, with a view to eventual 100 per cent ammonia fuelling. Japan is aiming at ammonia use of 3 million tonnes (Mt) by 2030, enough to co-fire some 6 gigawatts (GW) of coal fired plants at a co-firing level of 20 per cent.

Global annual production of hydrogen is currently around 90 Mt, almost all (79 per cent) based on natural gas or coal (especially in China) and used in oil refining and fertiliser manufacture (Figure 1). The remainder (21 per cent) was produced as a byproduct in facilities designed primarily for other products, mainly refineries. Greenhouse gas emissions associated with this production are estimated at 900 Mt annually. This presents an opportunity for emission reductions. However, replacing this hydrogen by electrolysis would require more than 1,000 GW of electrolyser capacity. This is greater than total EU electricity generating capacity today. Producing clean hydrogen from fossil fuels with carbon capture, utilisation and storage (CCUS) is another option. CCUS-equipped hydrogen facilities are already operating in seven locations today including at the Air Products and Chemicals Inc facility in Texas, USA, at Quest, a joint venture of Shell, Chevron and Marathon Oil, and at North West Redwater Partnership, both in Alberta, Canada.

While hydrogen is a versatile and available energy carrier, the major barrier to greater widespread use of hydrogen remains cost.

Currently hydrogen produced from natural gas, without CCUS, costs around US$0.8 - 1.7 per kg, (depending heavily on gas prices) or around $A15 per GJ. CCUS is estimated to add around USD 0.5 per kg. Coal based production with CCUS is estimated at USD 2-3 per kg.[1,2]

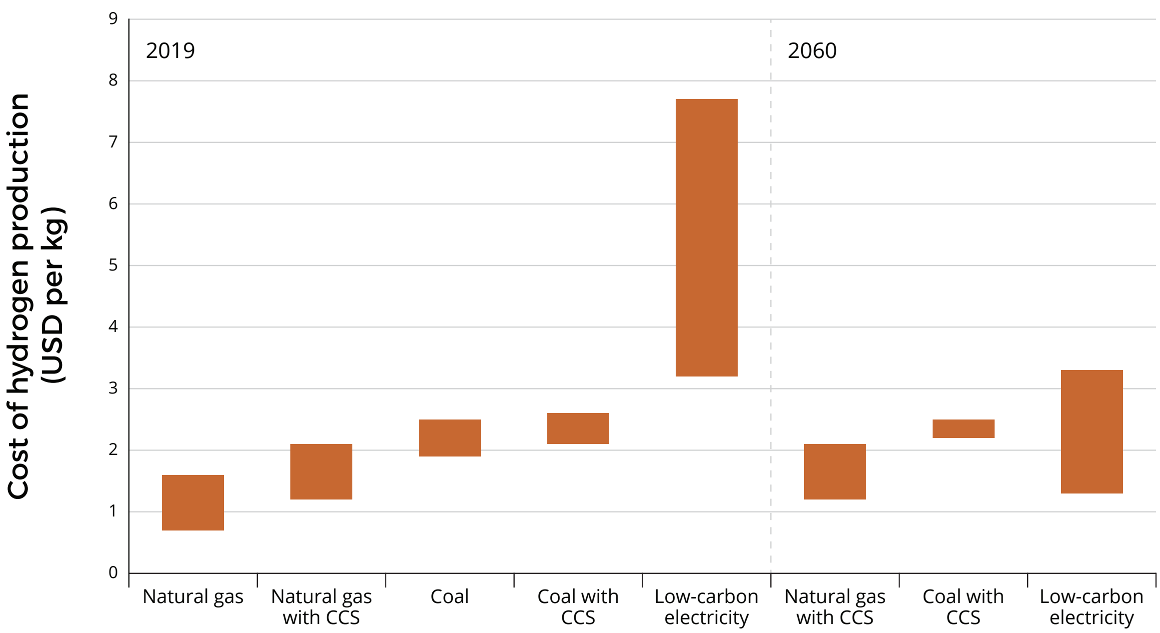
FIGURE 1. SOURCES OF HYDROGEN PRODUCTION, 2020



Source: International Energy Agency, *Global Hydrogen Review 2021*, p. 108.

Electrolysis costs using low-carbon power are around USD 3 - 8 per kg, based on around 60 kWh of power demand per kg H_2, but with strong prospects for cost reductions. As electrolysers are deployed more widely, rapidly and scaled up, renewable power costs may fall further. Greater widespread deployment of electrolysers can be expected to improve efficiency and lifetimes, and reduce costs (see Figure 2).

FIGURE 2. GLOBAL AVERAGE LEVELISED COST OF HYDROGEN BY ENERGY SOURCE AND TECHNOLOGY: 2019 AND 2060 PROJECTED



Source: International Energy Agency, Global Average levelised cost of hydrogen by energy source and technology, 23 September 2020 update.

1 International Energy Agency (IEA): *Global Hydrogen Review 2021*, October 2021.
2 US Department of Energy, *DOE Hydrogen and Fuel Cells Program Record*, 14 September 2020.

2 HYDROGEN IN A LOW CARBON FUTURE

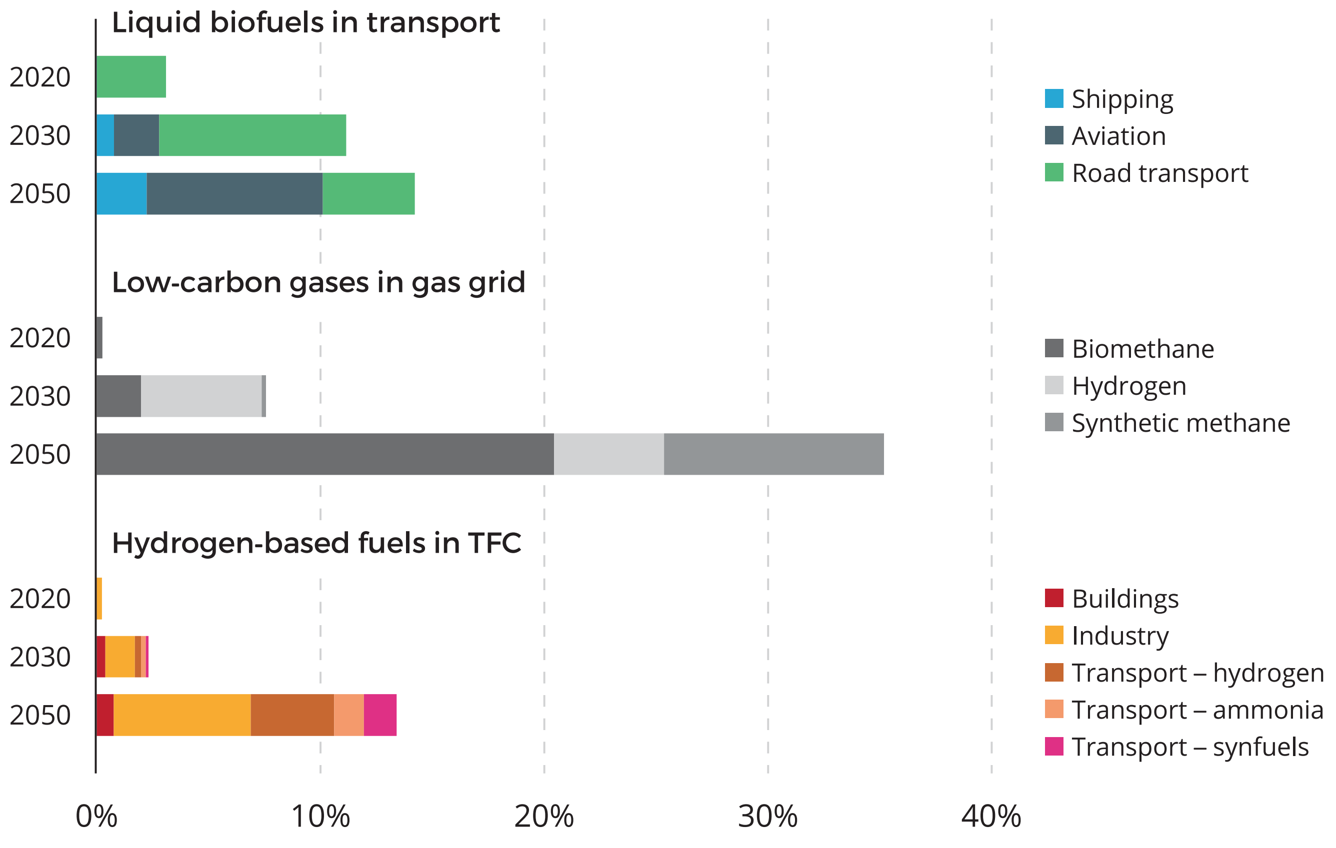
In May 2021 and ahead of the COP 26 climate change conference in Glasgow (31 October - 12 November 2021), the International Energy Agency (IEA) outlined a scenario that reduced global greenhouse gas emissions from the energy sector (responsible for around three-quarters of global emissions) to net zero by 2050.[3]

