Embracing clean hydrogen for Australia

How the journey towards decarbonisation can be fuelled by Hydrogen

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Executive summary

Clean hydrogen provides the opportunity to decarbonise the hard-to-reach sectors of our economy, where electrification may otherwise fall short

We aspire to reach a day in which the resource that powers our heating and cooking, fuels our daily commute, and forms the cornerstone of our international exports is a carbon-free fuel source, safeguarding the stability of our environment while continuing to serve and benefit the Australian economy.

To date, adoption of renewable energy targets have been at the forefront of curbing carbon emissions globally, with nations setting ambitious but increasingly deliverable targets of 30%, 50% or even close to 100% of power generation from renewable sources in the coming decades.

However, with only approximately one third of greenhouse gas emissions attributable to the electricity and heat sector,[1] a further solution within the transport, chemical and industrial sectors must be pursued if we are committed to extending decarbonisation throughout the economy.

The opportunity to realise this future as a reality lies with the production and use of clean hydrogen, a versatile, storable, transportable, carbon-free fuel source.

Global momentum is growing across the hydrogen industry, with few sectors likely to remain untouched by this energy revolution.

Within Australia, recent funding and policy announcements from State and Federal governments, including adoption of the National Hydrogen Strategy in November 2019, is building upon the momentum of existing pilot programs. Projects are already underway to address new uses for hydrogen and improve the economics of production to meet forecast demand, both domestically and internationally.

At PwC, we are monitoring the sector landscape and engaging with research bodies, policymakers, developers, industrial players and strategic investors, each with an incentive and role to play in helping to progress this nascent industry.

The industry may appear to be slowly finding its feet, with disaggregated projects from a number of sectors looking to develop links across the supply chain, but the future of the hydrogen industry over the coming decade looks bright, as it aims to take its first steps from crawling to walking.

Within this paper, we provide an introduction to:

- **the hydrogen supply chain, considering the opportunities and challenges of producing and using clean hydrogen;**
- **the steps needed to keep clean hydrogen on a pathway toward cost-competitiveness with existing hydrocarbon fuels;**
- **the physical and regulatory infrastructure needed to support a clean hydrogen industry in Australia;**
- **policy tools and lessons that can be learned to help promote and adapt the hydrogen industry in Australia;**
- **a glimpse at early-movers within the sector and how they are moving the industry forward through investing in projects today.**

[1] World Resources Institute, Climate Analysis Indicators Tool, 2019

Executive Summary (cont'd)

Harnessing energy from the universe's most abundant element is not a new concept, but we can do much more to produce and use hydrogen in a way that maximises its potential to transport and use carbon-free energy across multiple sectors

To date, global demand for hydrogen has been limited primarily to its use as an industrial feedstock, relying on 'grey' hydrogen generated through steam reforming of fossil fuels, emitting approximately 9kg of Carbon Dioxide for every 1kg of Hydrogen produced.

With the rapid growth in renewable electricity and falling costs of wind and solar power, the opportunity to produce low or zero carbon-emitting forms of hydrogen has captured the imagination of industry, consumers and policymakers seeking further opportunities to decarbonise our society.

For climate-conscious consumers seeking alternatives to hydrocarbon fuels in the transport, heat and chemical sectors, hydrogen has certain competitive advantages over batteries and electrification, although hydrogen and battery fuel cells should be viewed as complementary as each finds its niche in a zero carbon economy.

Hydrogen is:

- ✓ **Storable**, retaining its energy far longer than utility-scale batteries;
- ✓ **Transportable**, in gas or liquid form;
- ✓ **Easily converted** (eg. to Ammonia) or blended (eg. with natural gas) to tailor its composition to the end use;
- ✓ **Lighter than battery-stacking**, for more efficient use in heavy vehicle transport such as trucks, buses and trains.

Australia can lead the global shift to hydrogen:

- **Abundant renewable energy potential at low cost –** integral for the development of industrial-scale green hydrogen;
- **Strong existing trade links –** well-positioned geographically for the high hydrogen demand economies of Japan, South Korea, China and Singapore;
- **Proven track record in industrialising commodity production –** at the forefront of natural gas production and trade, with well-developed regulatory, safety and market infrastructure.

Understanding hydrogen terminology

Grey Hydrogen – hydrogen derived from fossil fuels, typically involving the combustion of gas or coal in steam methane reforming (SMR), with little to no Carbon Capture, Utilisation and Storage (CCUS) involved.

