THE ANZ

HYDROGEN HANDBOOK

VOLUME II EXECUTIVE SUMMARY

MARCH 2024

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VOLUME II EXECUTIVE SUMMARY

Hydrogen (H_2) is the chemical element with the symbol and atomic number 1. Hydrogen is the lightest element in the periodic table and the most abundant chemical substance in the universe. At standard temperature and pressure, hydrogen is a colourless, odourless, tasteless, nontoxic, highly combustible gas.

VALUE OF HYDROGEN

Hydrogen rarely appears in its free form on Earth so requires energy to separate it from other compounds. Hydrogen is also similar to natural gas in terms of its applications and handling, and from an energy perspective has two outstanding properties:

- Hydrogen is unique among liquid and gaseous fuels in that it **emits absolutely no CO_2 emissions** when the energy is released as heat through combustion, or as electricity using a fuel cell. In both cases the only other input needed is oxygen, and the only by-product is water.
- It is an excellent carrier of energy, with each kilogram of hydrogen containing about 2.4 times as much energy as natural gas[1].

HYDROGEN'S ROLE IN THE ENERGY TRANSITION

Zero emissions fuel source	Stable energy storage medium
Global export opportunity for Australia with emerging import demand	Versatility allowing decarbonisation in historically hard-to-abate sectors
Firm source of renewable energy	Job creation possibilities

COLOURS OF HYDROGEN

Hydrogen is the lightest and most abundant chemical substance in the universe, however it rarely appears in its free form on Earth so requires energy to separate it from other compounds.

The different methods of producing H_2 have colourful names:

Green Hydrogen

- Produced through electrolysis, whereby water molecules are split into hydrogen and oxygen within an electrolyser powered by renewable energy
- Zero carbon emissions produced

Blue Hydrogen

- Produced from fossil fuels, similar to the process as brown or grey
- Incorporates the use of **carbon capture & storage (CCS)** to capture emissions

Grey Hydrogen

- Produced from methane or natural gas through steam methane reforming
- Material carbon emissions released during production
- Currently the most common and cheapest method to produce

Brown Hydrogen (AKA Black Hydrogen)

- Produced from coal through **regasification**
- Material carbon emissions released during production

Turquoise Hydrogen

- Produced in the breakdown of natural gas via methane pyrolysis into hydrogen and solid carbon. The process is driven by heat produced with electricity, rather than the combustion of fossil fuels
- Where the electricity powering the pyrolysis is renewable, zero carbon emissions are produced

Yellow Hydrogen

- Produced by electrolysis using **grid electricity**

White Hydrogen (AKA Gold Hydrogen)

- Naturally occurring geological hydrogen found in underground deposits and created through **fracking**
- Several reservoirs have been found across the world, however there are no strategies to exploit this hydrogen at present

Pink/ Purple/ Red Hydrogen

- Produced by electrolysis using nuclear power

THE OPPORTUNITY FOR AUSTRALIA

A switch to hydrogen for Australia would not only be expected to avoid greenhouse gas (GHG) emissions equivalent to one third of Australia's fossil fuel emissions by 2050. In fact, Australia is expected to service 9.1% of global export demand for hydrogen in 2025. It could also generate an additional A$50b of GDP while creating more than 26,000 jobs[2].

With an estimated 262,000km^2 of space available to be used for hydrogen (circa 3% of Australia's land and larger than the average EU member state), a stable political system and favourable geography, Australia is in a prime position to use hydrogen for energy, transportation, and export[2].

Many of Australia's major trading partners are also interested in hydrogen use but do not have the same characteristics as Australia to produce it. The proximity of Australia to the Asia Pacific region particularly provides a key export opportunity, as other potential competitors could be disadvantaged by additional transport costs.