The scenario emphasises significant emissions reductions in the next decade, based on a massive expansion of solar PV and wind, with annual capacity additions of 1,000 GW by 2030. This is more than four times the record levels of 2020. By 2030, electric vehicles account for 60 per cent of global new vehicle sales, almost 20 times more than 2020. By 2050, electricity is half of global energy use, up from a fifth today.

Despite these dramatic increases, sectors and energy end uses remain that require different approaches, including using a range of new fuels such as hydrogen and hydrogen-based fuels (see Figure 3) and the application of carbon capture and storage in a range of applications.

Such low emission fuels provide just 1 per cent of the world's final energy demand today but must expand rapidly to meet one fifth of demand in 2050.

FIGURE 3. A RANGE OF NEW FUELS HELP TO DECARBONISE SECTORS WHERE ELECTRIFICATION IS DIFFICULT



Source: IEA Special Report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021, p. 106.

[3] IEA Special Report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021.

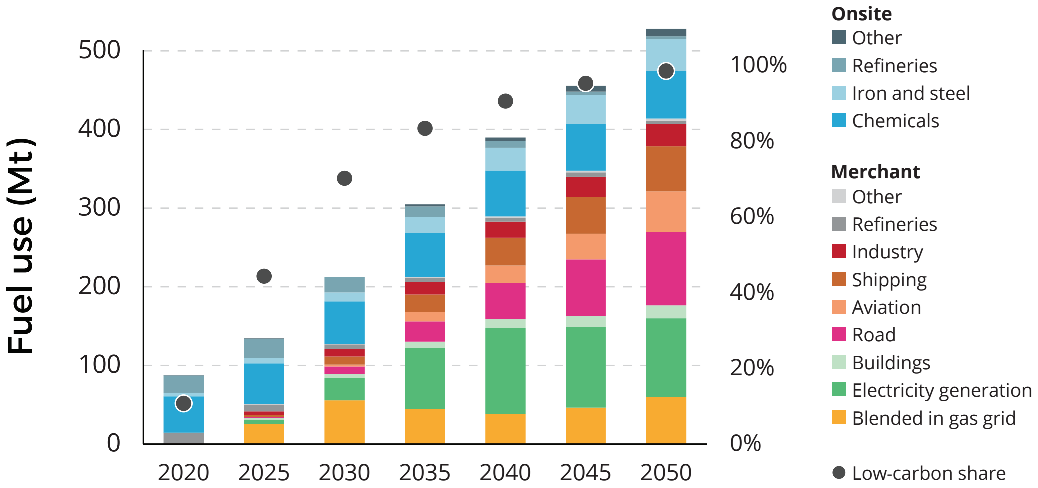
The initial focus over the next decade is replacing existing fossil energy uses with low carbon hydrogen, using existing transmission and distribution infrastructure. This includes existing hydrogen use in industry, and refining, as well as supplying part of current reticulated gas supply. Hydrogen and hydrogen-based fuels in this scenario meet 28 per cent of transport energy needs by 2050, while low carbon gases (hydrogen, biomethane and synthetic methane) meet a third of gas demand via networks.

By 2050, the share of low-carbon hydrogen and hydrogen-based fuels reaches 13 per cent of total global energy use. By then, hydrogen and ammonia will provide around 2 per cent of power generation, providing important flexibility services. Steel and chemicals, plus road transport will account for half of direct hydrogen use. Hydrogen and hydrogen-based fuels, notably ammonia, will power three-fifths of global shipping demand.

To meet these impressive increases in demand for hydrogen, current output levels more than double by 2030, and increase more than six-fold to 530 Mt by 2050 (see Figure 4). The production paths for hydrogen output at these levels require massive investment, with a shift to low carbon routes accelerating by 2050.

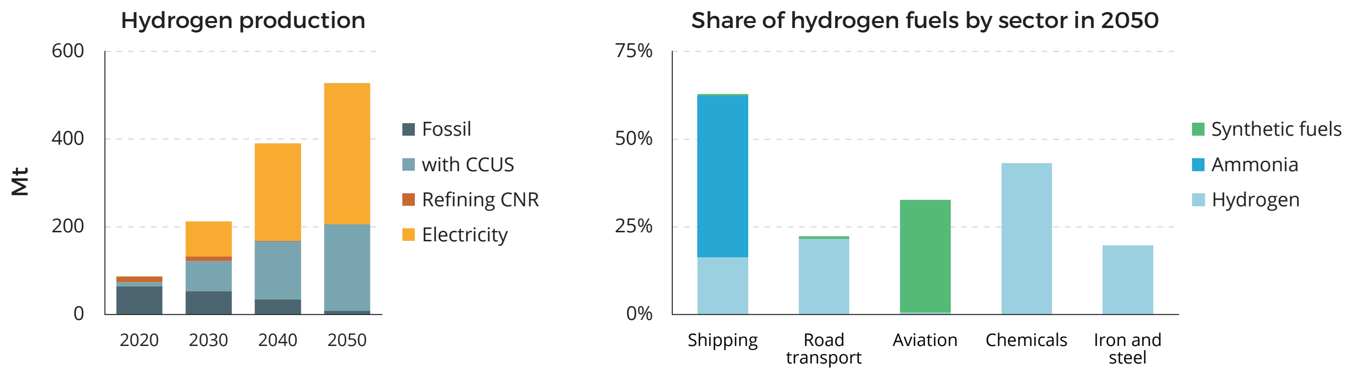
In 2030, around 60 per cent of hydrogen is fossil based, but with rapidly increasing shares of CCUS. By 2050, water electrolysis dominates production, requiring electrolyser capacity of 3,600 GW and generation of 15,000 terawatt hours (TWh) of power (see Figure 5). This is about a fifth of 2050 projected global power output and more than half of total world generation today. While fossil-based hydrogen production with CCUS is projected to be playing a secondary role by 2050, it is still significant and would require an additional 9,000 TWh of low carbon power to replace it.

