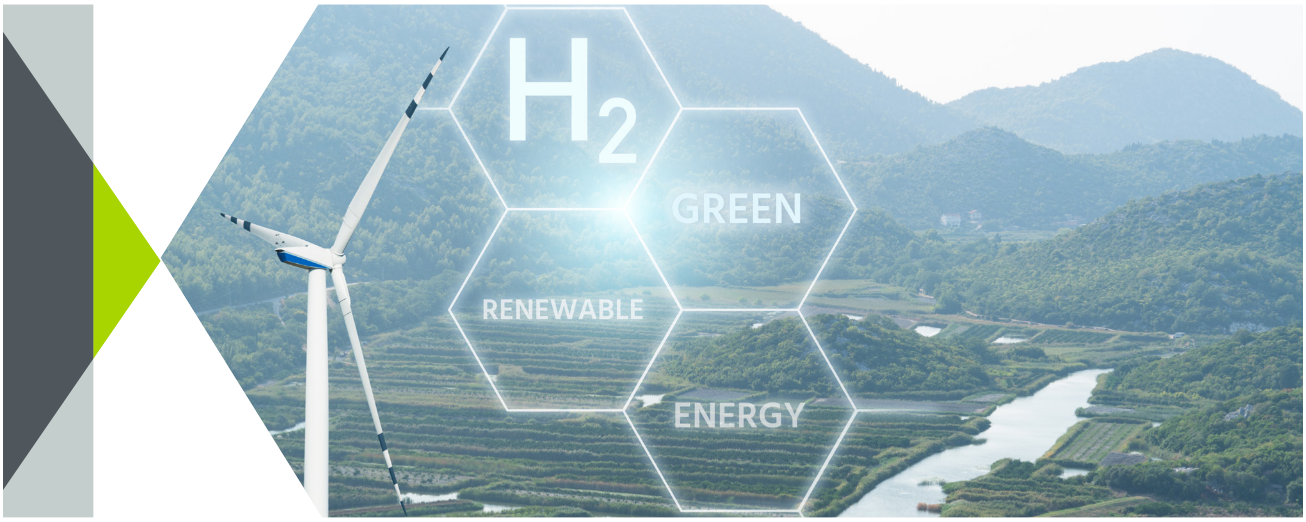


EXECUTIVE INSIGHTS

Green Hydrogen — Zero Emissions, One Careful Balancing Act

Key takeaways

- Hydrogen is expected to play a key role in global decarbonisation efforts, with global demand projected to grow at around 6%-9% per annum if governments and industries around the world expect to meet their emissions targets by 2050.
- The fast-evolving hydrogen industry is in its early stages of development in Australia. It is considered to have potential as an important solution for the evolving domestic energy market, as a clean energy input for industry, and also as a clean source of energy for export customers.
- 'Green' hydrogen, generated entirely from renewable energy, has significantly lower carbon emissions compared to other hydrogen production methods, but the cost of production can be considerably higher today than for other approaches.
- L.E.K. Consulting has identified the key issues that industrial users of hydrogen such as ammonia and steel producers, energy market participants, and service providers to these industries need to consider when determining how to position and participate in the potential opportunities from green hydrogen.

For some in the renewable energy debate, green hydrogen — generated via electrolysis, entirely using low-cost renewable energy — appears an ideal clean energy source that could make an important contribution to bring the world to net-zero emissions. However, there is a prevailing market view in Australia that the current production costs for green hydrogen make it too expensive to consider when compared to alternative approaches to decarbonisation or when considering exposure to higher emission inputs. There are strong views on both sides: like many debates, the most likely answer lies somewhere in the middle.

Whatever the answer, it's important for investors, manufacturers or energy operators looking to enter this area to have a very clear view of the factors behind 'the case for green hydrogen', and how these variables will work for and against them in their individual activities in this space.

Why hydrogen?

Expectations about hydrogen's role as an energy alternative to petroleum products are growing daily, particularly given the focus on global decarbonisation and emissions targets.

Hydrogen has many applications as an alternative fuel across a wide range of industries and uses. The transport sector has many examples: for fuel-cell hydrogen electric cars and trucks, or for container ships powered by liquid ammonia made from hydrogen. In fleet applications, hydrogen competes against direct electrification using batteries for clean energy.