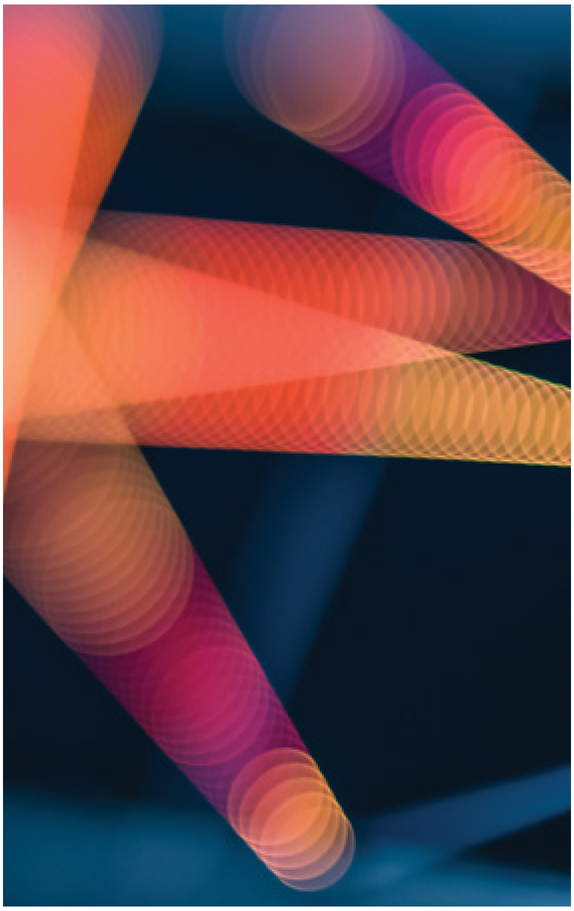
Furthermore, Australia can also capitalise on its already proven track record in energy exports such as LNG, utilising its existing gas infrastructure and shipping expertise to enable lower costs of hydrogen production, storage and transportation.

AUSTRALIA IS THEREFORE WELL-POSITIONED TO TAKE A LEAD IN THE EMERGING HYDROGEN INDUSTRY.

As part of ANZ's ambition and commitment to be the leading Australia and New Zealand based bank in supporting customers' transition to net zero emissions, our goal is to be the go-to bank for the emerging sustainable hydrogen economy, helping customers develop new technologies, products and services.

INDUSTRY CONSIDERATIONS

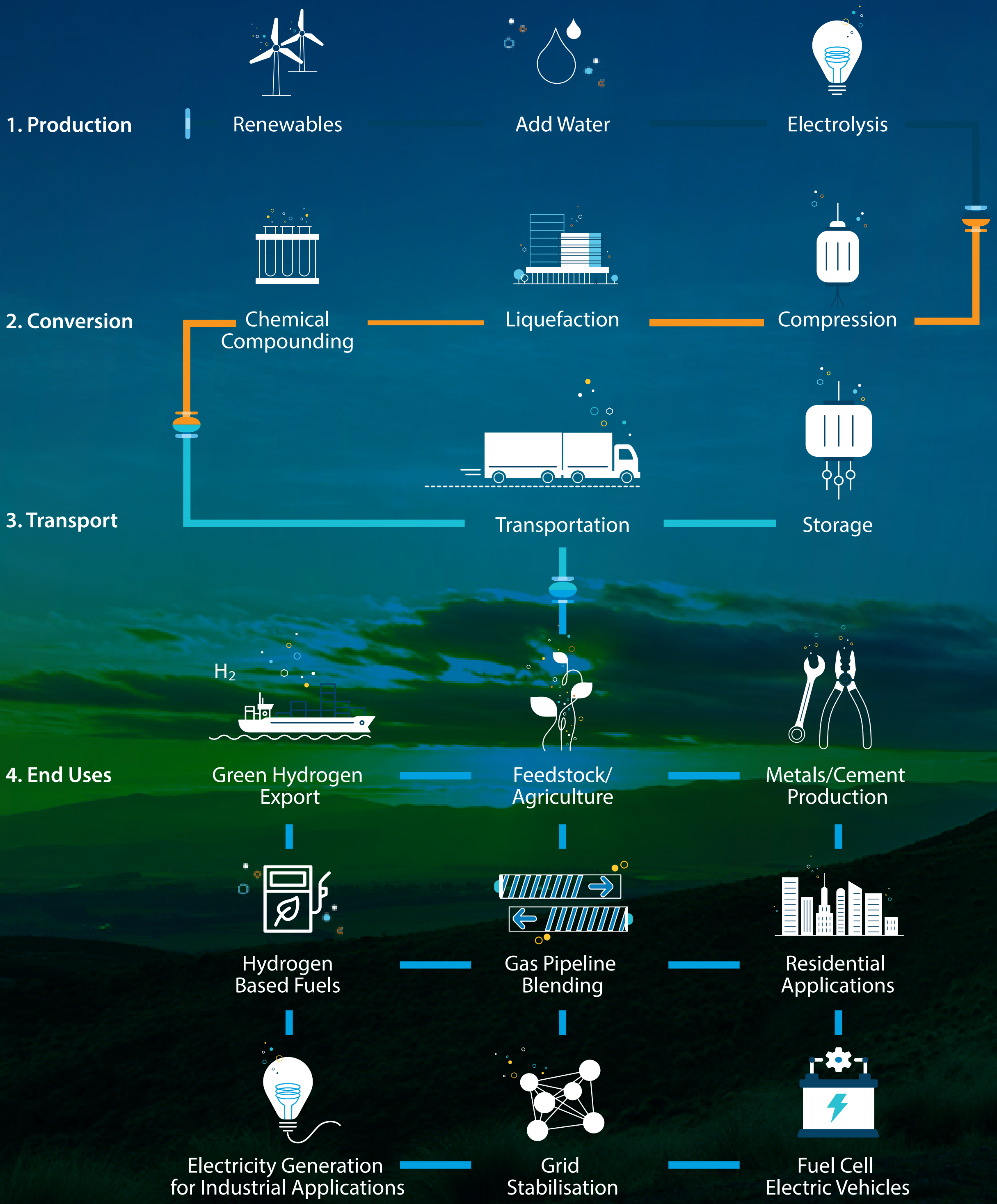
- **Safety** of hydrogen is a common concern even though it is safer to handle and use compared to other commonly used fuels. Due to its light density H_2 dissipates quickly when released allowing for rapid dispersal in the case of leaks.
- **Water** use can also be of concern due to the availability and restrictions on the resource. Green H_2 currently requires the input of high-purity water, however utilising sufficient supportive infrastructure (e.g. desalination, reverse osmosis plants) can be effective ways to combat the strain on Australia's water security.
- **Electricity requirements** needed for clean H_2 to meet global energy demands are vast. The production, storage and transportation of H_2 itself can be quite energy intensive, however with global renewable electricity capacity expected to increase while costs decline, this is anticipated to support the consumption requirements.
- **Highly capital-intensive long-life assets** can be required in cases such as blue H_2 projects utilising CCS. In Australia, acceptance is expected to increase as hydrogen projects progress and through developing technologies and economies of scale. These factors are also expected to help reduce perceived risk from current limited application.
- **Demand/customer offtake** in comparison to supply availability for H_2 will be increasingly important. Achieving an equilibrium between hydrogen supply and demand will require further infrastructure build-out requirements, potential Government stimulus and increased energy affordability.
- **Implications for other industries**. Hydrogen should be seen as an opportunity for oil and gas producers and infrastructure operators to expand the terminal life of their assets and reduce stranded asset risk. Blue H_2 is uniquely positioned to act as a bridge to transition the energy system and help build momentum.