FIGURE 4. GLOBAL HYDROGEN USE IN IEA NET ZERO EMISSIONS



Source: IEA Special Report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021, p. 75.

FIGURE 5. GLOBAL HYDROGEN PRODUCTION 2020 – 2050



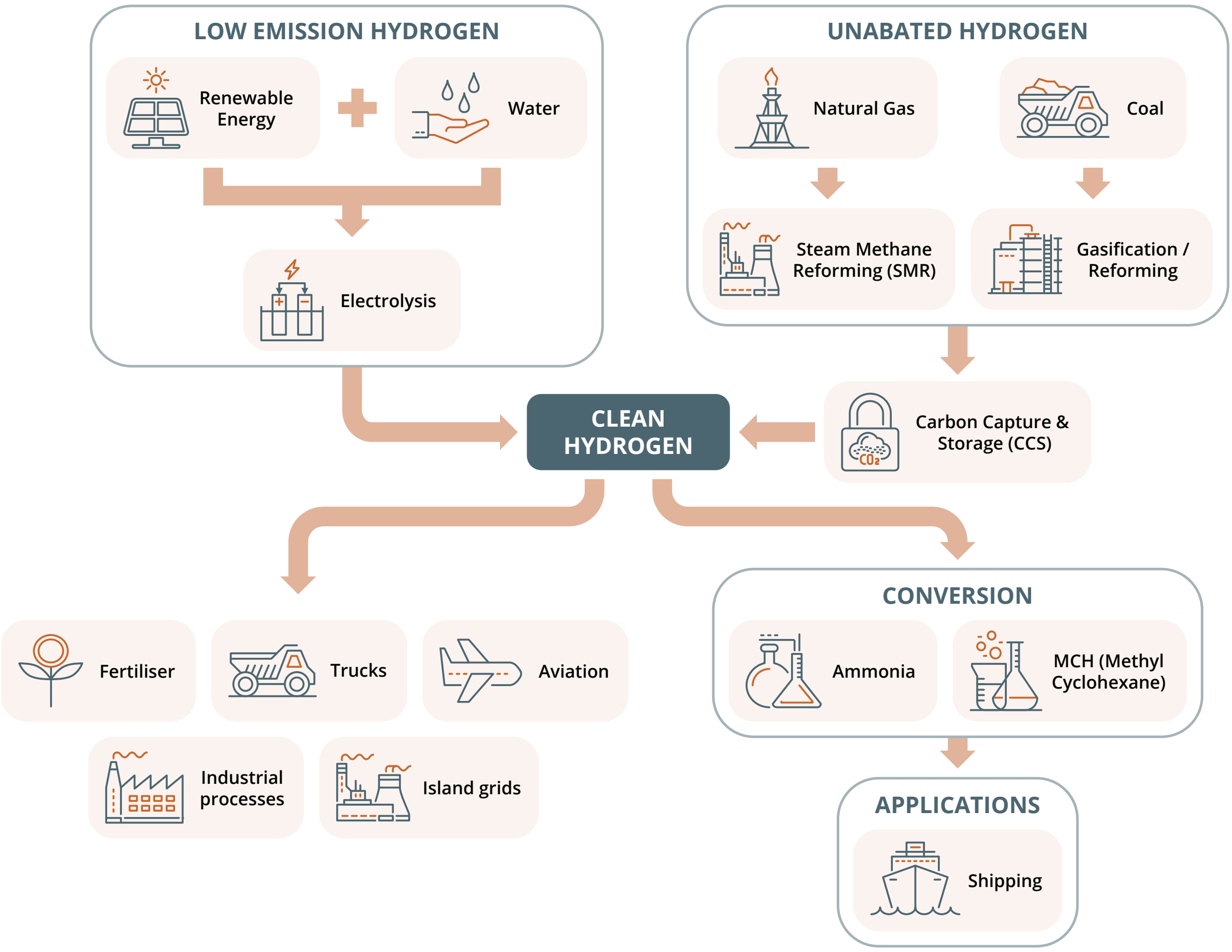
Note: Refining CNR = hydrogen by-product from catalytic naphtha reforming at refineries.
Source: IEA Special Report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021, p. 109.

In the IEA's net zero scenario, CCUS is deployed in a wide range of end-uses: industry, steel, cement, as well as power and hydrogen production. If the technology is not available, the 7.6 Gt of CO_2 postulated to be sequestered in the scenario would need to be offset in the power sector by an extra 11,000 TWh of renewable or other low carbon power. This is more than 40 times Australia's current power demand. Achieving net zero by 2050 in the absence of widespread CCUS would make an already challenging task virtually impossible.

Consider comparisons with scenarios developed for the Intergovernmental Panel on Climate Change.[4] The IPCC modelled some 90 scenarios that have at least a 50 per cent chance of limiting global warming to 1.5°C in 2100. Of these, 18 have net-zero energy sector CO_2 emissions in 2050, approximating the IEA approach. The shares of wind and solar in the power sector range from 15-80 per cent in the IPCC modelling. In the IEA scenario, wind and solar provide 70 per cent of total power. With respect to hydrogen, the IPCC postulates 2050 use of around 300 Mt per annum and the IEA near 530 Mt per annum. CCUS features strongly in the IPCC scenarios, with around 15 Gt sequestered in 2050, and in the IEA scenario at around half that level.

The growth of hydrogen use over the next three decades provides an obvious opportunity to develop hydrogen trade from countries with abundant low cost, low carbon energy sources and feedstocks. The IEA recognises however that liquefaction and transport costs of exporting hydrogen will be high, and that half of global ammonia output will be traded across international borders.

FIGURE 6. HYDROGEN PRODUCTION



Currently, hydrogen is mostly made using unabated fossil fuels. The addition of carbon capture, utilisation and storage (CCUS) can dramatically reduce CO_2 emissions and produce clean hydrogen. Clean hydrogen can also be produced by electrolysis using renewable energy. Hydrogen can be used as a combustion gas in a number of industrial, automotive and power generation processes. It can also be converted to ammonia for use as a fuel for shipping and in other industrial applications.

[4] United Nations Intergovernmental Panel on Climate Change, *Special Report: Global Warming of 1.5°C*, 2021.

3 INTERNATIONAL AND NATIONAL PROJECTS FOR HYDROGEN PRODUCTION

Between 2019 and late 2022, global progress on hydrogen policy and production has been marked and, in response to the war in Ukraine, the EU's ambition increased significantly in 2022. Around 26 Governments now have major hydrogen strategies in place, the capacity of electrolysers has tripled, and at least 350 projects globally should see electrolyser capacity increase to 134 GW by the end of the decade (more than double the forecast in 2021), with potential output of 8 Mt by 2030. Some 17 projects currently produce 0.7 Mt of hydrogen from fossil fuels with CCUS. Another 50 are under development, with potential output of over 10 Mt by 2030.[5]

However, this combined output will still be well below the levels needed for global climate objectives to be met. On the demand side, some important early steps include the first shipment of low carbon steel from a pilot plant in Sweden using low carbon hydrogen injection into existing blast furnaces, and the imminent startup of a pilot plant for low carbon ammonia.

In Australia some 106 projects can be identified and, although most are relatively small scale with only a few under construction, it is clear that momentum for more large scale projects is growing.[6] In mid-2021, the Australian Renewable Energy Agency (ARENA) announced funding for three commercial scale hydrogen projects, totalling $103 million. The plants will utilise 10 MW electrolysers, some of the largest globally, making these important demonstration projects. Hydrogen will be blended with existing gas streams, or used in ammonia production. Construction was planned to start in 2022.