Green hydrogen also has many other industrial applications that range from clean energy through to use as an alternative input for the chemistry involved in industrial processes. As a clean industrial energy source, green hydrogen can be created and stored to power electricity turbines to generate electricity at times of peak demand to help firm the electricity grid, or as a substitute for natural gas for cooking and heating in homes (albeit to an estimated 10%-15% mix limit with present day pipe infrastructure and appliances).[1]

Examples of use in industrial processes include using hydrogen in place of coking coal to strip oxygen from iron ore and reduce it into pure iron for 'green steel' (rather than for heat), and to create hydrogen required to synthesise ammonia for use in fertiliser and explosive production. Indeed, in Australia today, ammonia and ammonia nitrate products account for almost 75% of Australian hydrogen production (made via steam methane reforming).

Hydrogen can also play a role as an 'energy carrier' for exports, either through compression and transport in a similar fashion as natural gas today or when converted into ammonia. Australia is seen as a potential net exporter of hydrogen given its access to renewable energy sources and existing natural gas trade routes. This means there is a potential opportunity for Australia to export hydrogen to energy-hungry countries that are not blessed with Australia's renewable energy resources and potential.

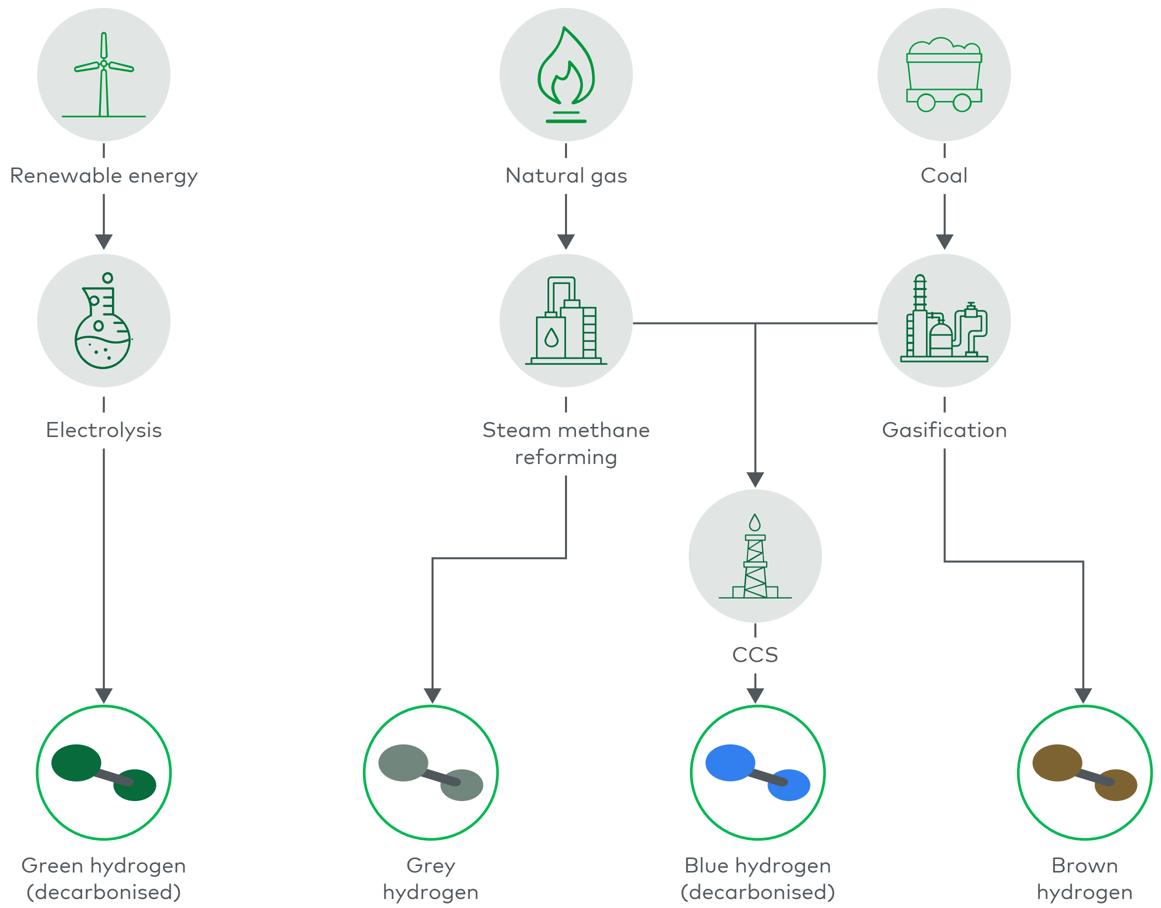
While hydrogen has significant potential in this range of applications, market demand is still developing while technologies mature, costs reduce across the value chain, and similar dynamics play out for alternative approaches that are effectively competing against hydrogen to reduce emissions in various applications (see the case study below "Bringing it to life – hydrogen as a use case in Transport" for an example of this).