Clean Hydrogen – hydrogen with little to no carbon emissions directly resulting from the production process. Comprising both Blue and Green Hydrogen.

Blue Hydrogen – hydrogen derived from fossil fuels but considered carbon-neutral due to substantial use of CCUS technology.

Green Hydrogen – hydrogen derived from renewable electricity, produced from electrolysis of water, with effectively zero carbon emissions.

Quantifying hydrogen

Hydrogen can be deployed for many uses, as a form of electrical energy, molecular energy, or as a chemical input. The relevant use will determine the appropriate unit of measurement when referring to quantities of hydrogen.

For consistency throughout this paper we will refer to hydrogen by weight:

- 1kg hydrogen = 33.3kWh = 120MJ

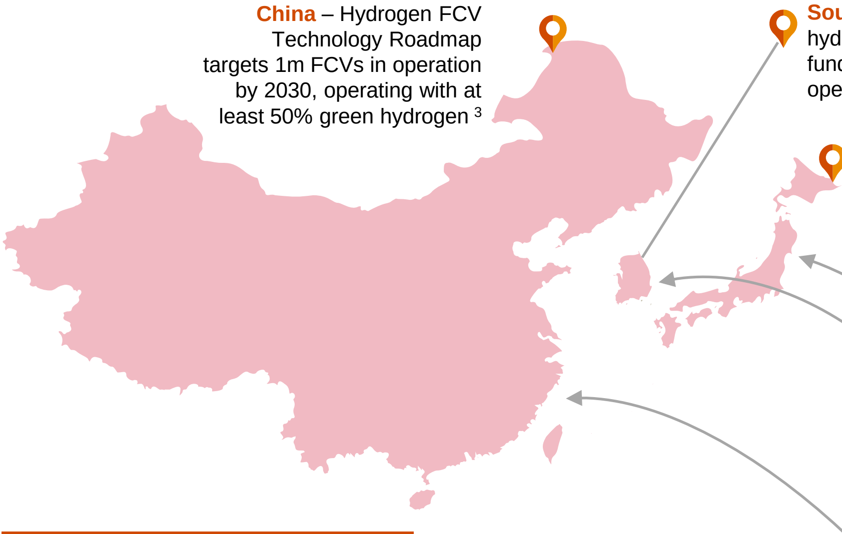
Or in other words:[2]

- 1kg hydrogen = 100km driven in a hydrogen fuel cell passenger car
- 1kg hydrogen = 14.5hrs of air conditioning
- 1kg clean hydrogen avoids 15kg CO_2-e

[2] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. xv

Executive summary (cont'd)

Opportunities to put Australia on the clean hydrogen map exist across the supply chain, but will rely on investment in renewable energy generation, transport, storage and end-use technologies.



China – Hydrogen FCV Technology Roadmap targets 1m FCVs in operation by 2030, operating with at least 50% green hydrogen [3]

South Korea – kickstarting investment in hydrogen until 2022 through a US$1.8bn fund, with 2.9m FCVs targeted to be in operation by 2040 [4]

Japan – projected demand of 300 kt of hydrogen per annum by 2030, to power 800k FCVs, 900 refuelling stations, and 5.3m stationary fuel cells in households [5]

Export logistics

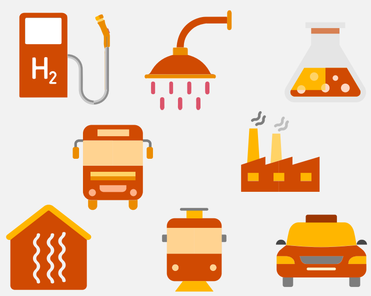
Hydrogen may be exported internationally through specialized hydrogen tankers or via conversion into ammonia

Global demand

Existing demand for grey hydrogen as a chemical feedstock is set to be surpassed by hydrogen's versatile uses in providing transport, heat and power.