An integrated project known as the Hydrogen Energy Supply Chain (HESC) Project, is being advanced in Victoria's Latrobe Valley. As its title suggests, it aims to demonstrate the fully integrated hydrogen supply chain, along similar lines to current LNG production. Hydrogen production, which started early in 2021, was successfully produced from brown coal via coal gasification and refining. In the pilot stage

The Suiso Frontier, world's first vessel capable of shipping liquid hydrogen over intercontinental distances.

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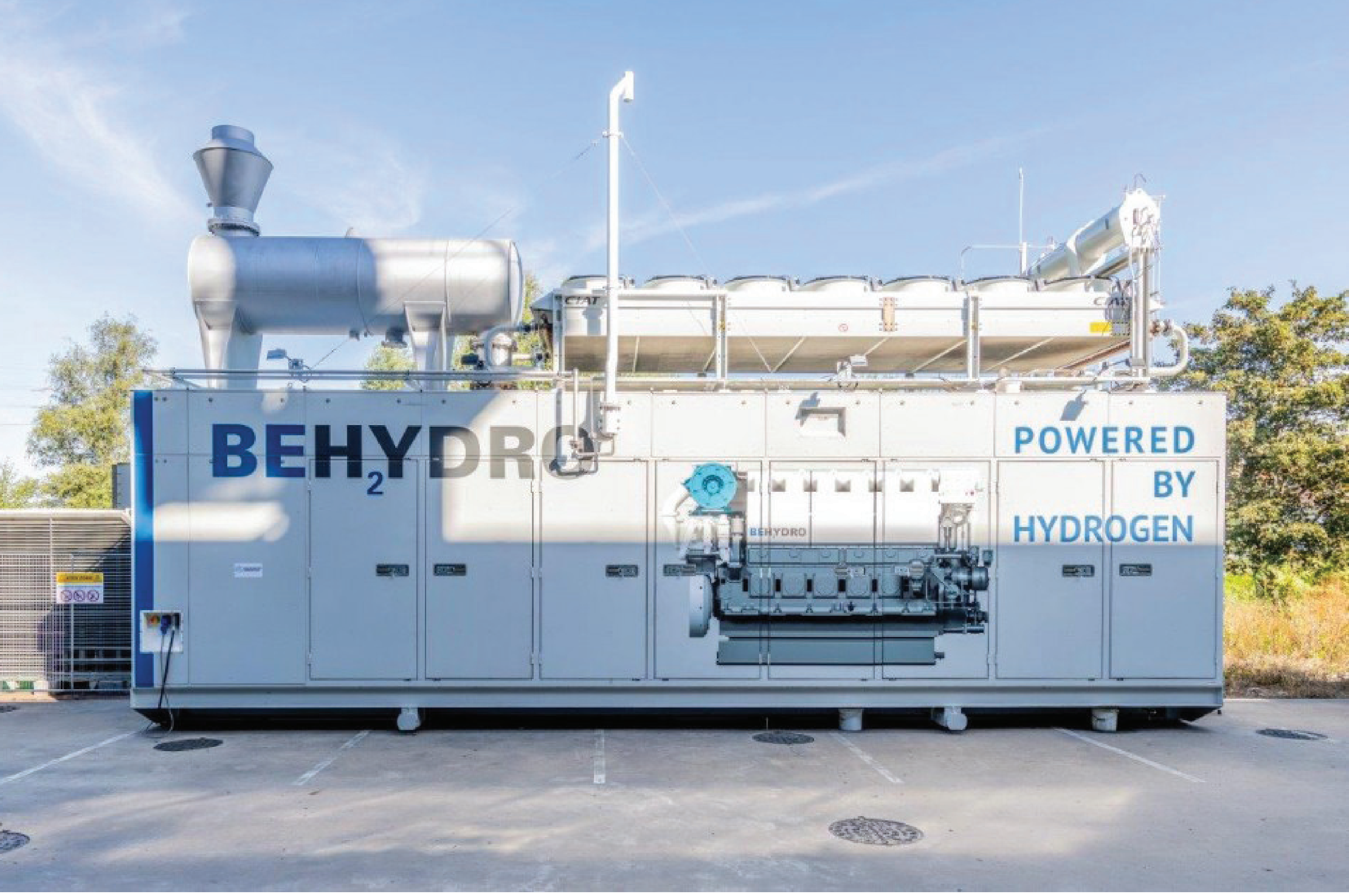
[5] International Energy Agency, *Global Hydrogen Review 2021*, pp. 5, 130; *Global Hydrogen Review 2022*, pp. 8, 14, 88; European Commission, Clean Hydrogen Joint Undertaking, *Going global: An update on Hydrogen Valleys and their role in the new hydrogen economy*, 2022, p. 7.

[6] Commonwealth Scientific and Industrial Research Organisation (CSIRO), *HyResource 2021*, viewed 7 October 2022.



about one tonne of hydrogen was transported by road to Western Port, where the gas was liquefied at a temperature of -253°C. In January 2022 liquid hydrogen was loaded onto a dedicated ship, the first of its kind, the Suiso Frontier, and arrived at the Port of Kobe, Japan on 25 February 2022. It was then safely unloaded marking the successful completion of the Pilot Project.

Gas turbines are being modified to use the fuel in Japan. With an estimated cost of around \$500 million, the project is the largest integrated project in Australia. Australian and Victorian Governments have each contributed \$50 million, with the balance from the Japanese Government and Australian and Japanese companies.

Following evaluation of the pilot phase a commercialisation demonstration phase is proposed from 2026-2030 after which a decision will be made to proceed to commercial operation, anticipated by 2030. In this case, CCUS technologies will need to be employed. Planning for commercial operation centres on storage via the CarbonNet project. CarbonNet will build on the experience of the Otway project, where some 80,000 tonnes of CO_2 has been stored onshore in a depleted gas field and saline formations since 2008. CarbonNet is designed to capture CO_2 from a range of industries in the Latrobe Valley, for sequestration in the Pelican site, 8 km off the Gippsland coast. The facility is designed to accept 5 Mt per annum for 25 years. Development is well-advanced, with a final investment decision anticipated in 2024. The project is underwritten by \$150 million from the Australian and Victorian governments.

As noted above, hub based carbon sequestration approaches are expected to substantially reduce costs and accelerate deployment of CCUS technology. An additional Australian example of a hub based approach, with the goal of sequestering CO_2 from multiple sources, including hydrogen production, will be located in the Surat basin. A final investment decision by the Carbon Transport and Storage Company, based on a goal of capturing and storing around 100,000 tonnes annually, is expected soon. This project is intended as a first step toward large-scale CCUS, with the potential for emissions from multiple generators and other industrial sources being captured and safely stored.

4 INTERNATIONAL TRADE IN HYDROGEN AND HYDROGEN FUELS

As hydrogen demand develops, some countries will have limited domestic capabilities to produce it, either through lack of domestic resources of gas and coal, limited options for low cost, low carbon power production, or few opportunities for CCUS (e.g. because storage is not available or too costly).

Other countries will have cheap supplies of coal or gas, more readily available options for CCUS, and/or low cost low carbon power options. These will likely include the Middle East, Russia, Chile and Australia. Importing countries seem likely to include Japan, Korea, and countries in the EU.

Hydrogen can be transported via pipelines (either existing or new) or by ship (either as compressed hydrogen or liquefied). While natural gas is widely traded, both by pipeline and as liquefied natural gas (LNG), liquid hydrogen needs to be much colder, implying additional energy and cost.