Green vs 'the other colours'

There are many different types of hydrogen production (see Figure 1), all described by different shades and with varying levels of embodied carbon, including:

- Brown hydrogen, which is produced using coal, where the emissions are released to the air.
- Grey hydrogen, which is produced from natural gas, where the associated emissions are released to the air.
- Blue hydrogen, which is produced from natural gas, where the emissions are captured using carbon capture and storage (CCS). Blue hydrogen is derived from natural gas, typically through the process of steam methane reforming (SMR) coupled with CCS, but can also use alternative hydrogen production technologies like autothermal reforming (ATR) or partial oxidation (POX) combined with CCS. As the main method of producing (grey) hydrogen today, SMR mixes natural gas with very hot steam, in the presence of a catalyst, where a chemical reaction creates hydrogen and carbon monoxide.
- Green hydrogen, which is produced from electrolysis powered by renewable electricity generated from low carbon sources.

Figure 1
Key Hydrogen production methods



Source: CSIRO, IEA, ARENA, L.E.K. research

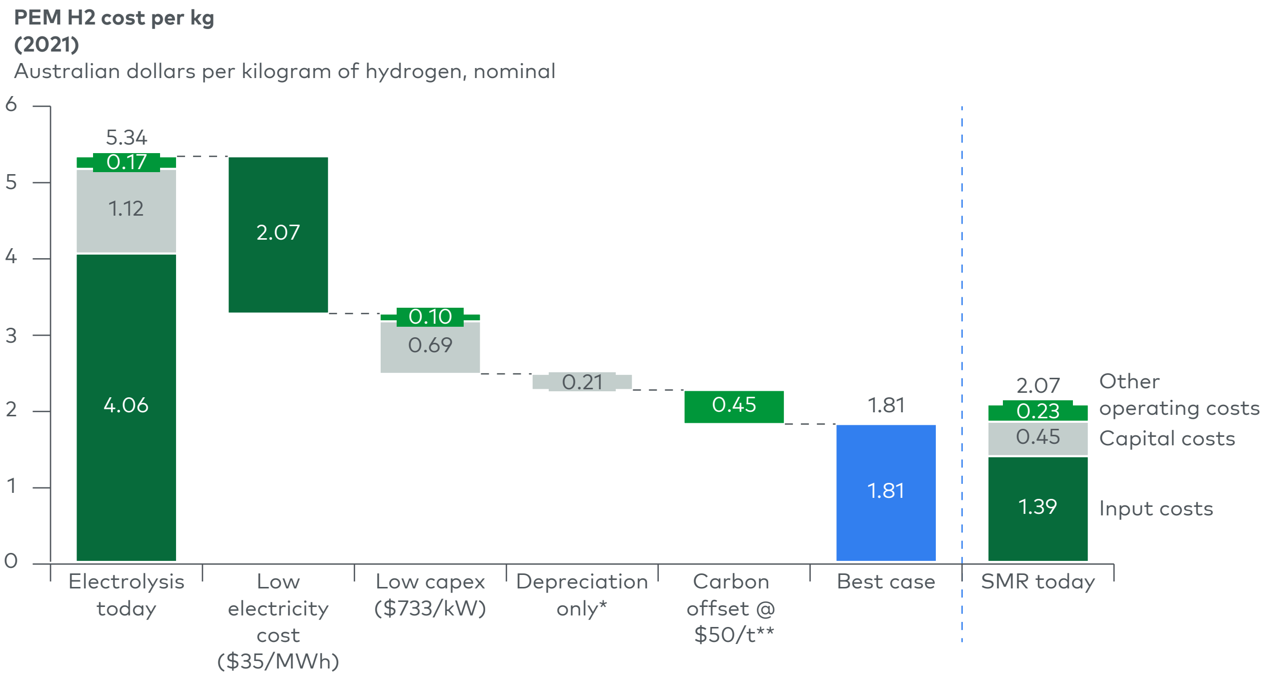
Green hydrogen — produced with electricity from renewable sources — is compatible with sustainable, climate safe energy use or net-zero emissions, and provides the best long-term alternative hydrogen source, in comparison with other options such as grey or hybrid blue hydrogen. Blue hydrogen does appear to present short-to-medium term advantages of being more cost competitive than green hydrogen, and it does provide lower emissions than other alternatives aside from green, so it will have a bridging role in the shift to more environmentally friendly alternatives, but green hydrogen appears to provide the best long-term alternative.