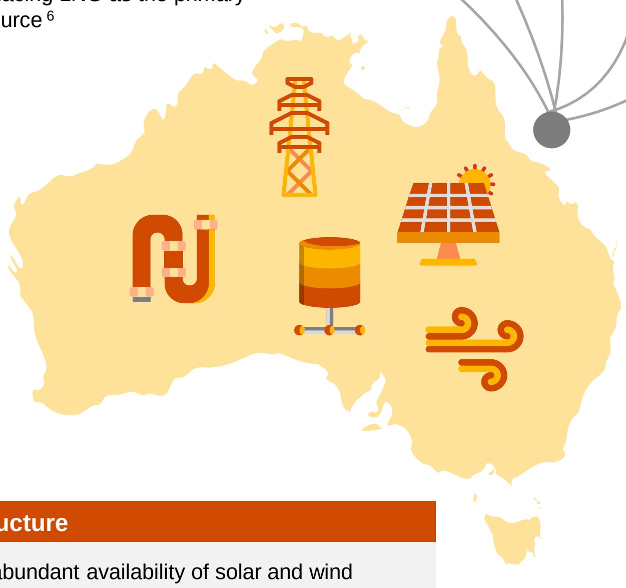
Given Australia's strong existing trade links with its East Asian neighbours, it is in a prime position to capitalise on the high levels of anticipated demand.

As a potential export giant, Australia can also play a leading role in setting certification of origin guidelines, safety standards and creating trade partnerships.



Singapore – National Hydrogen Strategy currently under development, with aims to cut national emissions by over 60% by replacing LNG as the primary fuel source [6]

Rest of World – Global interest in hydrogen is rapidly growing, particularly in the EU and California



Australia – National Hydrogen Strategy identifies 57 Joint Actions across to ensure progress across the entire supply chain, looking ahead to 2030 and beyond [7]

Developing domestic production and infrastructure

Through the falling cost of renewable energy and the abundant availability of solar and wind resources, Australia has the potential to produce hydrogen for global export at a competitive price.

Additionally, the ability to convert and store renewable energy in hydrogen, which is then either pumped into the gas networks or contained in hydrogen fuel cells, provides an opportunity to strengthen Australia's domestic power supply.

[3] SAE China, Hydrogen Fuel Cell Vehicle Technology Roadmap, 2016, p. 13
[4] Ministry of Trade Industry and Energy, Hydrogen Economy Roadmap of Korea, 2019, p. 8
[5] Ministerial Council on Renewable Energy Hydrogen and Related Issues, Basic Hydrogen Strategy, 2017, p. 20
[6] Australian Trade and Investment Commission, Singapore seeking assistance to transition to a clean energy future, 2019
[7] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. ix

1. Potential for Hydrogen in Australia

Hydrogen's many uses will lead to demand from diverse geographies and sectors

The emerging demand for clean hydrogen

1. The global hydrogen market is expected to boom between 2030 and 2050, but it is necessary for Australia to invest domestically today to anticipate this growth.
2. The largest emerging roles which hydrogen is expected to play in the future of Australia's domestic energy system is as a blended gas and as a transport fuel, but its growth will present many investment opportunities across numerous sectors.
3. Japan, South Korea and other markets have set ambitious hydrogen targets, presenting a multibillion-dollar opportunity for the Australian export industry in the long-run.

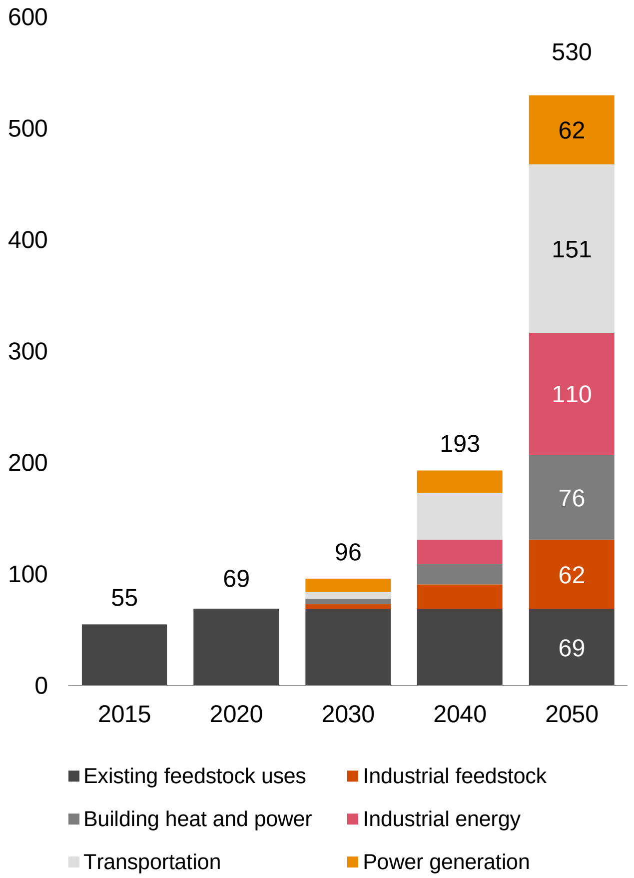
Hydrogen adoption is forecast to grow as different uses for green hydrogen emerge and mature