Alternatively, hydrogen can be converted into liquid ammonia, utilising existing shipping technologies. In a low carbon world, as much as a third of global hydrogen output could be converted into ammonia. Hydrogen could also be used locally to produce high value products, such as iron or steel and alumina reduced to aluminium, using high purity hydrogen as a reductant, simplifying trading logistics and costs. This will require a significant amount of electricity investment to make the hydrogen. For example, if Germany was to use hydrogen to replace its current annual steel output of 40 Mt, national power output would need to rise by between 20 and almost 30 per cent from current levels.

Moreover, if hydrogen is to play a significant role in the energy transition, all parties involved will need to have confidence in the low carbon content of produced and traded hydrogen, and materials produced from hydrogen. As already noted, hydrogen can be produced by a number of differing production technologies, from different feedstocks, in different regions.

Recently, a colour coding system has been used to describe different production routes. Blue is used for hydrogen from fossil fuels with CCUS. Hydrogen produced by electrolysis powered by renewable energy is coded 'green'. Hydrogen from nuclear power is coded 'pink'. However, there is neither international consensus on these terms, which are essentially marketing approaches, nor on how the complex value chains that are emerging should be evaluated.

The IEA, the International Centre for Sustainable Carbon and the IEA Greenhouse Gas R&D Programme do not distinguish different sources of hydrogen production routes by colour coding. This is because the environmental impacts of various production routes can vary considerably by energy source, region, type of CCUS applied and so on. Rather they highlight low-carbon hydrogen production routes.

The development of international trade will rely on international standards and certification of the carbon footprints of different hydrogen production routes and regions. It seems inevitable that the emissions profile of different hydrogen production pathways will form the basis of sale contracts. Additionally, payment for the hydrogen product will be based on analytical results, which are in turn based on International Organization for Standardization (ISO) standards of hydrogen quality and emissions profile. In other words, the price of hydrogen, as with other products, will reflect the quantity of H_2 and its quality. Discussions are ongoing, at both international and national levels.[7,8]

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), a government-to government partnership, has formed a Hydrogen Production Analysis Taskforce to develop agreed standards of emissions associated with hydrogen production.[9] While led by France, active participants include the US, the EU and Australia as well as likely importing countries Japan and Korea. Australia leads two of the four subgroups determining a detailed carbon accounting methodology for Electrolysis and Coal gasification with CCUS. France and The Netherlands are leading subgroups on Steam Methane Reforming of natural gas with CCUS and on By-product routes respectively. Australia will begin trials for a hydrogen guarantee of origin scheme for its two subgroups in 2023. The approach will ensure a local scheme is internationally aligned and accepted by Australia's trading partners. This will enable customers who buy Australian hydrogen in the future to make an informed choice and easily identify the product best suited to their needs.

Predictions of global hydrogen trade levels and Australia's share of that trade are highly uncertain. Nonetheless, a number of recent studies are available.

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7 IEA, *Global Hydrogen Review 2021*, October 2021.

8 Australian Government, *A Hydrogen Guarantee of Origin Scheme for Australia. A Discussion Paper*, June 2021.

9 International Partnership of Hydrogen and Fuel cells in the economy (IPHE), *Terms of Reference Hydrogen Production Analysis Task Force*, 10 March 2020.

Deloitte considered several scenarios, of which their high growth scenario postulated global hydrogen demand of over 300 Mt per annum in 2050 with Australia producing some 20 Mt. Major buyers such as China, Japan and Korea are projected to take over 70 per cent of exports.[10]

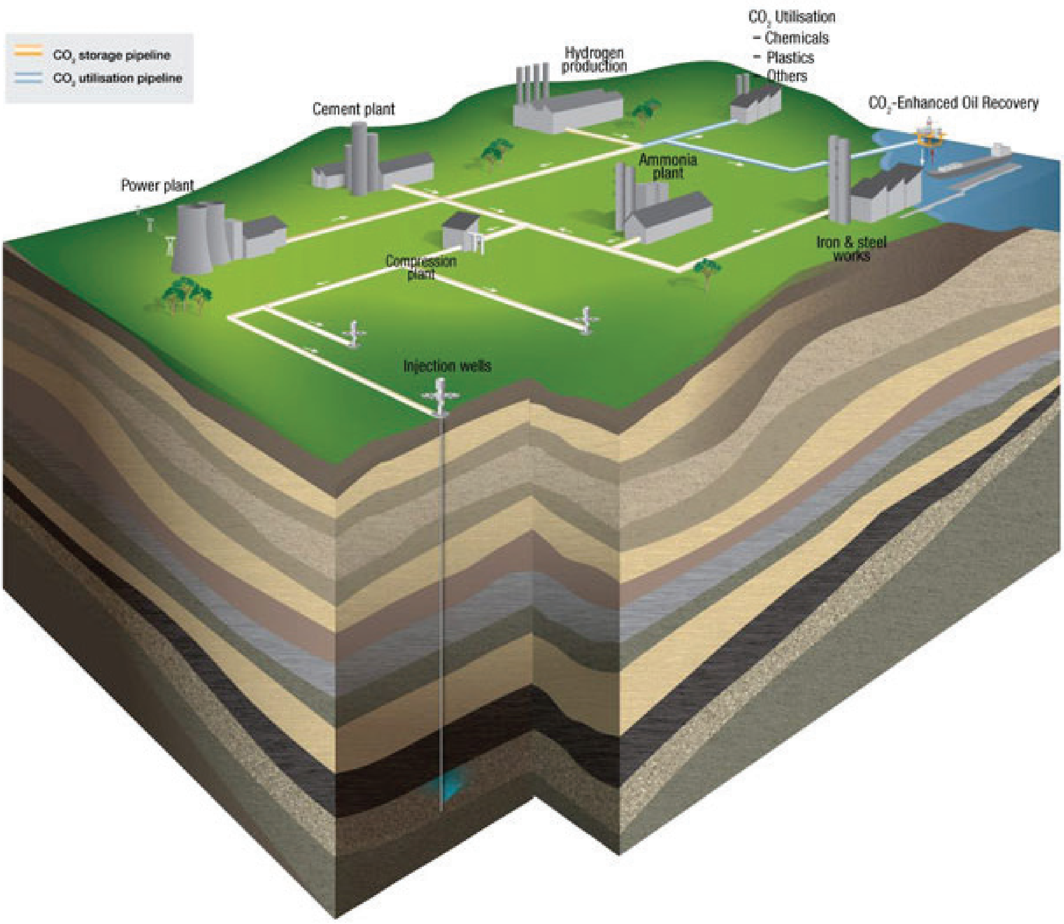
By 2050, the value of the hydrogen sector would be around $23 billion. This analysis highlights the growing share of electrolysis in hydrogen production, similar to that set out by the IEA, so that by 2050, some 900 TWh of power is used in the industry. This compares with current annual Australian power use of 260 TWh today. By 2050, hydrogen produced in Australia by electrolysis and fossil fuels with CCUS globally saves 131 Mt of CO_2 annually, with accumulated emissions avoided totalling 1.08 Gt.

ACIL Allen in a report prepared for ARENA, assessed Australia's hydrogen exports by 2040 to be between 0.62 and 3.2 Mt based on relatively conservative assumptions.[11]

The value of these exports was estimated at A$13.4 billion. Again, ACIL Allen noted that in this case, assuming all hydrogen was based on electrolysis powered by renewable power, an additional 200 TWh would be needed, a near doubling of existing power use. Taking into account the assumed rapid decarbonisation of the existing power system, plus additional demand from electric vehicles and electric heat pumps, this would be challenging without hydrogen production based on fossil fuels with CCUS.