THE HYDROGEN VALUE CHAIN

Hydrogen's versatility means it can play a key role across all energy sub-sectors. H_2 is particularly noted for its applications in providing long-term energy storage, decarbonising hard-to-abate sectors such as iron, steel, aluminium, ammonia and chemicals production, and in powering heavy-duty transport.

The diagram below shows the full green hydrogen value chain, inclusive of its multiple end uses across varying sectors:



AUSTRALIA AND HYDROGEN

FEDERAL POLICIES

- The 2019 National Hydrogen Strategy aims to position Australia as a major global player by 2030 through establishing international agreements, developing hydrogen hubs and financing projects. A review of the strategy is currently underway.
- The Hydrogen Headstart Program aims to accelerate large-scale renewable hydrogen projects to bridge the early-stage commercial gap. Australian Renewable Energy Agency (ARENA) will provide A$2b in funding as a production credit that will cover the current gap between the cost of H_2 produced from renewables and its market price, enabling producers to offer H_2 to users at a price to encourage them to switch to using the clean fuel.
- The Government is providing A$38.2m to establish a Guarantee of Origin Scheme to underpin markets for green energy, including hydrogen and other low emissions products. The purpose is to certify renewable energy and track and verify emissions from clean energy products.
- The industry is also set to indirectly benefit from other Federal initiatives such as Rewiring the Nation (A$20b program to modernise Australia's electricity grid) and the Amended Safeguard Mechanism (policy aimed at reducing emissions from Australia's largest facilities).

FEDERAL AGENCIES

- Policies are supported by national agencies including ARENA, Clean Energy Finance Corporation (CEFC) and Australian Hydrogen Council (AHC).