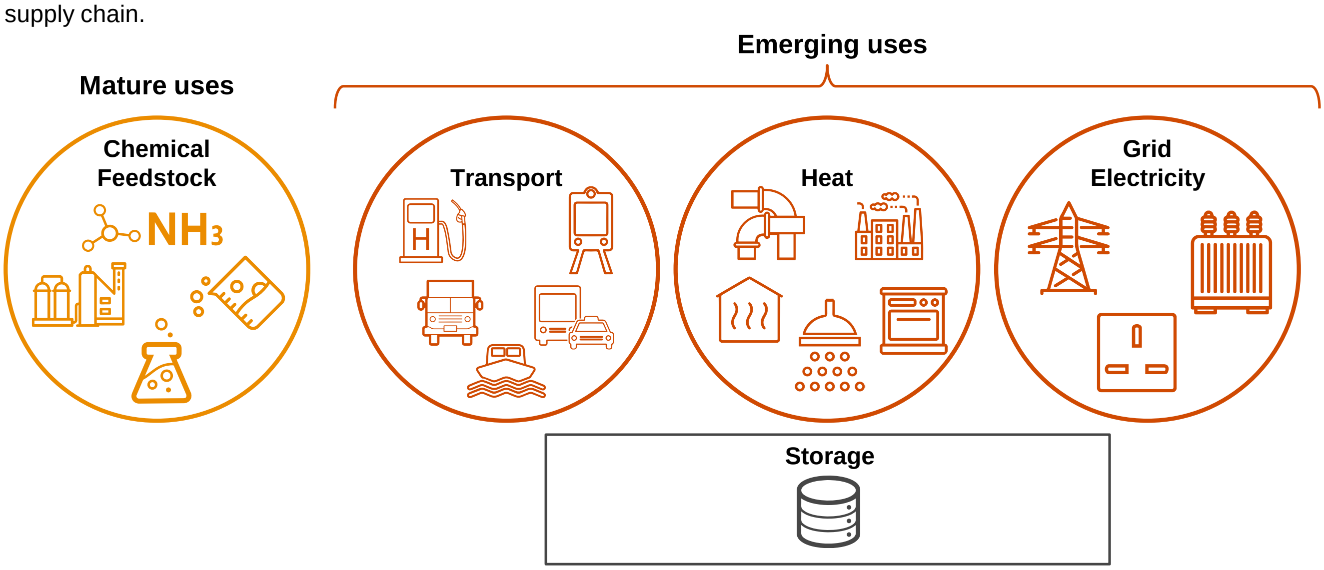
Global demand for hydrogen currently approximates 70 million tonnes, primarily for use in oil refining and ammonia production for fertilisers, with over 98% of current supply being 'grey' hydrogen produced from fossil fuels.[8]

Global demand is projected to increase to 100 million tonnes by 2030 and exceed 500 million tonnes by 2050, as shown opposite. Whilst demand for clean hydrogen will partly be driven by its capacity to replace grey hydrogen in existing processes, the greatest contributing factor to future hydrogen demand is forecast to be in emerging uses as a replacement for carbon-based fuels, including petrol, diesel, natural gas and bunker fuel. Accordingly, investing in these future uses of hydrogen today will help build confidence and stimulate investment across the supply chain.

Forecast growth in demand for hydrogen to 2050[9]

Global demand supplied by hydrogen, million tonnes





[8] IEA, The Future of Hydrogen, 2019, p. 31
[9] Hydrogen Council, Hydrogen Scaling Up, 2017, p. 20

1. Potential for Hydrogen in Australia

Projects to prove and develop hydrogen's potential in emerging uses are already underway globally and in Australia

Hydrogen in the gas network

Hydrogen may be blended into the gas network to reduce overall carbon emissions from domestic, commercial and industrial heating and power.

Many existing gas distribution networks can support between 10% and 20% hydrogen-blending before the effects of pipe embrittlement are encountered, depending on the composition of the pipes.

Within Australia, the progressive replacement of existing cast-iron distribution pipelines with 'hydrogen ready' high-density polyethylene (**HDPE**) is already underway, with ACT and Tasmania largely already hydrogen-ready and Victoria set to join by 2035.[10]

Hydrogen for our daily commute

Hydrogen contains approximately three times the energy per unit mass when compared to gasoline, making it very attractive for use as a transport fuel.