A comparison with the growth of the export natural gas industry in Australia is instructive. Over the last 30 years, Australian shipments of LNG expanded from an initial 5 Mt to some 77 Mt, to be worth some $50 billion in 2018 and 2019 before the pandemic impacted prices. Of course, recent price rises have seen revenues from LNG exports rise very substantially.

FIGURE 7. ACTIVITIES INVOLVED IN CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)



Source: CO2CRC

[10] Deloitte, *Australian and Global Hydrogen Demand Growth Scenario Analysis*. Report to COAG Energy Council, National Hydrogen Strategy Taskforce, November 2019.

[11] ACIL Allen Consulting, *Opportunities for Australia from Hydrogen Exports*, August 2018.

BOX 1: CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)

Currently, 30 CCUS commercial projects are operating globally, with a capacity of around 42 Mt CO_2 annually, and a further 164 are in various stages of development.

The first dedicated capture and geological storage project started in 1996 off the coast of Norway at the Sleipner gas field. It has sequestered some 20 Mt so far. Early CCUS projects have focused on facilities where CO_2 is already extracted, or where there are large concentrated CO_2 waste streams. The former include natural gas processing facilities (with Occidental Petroleum Corporation's Terrell capture facility in Texas, USA, celebrating its 50th birthday in 2022), and more recently, some sixteen hydrogen production facilities based on fossil fuels.[12]

However, CCUS has not advanced as fast as required in any low carbon future scenario. Global investment has consistently been less than 1 per cent of total investment in clean energy technologies. Lack of consistent policy support is the main reason. This is changing as costs have inevitably declined, and support measures, notably in the US, have emerged. For example, in 2022 the total capacity of the CCUS project-pipeline increased for the fifth year in a row and by 44 per cent over the previous year.

More than 70 new integrated projects have been announced in recent years, capable of around 90 Mt of annual capture capacity. Some of these projects are based on coal and gas fired power, and cement manufacture; applications where retrofitting will be essential if carbon reductions plans are to be met. Cement alone emits some 5 Gt annually, or 8 per cent of global CO_2 emissions, and CCUS is considered one of the few viable routes to address this. Amongst a number of recent project announcements, Norway's Equinor announced plans to produce hydrogen with CCUS in the UK.

More than one-third of planned projects involve the development of industrial CCUS hubs with shared CO_2 transport and storage infrastructure, in more than two dozen locations. One notable example is Norway's Longship project, involving CO_2 capture from industrial sources in the Oslo-fjord region (cement and waste-to-energy), plus other potential sources with sequestration under the North Sea. The associated Northern Lights project is the world's first cross-border, open-source CO_2 transport and storage infrastructure network and offers companies across Europe the opportunity to store CO_2 safely and permanently underground. Phase one of the project will be completed in mid-2024 with a capacity of up to 1.5 million tonnes of CO_2 stored each year. Australia's CarbonNet and Carbon Transport and Storage Company (see Section 3) are also adopting this model.

One particular region where CCUS may play an important role is Southeast Asia, where over 90 per cent of the region's energy supply is fossil based, energy consuming infrastructure is relatively new and where several large coal and gas producers and exporters are located. Regional approaches, emulating those being developed in the North Sea, could utilise depleted oil and gas fields in the region. Seven large scale CCUS projects have been identified, including several linked to offshore gas processing, with offshore storage. One plan recently announced involves capturing emissions from Singapore manufacturing plants for storage in the region. Emissions in the region from existing power generation and industrial plants are currently around 1 Gt. By 2050, taking into account facilities under construction, emissions from these facilities will still be 400-500 Mt, without CCUS retrofitted or other abatement measures such as biomass, or co-firing with hydrogen or ammonia. Given this it is important to note the launch of the Asia CCUS Network in 2021. Its members include Australia, India, Japan, US and nine of the ten ASEAN member states. Its aim is to provide a platform for policymakers, financial institutions, industry and academia to work together to ensure the successful development and deployment of CCUS in the Asia region. Opportunities to use offshore storage options in Malaysia, Indonesia and northern Australia could form the basis of new CCUS transport and storage hubs.

[12] IEA, Energy Technology Perspectives 2020, *Special Report on Carbon Capture Utilisation and Storage*, 2020.

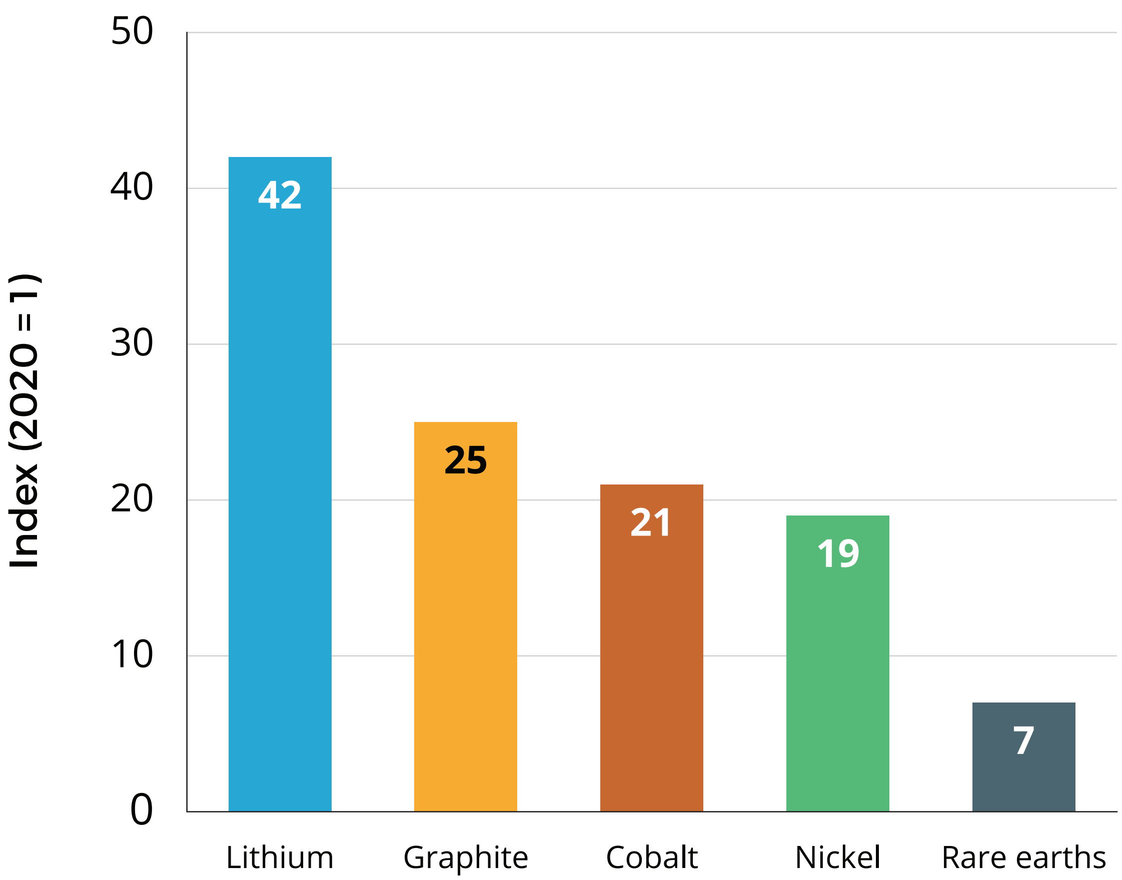
5 AUSTRALIA'S RESOURCES ENABLE RENEWABLE AND FOSSIL-BASED HYDROGEN INDUSTRIES

There seems little doubt that the commitment by governments globally to an accelerated energy transition is increasing.