Green hydrogen forms a cornerstone of the shift away from fossil fuels. Its uptake will be essential for sectors like heavy industry, international shipping and aviation, where energy intensity is high and emissions are hardest to abate; consequently, these industries have a particular need for the benefits that green hydrogen will bring as an energy or process input alternative.

However, the majority of hydrogen currently produced globally and in Australia today is derived from fossil fuel sources, with nearly 99% of hydrogen fuel coming from carbon-based sources rather than renewables — and can't therefore be classed as green — but existing production capacity and the need to demonstrate demand to underwrite green hydrogen investments may create a transitional role for other shades of hydrogen (e.g. blue).

The economic case

Figure 2
Key drivers for cost competitive green hydrogen



Note: Calculated based on $72/MWh electricity, $8/GJ gas, $1,933/kW capex, 10% capital charge
*Represents the difference between a 10% capital charge and straight line depreciation over a 20-year useful life
**Revenue assumes 9kg of CO2 emissions produced for 1kg of H2 produced using SMR technology, and reduces the net costs of electrolysis through carbon offset
Source: IEA; ARENA; MDPI; US Department of Energy; IOP Science; Argonne National Laboratory; L.E.K. research and analysis

Currently, the high cost of production of green hydrogen versus the current low cost of other hydrogen production methods is a key challenge for adoption. As noted above, grey or blue SMR hydrogen has a considerable short-to-medium term energy input cost advantage over green hydrogen, with the natural gas it requires costing about half on the east coast of Australia of what it costs to produce green hydrogen — and this is despite gas prices that are relatively high by global standards.

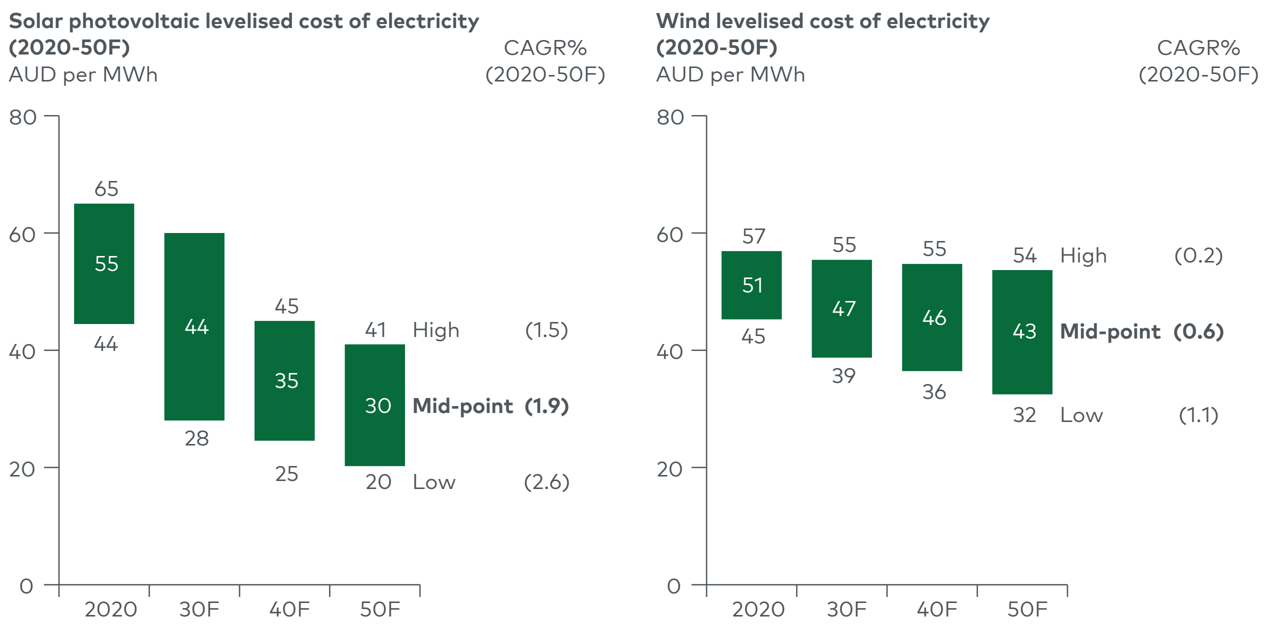
The chart Figure 2 above shows that hydrogen produced by electrolysis today using c.$70/MWh delivered electricity is much more expensive than hydrogen produced using steam methane reforming of natural gas at c.$8/GJ. However, the key factors that really drive the case for grey or blue (SMR) hydrogen versus green hydrogen production are the cost differences around electricity input, the capex costs for electrolysers and other equipment, the efficiency of electrolysers, and associated costs like carbon pricing.