VIC

- The vision for Victoria is to accelerate decarbonisation, promote economic recovery and establish a thriving renewable H_2 industry. The goal is to achieve this via a range of policies including Accelerating Victoria's Hydrogen Industry (AVHI) Program, Victorian Renewable Hydrogen Industry Development Plan, Climate Change Strategy & Zero Emissions Vehicle Roadmap, and the Hydrogen As Long Duration Energy Storage Report.
- Key projects include Hydrogen Energy Supply Chain, Hydrogen Park Murray Valley and Zero Degrees Rosella.

WA

- Released in 2019, the West Australian Renewable Hydrogen Strategy outlines export, remote applications, hydrogen blending in natural gas networks and transport as focus areas for investment. WA aims for its market share in global hydrogen exports to be similar to its share in LNG by 2030.
- Support has included A$22m for nine initiatives, A$50m for H_2 industry development, A$117.5m to attract Federal funding for Pilbara and Mid-West H_2 hubs and various grants by the WA Investment Attraction Fund.

SA

- South Australia aims to become a world-class, low-cost H_2 supplier, supported by an abundance of renewable energy.
- Underpinned by the Hydrogen Jobs Plan, the Government is investing more than A$750m dollars to accelerate new hydrogen projects and shipping infrastructure. This includes building a world-leading green H_2 facility near Whyalla including 250MW of electrolyser capacity.

NSW

- The vision for New South Wales is to produce 110,000t/a of green H_2 from 700MW of electrolyser capacity and reduce the cost of green H_2 to under A$2.8/kg by 2030, making NSW one of the cheapest suppliers of hydrogen in the region. The NSW Hydrogen Strategy included up to A$3b of incentives to support industry development, H_2 infrastructure masterplans and a regulatory framework.
- Key projects include Illawarra Hydrogen Technology Hub, Good Earth Green Hydrogen & Ammonia Project, Origin's Hunter Valley H_2 Hub and the Tallawarra B Project.

TAS

- Under the Tasmanian Renewable Hydrogen Action Plan, the Government intends to capitalise on its expanding renewable energy resources to become a significant global supplier by 2030. The Government is focused on creating the Tasmanian Green Hydrogen Hub Project at Bell Bay.

QLD

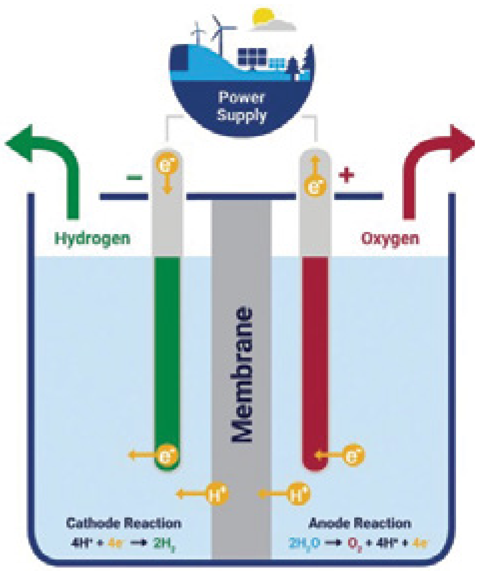
- The Queensland Hydrogen Industry Strategy focuses on supporting innovation, facilitating private sector investment, supplying to both domestic and export partners, ensuring effective policy, and skills development. Currently, more than A$110m has been invested to capitalise on emerging green H_2 opportunities.
- QLD Renewable Energy & Hydrogen Jobs Fund is an A$4.5b program allowing QLD GOEs to increase ownership in commercial renewable energy and H_2 projects. It could also support new infrastructure including hydrogen refuelling stations and conversion and storage facilities.

HOW IS HYDROGEN MADE?

Green H_2 is produced within an electrolyser powered by renewable energy. An electrolyser is a highly complex piece of equipment and there are different types that support a wide range of solutions based on cost, capacity and application. The two main types of electrolysers include alkaline and PEM technologies:

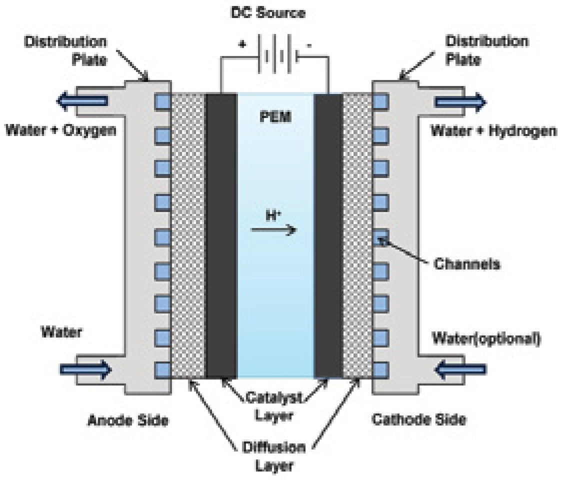
ALKALINE

- Alkaline electrolysers are the most commonly used in the industry. In this technology, the water is split in the presence of a caustic electrolyte solution - frequently potassium hydroxide (KOH)[3].
- A reaction occurs between two electrodes in the solution, and when sufficient voltage is applied water molecules take electrons to make OH^- ions and a hydrogen molecule. The OH^- ions travel through the solution toward the anode, where they combine and give up their extra electrons to make water, hydrogen, and oxygen.
- Recombination of H_2 and O_2 at this stage is prevented by means of an ion-exchange membrane. The electrolyte remains in the system owing to a closed-loop, pump-free recirculation process[4].



PEM (POLYMER ELECTROLYTE MEMBRANE)

- PEM technology is the electrolysis of water in a cell equipped with a solid polymer electrolyte (SPE) to separate hydrogen and oxygen.
- A reaction is created using an ionically conductive solid polymer, rather than a liquid. When voltage is applied negatively charged oxygen in the water molecules produces protons, electrons, and oxygen at the anode.
- The H+ ions travel through the membrane towards the cathode, where they take an electron and combine to make hydrogen. The electrolyte and two electrodes are sandwiched between two bipolar plates, which transport water to them as well as gases away from them, conduct electricity, and circulate a coolant fluid to cool down the process[4].



COMPARISONS

- Alkaline electrolysis is the more established technology and typically more affordable, as PEM electrolysers involve an acidic environment which require precious metals for the catalyst.
- PEMs are often seen as a safer option since the membrane provides a physical barrier between the produced H_2 and O_2.
- Alkaline systems can be more difficult to pressurise and additional compression steps are required.
- PEM is a more compact machine which is better suited with renewables as they can operate dynamically using varying loads of electricity, allowing PEM electrolysers to be operated when renewable energy generation is cheapest.

NOTE:

For an electrolyser to operate at its highest capital efficiency it will require the input of firm renewable energy to mitigate the risk of unpredictable H_2 production volumes impacted by variables such as weather.

THE ECONOMICS OF HYDROGEN

Currently, fossil fuel-based processes produce hydrogen at a lower cost than its clean hydrogen alternatives.

While recent volatility in gas prices from various geopolitical events has impacted prices, Bloomberg conveys that grey H_2 costs in the range of US$0.98-2.93/kg (A$1.50-4.37/kg), blue H_2 costs US$1.80-4.70/kg (A$2.69-7.03/kg), and green H_2 remains the most expensive form at ~US$4.5-$12/kg (A$6.87-18.32/kg)[5].

Australia is targeting hydrogen production at less than A$2/kg, which the Australian Government coined as the 'H_2 under 2' strategy in 2020.

This is the benchmark for the fuel source to be able to compete with the landed costs of natural gas in importing countries and for it to achieve more widespread adoption across Australia.

COMPONENTS IN THE TOTAL COST OF HYDROGEN:

1. ELECTRICITY

The levelised cost of electricity (LCOE, measure of average electricity generation costs over the lifetime of a generating plant) for large-scale solar in 2020 was A$41-77/MWh internationally, with onshore wind at A$56-93/MWh.

In the post-Covid era, freight and commodities costs have risen and while that has now largely eased, the costs to finance have increased with interest rate rises. Onshore wind and solar LCOE is now expected to decline in 2024, however will likely remain above 2020 rates by 10-15%[6].

2. ELECTROLYSERS

Electrolyser capital costs vary, however they've fallen from an average of ~A$3,700/kW in 2020 to ~A$2,700/kW in 2022. The CSIRO estimates costs will fall further to A$200-800/kW by 2050[7].

The reductions in costs over the past few years have been mainly driven by market need for larger systems and innovation in system design/manufacturing. Costs are expected to drop by a further 30-50% in the next decade, as national targets and pilot projects produce enough volume to realise substantial declines.