Such a transition, powered by clean energy technologies, seems likely to have profound consequences for minerals and mining industries, as demand for some mined commodities falls, potentially quickly, while that for other commodities rises. Just the shift to electricity alone will increase demand for copper dramatically.

Greater battery deployment will increase demand for lithium, nickel, cobalt, and manganese. Moves to end sales of conventional internal combustion engine vehicles will affect demand for metals used in catalytic exhaust systems. Countering this is the likely rapid growth of electrolyser produced hydrogen, which will drive major increases in nickel and zirconium, as well as platinum group metals for fuel cells (see Figure 8).

FIGURE 8. DEMAND GROWTH IN TRANSITION MINERALS BY 2040, RELATIVE TO 2020



Based on the IEA Sustainable Development Scenario in *World Energy Outlook 2020*, namely net zero by 2070. In a net zero scenario by 2050, demand could be expected to be around 50 per cent higher.

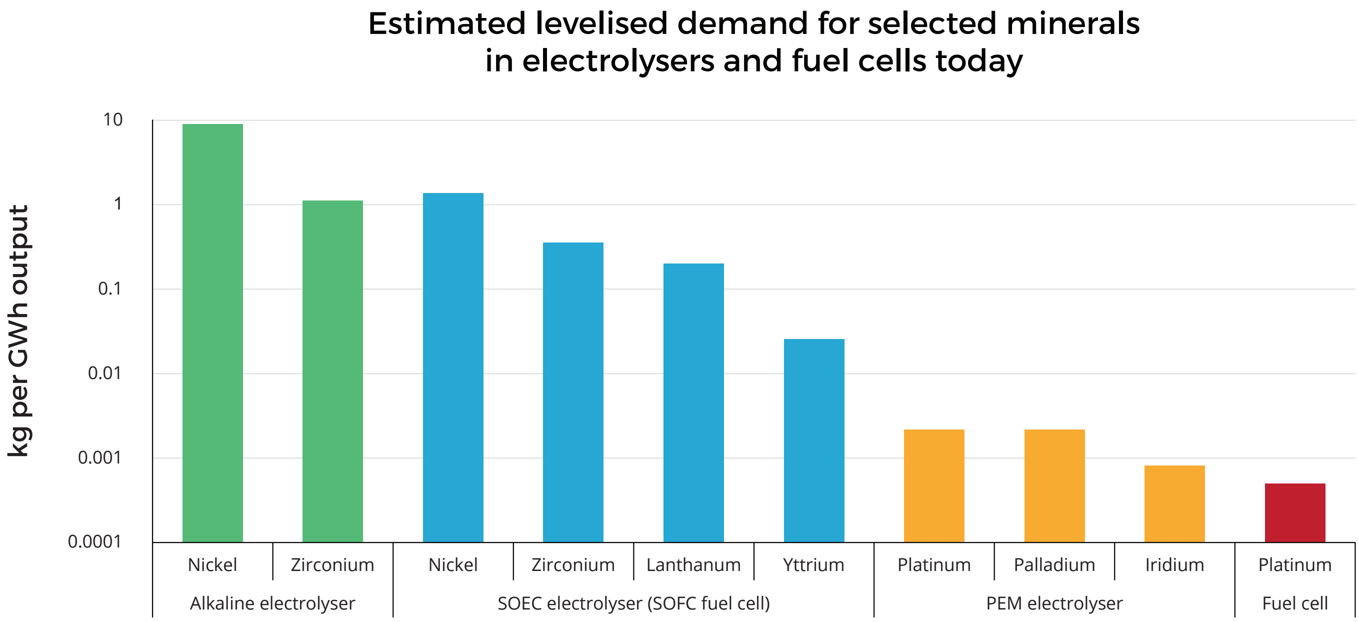
Source: IEA, World Energy Outlook Special Report, *The Role of Critical Minerals in Clean Energy Transitions*, May 2021, p. 9.

Potentially rapid technology change may reduce demand for some of these minerals, and recycling will be an important part of managing the transition. But major changes in the demand for minerals seem inevitable (see Figure 9). Investment delays, especially those brought on by uncertainty on the pace of climate action, could affect investments in new mines, often with long lead times, leading to price increases and issues around reliability of supply.

The supply of these and other minerals, such as rare earths used in magnets, raises potential new vulnerabilities in the energy system, as some of these minerals come from relatively few, geographically concentrated supply sources. For example, China dominates the processing of copper, nickel, cobalt, lithium, and rare earths, in the latter case accounting for near 90 per cent of global capacity. In a net zero emission trajectory, the total market size of these minerals increases seven fold over the next decade, raising real issues if supply cannot respond in a timely fashion, (hence causing price volatility) and also redefining energy security.[13]

Australia is well placed to respond to these challenges (Figure 10), with significant resources of key minerals and metals, a proven track record of innovative timely development, and a long history of reliable and responsible supply to a range of consumers. In particular, Australia provides just over half of global lithium supply, (emerging as the global leader only in 2017) with the capability to build a lithium hydroxide processing facility in Western Australia. Globally, demand for lithium for electric vehicles could grow from 25,000 tonnes to over 400,000 tonnes over the course of this decade, with total lithium demand rising to more than a million tonnes by the middle of this decade.[14, 15] Australian lithium production is expected to more than double over the next five years, with exports rising to 4 Mt by 2026. Australia is also in the top five global producers of cobalt and manganese, and some rare earth elements (dysprosium, neodymium). In the case of cobalt, Australian production provides important diversification benefits, as global production is dominated by the Democratic Republic of the Congo. For rare earth elements, Australian output (both existing and prospective) offers diversification from a global supply dominated by China.

FIGURE 9. ELECTROLYSER DEPLOYMENT DRIVES MINERALS DEMAND, DEPENDING ON THE TECHNOLOGY ADOPTED



Notes: PEM = proton exchange membrane; SOEC = solid oxide electrolysis cells; SOFC = solid oxide fuel cell. Normalisation by output accounts for varying efficiencies of different electrolysis technologies. Full load hours of electrolysers assumed to be 5,000 hours per year.

Source: IEA, World Energy Outlook Special Report, *The Role of Critical Minerals in Clean Energy Transitions*, May 2021, p. 111.

[13] IEA, World Energy Outlook Special Report, *The Role of Critical Minerals in Clean Energy Transitions*, May 2021.
[14] Department of Industry, Science, Energy and Resources, *Resources Technology and Critical Minerals Processing National Manufacturing Priority Road Map*, 2021.
[15] A Best and C Vernon, CSIRO, *State of Play, Australia's Battery Industries*, 2020.

Increasingly, international demand for clean energy commodities seems likely to focus on the emissions intensity associated with their production. Australia's mining industry has the ability to showcase some emerging technologies, such as electric and hydrogen powered mine haul trucks and in other operations and transport, renewable power replacing diesel and natural gas. For example, BHP's Nickel West refinery near Perth will buy half its power needs from the Merredin Solar farm.

Taking all the advantages into account, there are excellent prospects for enhanced upstream processing in Australia, and the employment and economic benefits that follow.