Many of the other potential variables have little impact on the overall cost difference — and the cost of electricity is far and away the most important factor for green hydrogen competitiveness. Our analysis shows that without a solution for lower-cost electricity than is supplied by Australia's grid today, green hydrogen cannot be cost competitive.

While bridging the economic gap from electrolysis to SMR today looks daunting, the factors that close this gap are not implausible.

Advocates for green hydrogen cite the experience and forecasts for declining cost of renewable energy (see Figure 3), and low wholesale electricity spot prices during daytime hours driven by strong uptake of solar PV.

Figure 3
Forecast costs for Australian renewable energy



Source: CSIRO - GenCost 2021-22 Final report; L.E.K. research and analysis

CSIRO, the Australian government agency for scientific research, has forecast a 2% per annum decrease in the Australian cost of solar utility photovoltaic each year to $30/MWh by 2050 ($20/MWh in a low case), and the Australian government's 2021 low emissions technology road map set a stretch goal for solar generation at $15/MWh. Of course, these renewable energy costs are not necessarily the energy costs that a hydrogen producer would face, with potential for additional transmission and distribution costs where hydrogen production is not co-located with renewable energy generation, or if 'firm' electricity from other sources is needed to enable 24/7 production.

Australia's governments are seeking to facilitate fast tracking commercial-scale deployments of renewable hydrogen, facilitate cost reductions in production and create appropriate market incentives. For example, in February 2020, the Australian government set a stretch goal of 'H2 under $2' to produce green hydrogen for $2 per kilogram, and there are numerous examples of projects receiving support from the Australian Renewable Energy Agency (ARENA) and Clean Energy Finance Corporation (CEFC).

This $2/kg H2 figure is in the range of current input prices of H2 to east coast ammonia production, but based on recent analysis performed by L.E.K., it is not cost-effective to be competitive as an input to other industrial processes such as steel, alumina or cement, where substantially lower-cost H2 would be required to compete with current higher emission methods of production.

L.E.K.'s analysis set out above also shows that while commonly cited factors like a carbon cost or credits and reducing electrolyser capital costs improve the relative economics of green hydrogen, they are not sufficient to make green hydrogen economically attractive — a much lower electricity price is a fundamental enabler for Australian-produced green hydrogen to be competitive against existing fuel sources and internationally.

Bringing it to life — hydrogen as a use case in transport

Hydrogen can be used to power a range of vehicles. Hydrogen-powered vehicles typically consist of an electric drive motor, a fuel cell and a liquid hydrogen storage tank.

Transport is one of the early use cases that can support the transition to hydrogen fuels. However, its suitability depends on several key factors:

- Capital premium of fuel cell electric vehicles (FCEVs) compared to other zero emission vehicle (ZEV) technologies.
- Storage and distribution challenges, especially ensuring attractive economics during ramp-up, before the industry is at scale.

- The physical and chemical properties of hydrogen, which mean it can't always be easily retrofitted into existing transport vehicle designs.
- The speed at which alternative technologies are evolving, in particular battery technologies.
- The extent to which there are suitable alternatives. In some transport use cases there are no compelling alternatives to hydrogen. The additional financial cost may need to be incurred to meet our net zero emissions targets.

Consequently, each transport use case needs to be examined independently to understand how hydrogen might play a role.