3. OTHER

Infrastructure

Of course, the necessary infrastructure required for the production, storage, and handling of hydrogen is also a critical component in the cost. Forecasts of the required spend are up to A$80b by 2030[8].

Transport & Conversion

As explored in further detail in the following page the requirement for H_2 gas to be converted to alternate forms in order to transport the fuel source efficiently across it's end-to-end supply chain adds further costs. Transportation can then be facilitated via pipeline, truck, ship or rail to its end destination.

WHAT WILL IT TAKE TO ACHIEVE COST-PARITY WITH FOSSIL FUELS?

The realisation of a vibrant H_2 economy will require early intervention and significant investment and subsidies from governments, businesses and energy consumers. Australia's opportunity to gain comparative advantage requires progressive development in both the domestic end-use market, as well as in international exports, to drive wider advancements within the industry. The phase out of fossil fuels and assessment of common user infrastructure, as well as a consistent policy and regulatory environment encouraging innovation to help build economies of scale, will help attract further H_2 investment in the future. Together, this will support the social licence of H_2 and contribute to Australia's decarbonisation efforts.

KEY CHALLENGES TO HYDROGEN UPTAKE

ENVIRONMENTAL/SOCIAL

Key environmental and social factors which need to be considered include the mining and processing of raw materials required for use in H_2 technologies, modern slavery in the supply chain due to the cross-border nature of the industry, and the large land requirements which will call for sizable stakeholder engagement on the wider impacts to environment and community. **It should also be noted that H_2 isn't the solution to all energy transition problems, but rather is best suited for the energy storage, heavy-duty transport and hard-to-abate sectors predominantly.**

REGULATORY BENCHMARKS

From the regulatory perspective, there is also no single international body which governs the colour system and sets benchmarks for the carbon intensity allowed in each category. While the colour system evaluates emissions throughout production/combustion, it lacks insight into the full value chain (including manufacturing/import of capital equipment, infrastructure build out, emissions from transport, and disposal of equipment at end of life).

TRANSPORTATION/CONVERSION

The low density of H_2 gas by volume means it requires more space for H_2 storage and transport. Therefore H_2 is generally converted into an alternate state to be moved efficiently which can add costs. As a result, most H_2 is used directly worldwide, with only a small proportion converted/transported to end-users. Conversion can be achieved in either of the following three ways depending on location, distance, scale and required end use:

1. Compression
2. Liquefaction
3. Chemical compounding

INFRASTRUCTURE REQUIREMENTS

The infrastructure required to support the widespread adoption of H_2 fuels or fuel cell electric vehicles will increase as technology becomes more advanced and the demand for low-emissions energy ramps up. In Australia there are six H_2 refuelling stations due to complete construction in 2024, with production capacities ranging from 20-1000kg/day. The Hume Hydrogen Highway project has also received funding to support the development of multiple refuelling stations, and is expected to be complete in 2025[9].

USES VS SUPPLY FACTORS

Development of uses and supply of H_2 are occurring simultaneously, facing a 'chicken or the egg' scenario. As demand for hydrogen increases, the supply infrastructure will be built as cost declines, leaving the question of which comes first.

The industry and regulators must consider how to put long-term offtake agreements in place to help foster expansion and allow projects to continue being developed while these two aspects continue to become established concurrently.

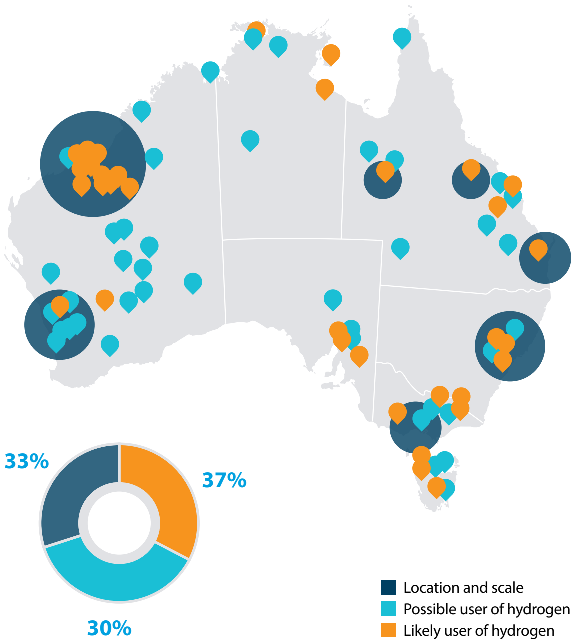
COST OF CONVERSION METHODS

Conversion Method	Density	Cost (A$)
Compression	40kg/m3 (700 bar)	+$0.9/kg
Liquefaction	70kg/m3 (1 bar)	+$4.1/kg
LOHC	47-57kg/m3	+$1.7/kg
Ammonia	123kg/m3 (10 bar)	+$2.6/kg