Australia's prospects for growing exports are best summed up by the government's commodity forecaster, the Office of the Chief Economist in the Department of Industry, Science, Energy and Resources:

> Australia's exports of the commodities that are central to new and low emission technologies are set to surge over the next five years. From an estimated $1 billion in 2020-21, lithium exports are set to rise more than five-fold in real terms. Nickel exports are expected [to] almost double, while copper exports are set to increase by a third over the same period. Revenue from these three commodities combined is now set to exceed current thermal coal revenue (in real terms) by 2025-26, as Australia's resources sector captures growth opportunities presented by new technologies and energy systems that are evolving.[16]

FIGURE 10. AUSTRALIA'S CRITICAL MINERALS: RESOURCES, RESERVES, AND PRODUCTION

CRITICAL MINERAL	GEOLOGICAL POTENTIAL	ECONOMIC RESERVES RANKING	PRODUCTION RANKING
Cobalt	High	2nd in the world	3rd largest producer
Graphite	Moderate	8th in the world	No production
Lithium	High	2nd in the world	World's largest producer
Rare earths	High	6th in the world	2nd largest producer
Titanium	High	Ilmenite – 2nd in the world Rutile – 1st in the world	Ilmenite – 3rd largest producer Rutile – world's largest producer
Tungsten	Moderate	2nd in the world	Minimal production
Vanadium	Moderate	3rd in the world	No production
Nickel	High	1st in the world	4th largest producer

Source: Department of Industry, Science, Energy and Resources, *Resources Technology and Critical Minerals Processing National Manufacturing Priority Road Map*, 2021, p. 12.

[16] Department of Industry, Science, Energy and Resources, Office of the Chief Economist. *Resources and Energy Quarterly*, March 2021, p. 4.

6 POLICY MEASURES TO DRIVE HYDROGEN DEPLOYMENT

Arguably, the key factor in the evolving hydrogen industry globally and nationally will be the development of firm demand.

One of the key learnings from the expansion of the global LNG industry was the key role of long-term, relatively inflexible purchase agreements, with competitive pricing formula that protected both buyers and sellers in the event of changing circumstances. The earliest LNG projects in Australia (and indeed in the Asia-Pacific region more broadly) were underpinned by 20 year contracts, indexed to oil prices, (seen as the competitive fuel) with protection at both high and low oil prices. With such contracts, finance was obtained, very capital-intensive projects were able to proceed and, over time, Australia was able to secure one-fifth of the growing global trade in LNG.

This illustrates the point that economically efficient and transparent techniques need to be considered to create demand for hydrogen, even where costs may be higher than fossil alternatives such as natural gas or oil. Some countries are using carbon pricing to address this issue. Other policies can also be deployed, such as investment incentives, quotas, auctions, or contracts for difference, where experience shows that working with markets can be a very effective way of driving down costs. Such firm purchase commitments can reduce risk, and thus improve the prospects for capital-intensive hydrogen production. However, such approaches can be expensive for both consumers and governments, and lacking in transparency, even where policy is carefully designed. As noted above, close collaboration with international partners was an essential feature of gas and other export trade development, and seems likely to be of equal importance in the development of hydrogen trading.

Strong support for innovation will be essential over the next decade, especially for demonstration projects. As noted above, international certification, standardisation and regulation will be basic to ensuring low carbon hydrogen reaches its full potential. This will be fundamental to developing a global hydrogen market that avoids transfer of carbon emissions from one country to another. A final policy strand will be intensified co-operation between countries, notably potential importing and exporting countries, to develop newer cost effective technologies and the supply chains needed to make large scale international trade a reality.

A growing number of countries and states have adopted hydrogen strategies, embodying some of these features. Most emphasise the need to establish hubs as a way to drive demand, by grouping users, encouraging supply to respond to that, as well as centres for research, development, demonstration, and expertise, all aimed at driving down costs.

Japan was amongst the first to develop a national Hydrogen Strategy Roadmap, first in 2014, and revised in 2019. It sets the goal of reducing hydrogen costs by 70 per cent by 2030, (noting that this would still be more than double current LNG prices), as well as a goal of building commercial hydrogen supply chains to provide 300,000 tonnes of hydrogen by 2030. Technical development of liquid hydrogen supply chains would need to be demonstrated by the mid-2020s. The Strategy also sets a near term target of reducing CO_2 emissions when hydrogen is produced from fossil fuels to below 60 per cent of current levels, with a longer term goal of virtually zero. Japan also has a goal of 1 GW of hydrogen based power generation by 2030, with a longer-term target of 15-30 GW. Ambitious targets are in place for fuel cell electric vehicles and buses, using hydrogen.[17,18] Clearly, the HESC project discussed above fits within this roadmap, along with other projects, including one with Brunei.

Korea published its national Strategy in 2019, with strong links to the vehicle industry, targeting six million fuel cell vehicles in 2040. Some 15 GW of fuel cells in power generation is also targeted for 2040, along with a million households powered by fuel cells.

China has ramped up hydrogen, with some 50 projects announced, half of which are linked to transport.[19] Some USD 20 billion in direct investment has been committed. Production costs for coal gasification, plus CCUS, are estimated at USD 2.8 per kg, with falls of around 10 per cent anticipated by 2030.

[17] Ministry of Economy, Trade and Industry, Japan, *The Strategic Roadmap for Hydrogen and Fuel Cells*, 2019.
[18] International Partnerships for Hydrogen and Fuel Cells in the Economy (IPHE), *Japan*, viewed 7 April 2021.
[19] Hydrogen Council, *Hydrogen Insights 2021*, updated 15 July 2021.

The EU published an updated Hydrogen Strategy in mid-2020, with a goal of 40 GW of electrolyser capacity by 2030. Spain, Germany and France all have individual hydrogen plans and targets. Over 80 per cent of new hydrogen projects are located in Europe, which must be considered the global leader in this field. Germany is funding 62 large-scale hydrogen projects with some €8 billion in Governments' funding.[20] The German Federal Government is also underwriting an initiative to purchase hydrogen on international markets, under long term contracts, to be auctioned in Germany. Supported by €900 million, this is amongst the largest demand building initiatives globally. Germany has signed co-operation agreements with several potential supplying countries, including Canada, New Zealand and Australia (see below). In an effort to reduce its dependence on Russian gas, the EU recently announced plans to increase hydrogen imports sharply by 2030.

Australia's 2019 Hydrogen Strategy set a goal of reducing hydrogen production costs to below $2 per kg, approaching an order of magnitude reduction. In co-operation with all States and Territories, some $400 million has been committed to support hydrogen development. As noted earlier, hub development is a key part of the strategy, along with a number of strategic partnerships with potential consuming countries, such as Germany. In September 2020, the Australian and German Governments agreed to fund a joint feasibility study to investigate hydrogen supply chains. Australia and Singapore have established a partnership to reduce emissions in maritime and port operations using low emission fuels like hydrogen, ammonia and hydrogen derivatives.[21] Joint initiatives are also in place with Japan, Korea, the UK and the US.

The Federal Government has a number of specific programs in place to support hydrogen production and trade, including some $464 million to develop regional hydrogen production, embracing industrial hubs. These programs are in addition to the near $1.8 billion administered through ARENA and $300 million through the Clean Energy Finance Corporation.

[20] CSIRO, *International Hydrogen Policy Developments—an Update*, July 2021.
[21] Prime Minister of Australia, *Australia partners with Singapore on hydrogen in maritime sector*, 10 June 2021.

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