Passenger vehicles: Lithium-ion battery technology is well advanced. There were more than 10 million battery electric vehicles (BEVs) and plug-in hybrid vehicles on the world's roads in 2020 compared to just over 25,000 FCEVs.[2] FCEVs benefit from a significantly higher energy density than batteries, decreasing fuel weight and refuel duration. However, they come at a significant price premium. Hyundai's FCEVs are currently c.4 times more expensive than the equivalent internal combustion energy vehicles (ICEVs).[3] With battery technology (range and density) improving quickly, FCEVs may be relegated to niche use cases where range cannot be adequately served by BEVs.

Buses: Hydrogen fuel cell electric buses (FCEBs) offer a longer range than battery electric buses (BEBs) and have lower infrastructure requirements at the depot. However, they are commercially unviable at present. The cost of hydrogen remains high and with current FCEB manufacturing limited, they are significantly more expensive than BEBs. This has been a key barrier to widespread adoption. Even at a delivered hydrogen cost of $2/kg, capital cost reductions of FCEBs are required to break even on a total cost of ownership basis with ICE alternatives. With 80%-90% of metro routes able to be serviced by BEBs, FCEBs are most suited to long-range applications such as coaches, and certain routes where en route fast charging may not be practical.

Aviation: There are several alternative energy sources in contention for reducing the emissions intensity of aviation. The main issue with hydrogen is that the energy density of liquid hydrogen is only 25% of jet fuel, therefore reducing space for fare-paying passengers or cargo. Airbus has presented three concept planes which it says could be ready for deployment by 2035. Each has required some modification to its standard designs, and all three configurations are envisaged as hydrogen hybrids.

Rail: The first hydrogen train was launched by Alstom in 2018. The Alstom Coradia iLint regional passenger train aims to show that fuel cell technology could provide sufficient capacity, range and speed to mirror today's diesel trains. From a design perspective, rail is more suited to hydrogen, as it can cater to larger volumes with limited modification. This improves the economics. The attractiveness of hydrogen depends on the alternative cost of electrification and is highly dependent on the specific use case. For example, hydrogen-powered trains would be most attractive in remote and rural areas with infrequent operation.

Trucks and other heavy vehicles: Current and even projected future battery technology may not be enough to store as much energy required to power trucks and other heavy haul vehicles without taking valuable cargo space and weight. Hydrogen would be most suited to those use cases with high-frequency predictable routes. Predictability of routes allows for consolidation of storage and refuelling infrastructure, which can improve the cost economics of hydrogen.

There are some positive factors to consider

Both here and overseas, green hydrogen seems to have some current factors and future potentials in its favour. For some industries in particular — fertiliser and ammonia production, and steel manufacturing — it becomes the most likely or indeed only solution as an alternative to 'traditional' hydrogen sources.

The United States Department of Energy forecasts that the global green hydrogen market is expected to grow, with the cost of green hydrogen production falling from $6 per kilogram in 2015 to $2 per kilogram or lower by 2025. Countries like Japan and South Korea are also pursuing hydrogen as a policy priority.

Supporting this, the Institute for Energy Economics and Financial Analysis (IEEFA) in January 2021 also predicted the price of green hydrogen will drop 70% in the next decade in regions with cheap renewables, such as the Middle East or the Pilbara in Western Australia with its access to cheap green energy sources like abundant daytime solar power.[4]