COST OF TRANSPORTATION METHODS

Transport Method	CAPEX (A$)	Cost (A$/ kgH_2/50km)
Pipeline	$1.03-1.55M/km	+$0.1-0.3
Truck	CGH_2: $0.96M LH_2: $1.39M	CGH_2:+$1.05 LH_2: +$5.95
Ship	$310-533M	NH_3: +$0.02 LH_2: +$0.05

CHEAT SHEET



State	Region
NSW	Hunter Valley Hub
QLD	Gladstone Hub
WA	Pilbara Hub
	Kwinana Hub
SA	Port Bonython Hub
TAS	Bell Bay Hub

KEY TERMS

- **Ammonia:** An inorganic chemical composed of nitrogen and H_2, with its chemical form being NH_3. Ammonia is a carrier of H_2, and is used in applications such as fertilisers, chemical feedstock and explosives.
- **Carbon, Capture and Storage (CCS):** An integrated suite of technologies that captures CO_2 from being released into the atmosphere. CCUS does not include the permanent geological storage of CO_2.
- **Chemical Compounding:** A method of storage and conversion of H_2. This can be with other molecules to form liquid organic H_2 carriers, with nitrogen to form ammonia, or with CO_2 with form methane/methanol.
- **Compressed Hydrogen:** The gaseous state of the element H_2 kept under pressure. Compressed H_2 can range from 350-1000 bar and is used in mobility, storage, transport and refuelling applications.
- **Distributed Power:** H_2 for use in stationary power generation microgrids for the power utility industry and industrial sites.
- **Fuel Cell:** An electric vehicle that uses a fuel cell, sometimes in combination with a small battery or supercapacitor, to power its onboard electric motor. Fuel cells in vehicles generate electricity generally using oxygen from the air and compressed H_2.
- **Liquefied Hydrogen:** H_2 in liquid form. Conversion typically requires energy intensive cooling processes and to be stored at -253°C .
- **Sequestration:** Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change through either geologic or biologic methods.

FURTHER RESOURCES

- Access the latest on Australia's hydrogen projects, policies, funding and key parties: CSIRO's HyResource
- The Australian Government's Department of Climate Change, Energy, the Environment and Water hydrogen strategy: Growing Australia's Hydrogen Opportunity
- Alternatively, please contact your ANZ Relationship Manager or John Hirjee (Head of Research & Analysis – Resources, Energy & Infrastructure Australia)

Find ANZ's full hydrogen report at anz.com/institutional/insights/hydrogen

BASIC CONVERSION FACTORS

PRESSURE CONVERSION

	Bar	Pascal (P)	megaPascal (MPa)
Bar	1	100000	0.1
Pascal	0.00001	1	0.000001
megaPascal (MPa)	10	1000000	1

VOLUME/ENERGY CONVERSIONS

	Kilowatt hour (kWh)	Joule (J)	Megajoule (MJ)
Kilowatt hour (kWh)	1	3,600,000	3.6
Joule (J)	$2.77778 \times 10_{-7}$	1	$1 \times 10_{-6}$
Megajoules (MJ)	0.277778	1,000,000	1

	Kilowatt (kW)	Megawatt (MW)
1 Kilowatt (kW)	1	0.001
1 Megawatt (MW)	1000	1

	Weight		Gas		Liquid	
	lb	kg	scf	Nm^3	gal	l
1 pound	1.0	0.4536	191.26	5.4159	1.6925	6.407
1 kilogram	2.2046	1.0	421.66	11.940	3.37313	14.125
1 scf gas	0.005309	0.002408	1.0	0.02679	0.008985	0.03401
1 Nm^3 gas	0.1982	0.08989	37.327	1.0	0.3354	1.2697
1 gal liquid	0.5908	0.2680	113.0	2.9815	1.0	3.7855
1 litre liquid	0.1561	0.07080	29.852	0.8453	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atmosphere and 60°F.
Nm^3 (normal cubic meter) gas measured at 1 atmosphere and 0°C.
Liquid measured at 1 atmosphere and boiling temperature.

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