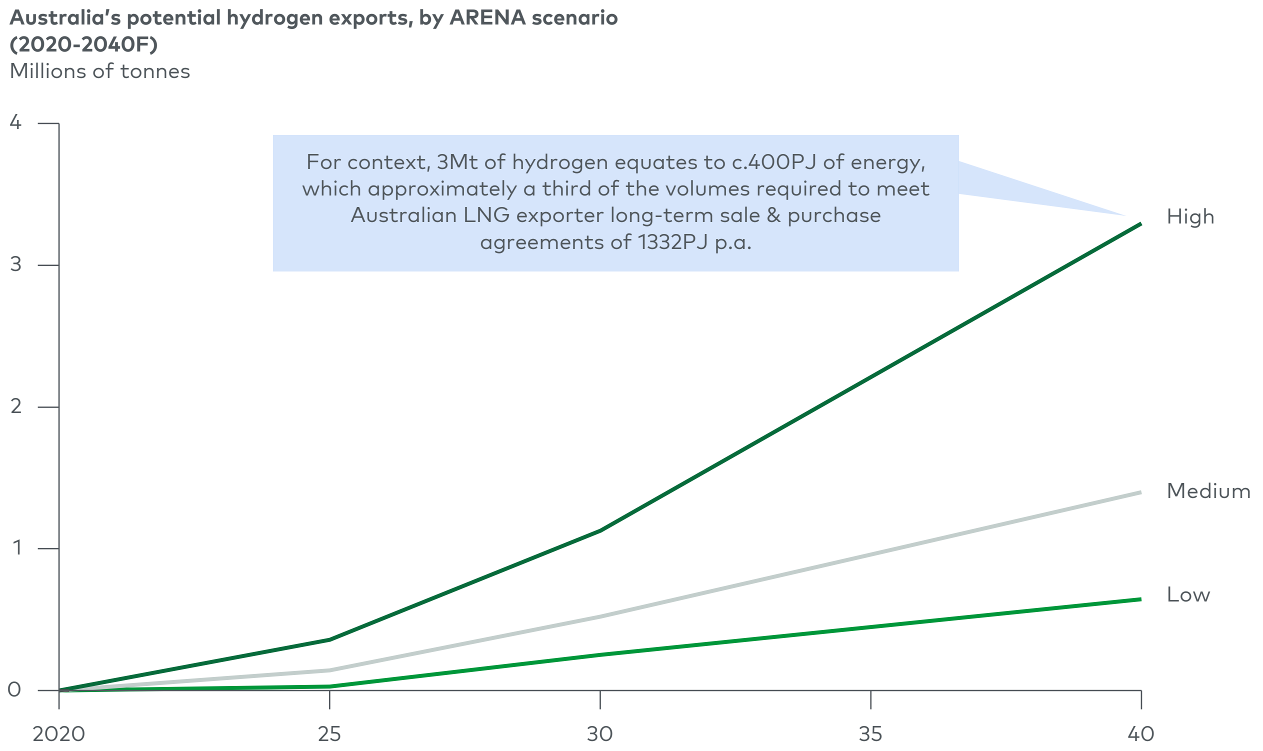
In east coast Australia, green hydrogen today costs twice as much as conventional grey hydrogen, but a 2020 Australian National University report estimated that Australia could be producing it for much cheaper, even currently, and it could equal the price of conventional hydrogen by 2030.

The CSIRO's 2018 National Hydrogen Roadmap report also suggests there is an opportunity for Australia to export green hydrogen to energy-hungry countries that do not have access to cheap renewable energy. It estimated potential demand for imported hydrogen in China, Japan, South Korea and Singapore could reach AU$9.5 billion by 2030. These nations all have stated hydrogen commitments that have the potential to be serviced by Australian-produced hydrogen:

- South Korea, which has targeted approximately three million fuel cell vehicles (FCVs) to be in operation by 2040, supported by a US$1.8 billion fund to invest in hydrogen
- Japan, which has a projected demand of 300 kilotonnes of hydrogen per annum until 2030, with the hydrogen to power approximately 800,000 FCVs and fuel 5.3 million stationary fuel cells in households
- China, which has stated a hydrogen FCV road map with a target of approximately one million FCVs operating, with at least 50% hydrogen-powered by 2030
- Singapore, which is currently exploring a national hydrogen strategy to replace national emissions by around 60%, predominantly through replacing existing liquid natural gas (LNG) with hydrogen

ARENA estimates of Australian hydrogen export volumes (see Figure 4) show the significant size of this opportunity for Australia. To put this approximately three million tonnes of hydrogen into perspective, it is broadly equivalent to a third of the energy exported today by Australia's LNG industry.

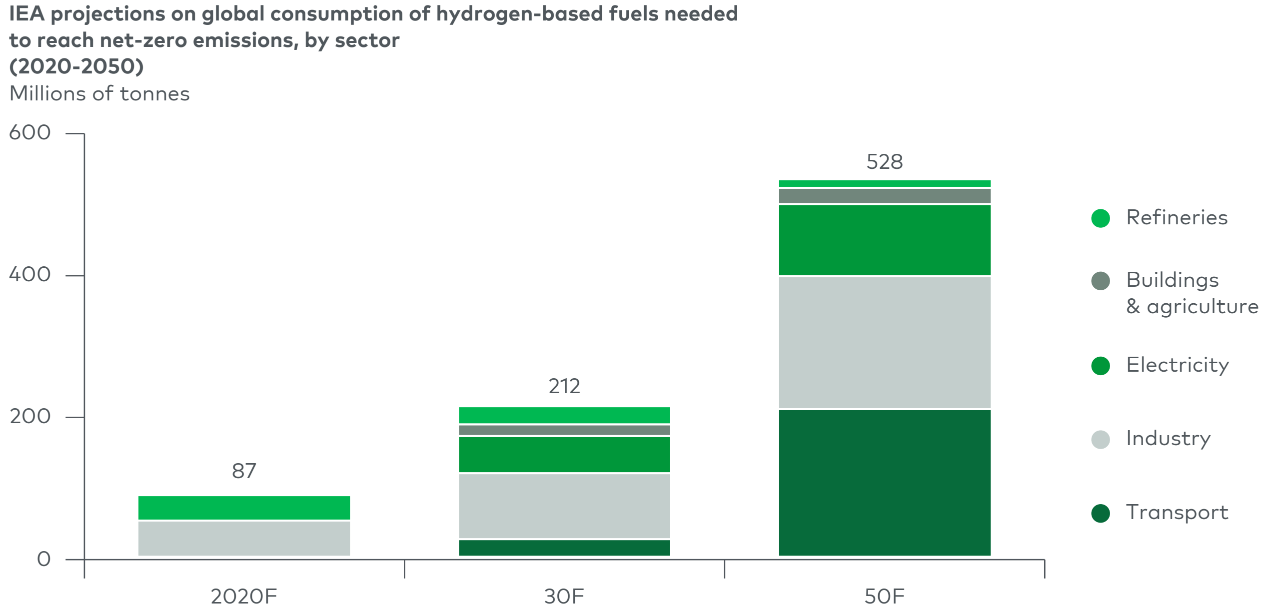
Figure 4
Australian Hydrogen export scenarios



Source: ARENA — Opportunities for Australia from Hydrogen Exports; L.E.K. research and analysis

By 2050, according to Goldman Sachs, green hydrogen could supply up to 25% of the world's energy needs and become a US$10 trillion (AU$13 trillion) global market. And this could be helped further by emissions targets, which will also have some influence in favour of hydrogen, green and otherwise. Hydrogen will have to play a key role in decarbonisation efforts, with demand forecast indicating growth at approximately 6% per annum if governments and industries around the world expect to meet emissions targets by 2050 (see Figure 5).

Figure 5
Global Hydrogen demand scenarios



Source: IEA

A careful balancing act

There is considerable debate and some confusion around the immediate and long-term economic viability of green hydrogen. Right now, it seems to be an uneconomic proposition, but this could change in the future.

Our experience shows the most important factors which will drive that change are:

1. The required shifts in energy costs
2. Support from institutions such as ARENA and CEFC to help producers and operators reduce capital and funding costs
3. Further reductions in the cost (and efficiency losses) of electrolysers and other related equipment
4. Governmental policy supporting a level playing field for green producers relative to traditional more carbon-intensive production methods

The demand side will also come into play — energy customers and other stakeholders will need to weigh up:

1. Whether there is potential to earn a 'green premium' for green hydrogen
2. The risks of carbon costs and reputational impacts if continuing to rely on high emissions sources of energy or process inputs
3. The costs of green hydrogen vs alternatives

These and the other factors discussed in this article make it clear that success in the green hydrogen market is a tricky proposition. There can be a positive economic case, dependent on how the above factors are used to the best advantage of the operator or investor.

Key questions for those who are considering the opportunities presented by green hydrogen:

- Who will be the customer for the hydrogen, and what is their use case?
- What alternatives are there to green hydrogen for the customer, and what are their relative economics?
- Will the customers (or their customers) recognise the economic value of green hydrogen and pay a price that reflects the cost of production?
- What commitments are the customers willing to make to support or underwrite hydrogen production?
- Can the demand for hydrogen be met with intermittent production, or is continuous production operationally or economically necessary?
- Where are the best locations for hydrogen production and associated renewable generation? What are the trade-offs involved when making choices about locations, capacity, utilisation, storage and transport, and how do these affect the type of generation and input costs for the electricity required?

If you're thinking about these questions, L.E.K. is able to help you get the right answer and develop the right strategy for your situation.

Endnotes

[1]Hydrogen can act as a partial substitute (c.10%-15%) for natural gas without modifications to infrastructure or customer equipment, or as a complete substitute with appropriate infrastructure and equipment.

[2]https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets

[3]Drive.com.au; InsideEvs; Hyundai website; Car Expert

[4]See https://ieefa.org/green-hydrogen-eyed-as-fuel-of-the-future/

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