This attraction applies to an even greater extent for larger vehicles such as buses, trucks and trains, where hydrogen's light but energy-dense properties provide an advantage over battery electric vehicles, which are better-suited towards passenger car applications.

Use as a transport fuel is forecast to constitute approximately 20% of total future demand for Australian hydrogen production.[13]

Case Study 1 – Blended hydrogen gas

There are currently 37 projects in Europe demonstrating the potential to employ blended hydrogen in the gas network. For example, the Ameland project in the Netherlands found that hydrogen could be blended up to 30% by volume without causing any difficulties for household appliances.[11]

In Australia, if a national target were set to blend 10% of the domestic gas network with hydrogen, up to 100 kt of this demand for pure hydrogen could be realistically met by 2030 and up to 1,000 kt could be supplied by 2050, constituting approximately 50% of the total demand for Australian produced hydrogen.[12]

Blended gas trials are soon to begin in NSW and SA, with the latter containing a 5% green hydrogen blend to service 700 properties.

Case Study 2 – Hydrogen transport

In October 2019 Hyundai announced strategic investments into three hydrogen companies (Impact Coatings, H2Pro and GRZ Technologies) to strengthen its position as a market leading hydrogen fuel cell electric vehicle (FCEV) manufacturer.

Hyundai has also co-invested in the ARENA supported $4.18m Renewable Hydrogen Production and Refuelling Project in Pinkenba, Queensland. Through this vertical integration and innovation, Hyundai intends to drive demand for hydrogen vehicles by decreasing the vehicles' operating costs and increasing fuelling accessibility.

Hyundai, Neoen, ActewAGL and the ACT Government are also on track to deliver the first public hydrogen refuelling station in Australia, in early 2020.[14]

[10] COAG Energy Council, National Hydrogen Strategy Issue Paper 6 – Hydrogen in the Gas Network, 2019, p. 4
[11] IEA, The Future of Hydrogen, 2019, p. 73
[12] COAG Energy Council, Australian and Global Hydrogen Demand Growth Scenario Analysis, 2019, p. 82
[13] COAG Energy Council, Australian and Global Hydrogen Demand Growth Scenario Analysis, 2019, p. 82
[14] COAG Energy Council, Australia's National Hydrogen Strategy, p. xxxiii

1. Potential for Hydrogen in Australia

Projects to prove and develop hydrogen's potential in emerging uses are already underway globally and in Australia

Other areas in which hydrogen is expected to play a key role in a decarbonised energy system include:

- Providing a stock-based energy supply to ensure grid stability by firming electricity generation.
- As a zero-carbon feedstock for industrial processes, including the production of ammonia, hydrocarbons and steel.
- As a fuel for heavy machinery used in industry, particularly fleet vehicles requiring rapid refuelling, such as mining and warehouse operations.

Case Study 3 – Power security through hydrogen

Increased intermittent renewable energy generation throughout the National Electricity Market (NEM) has created significant concerns for network service operators, leading to greater requirements on system strengths and reliability for generators. For investors and asset owners, this has resulted in increased capital infrastructure necessary to bring a new generator to the market.

The capital outlay to install synchronous condensers to resolve system strength issues is significant, hindering investment where installation obligations have now shifted to generators. While the cost of large scale batteries, used to address reliability risks, are falling, technical restraints limit their effectiveness to provide long-term electrical storage.

Hydrogen production could be deployed during periods of over-supply, storing electrical energy in hydrogen that can be redeployed in times of supply shortfall. In this way, hydrogen production can be used to encourage investment in renewables by providing power security support and increasing grid stability in a much longer-term option than the current remedies.

In a grid network that is seeking methods for system strength remediation, the potential to store and deploy energy at the times when it is most needed, rather than as and when it is produced, may provide an alternative to significant reliance upon synchronous condensers or grid-forming batteries.

1. Potential for Hydrogen in Australia

A valuable export commodity

Japan and South Korea have clearly articulated their ambitions to transform themselves into hydrogen fuelled societies by 2050 through their national hydrogen strategies, and are substantiating these ambitions through significant investments into research, development and commercialisation of green hydrogen technologies and by developing international supply chains.

Further, the Australian Government has already signed a cooperation agreement with Japan and a letter of intent with South Korea to underpin future hydrogen export, with a plan to spearhead the development of international certification standards.[15]

Australia has the opportunity to export over 500 kt of hydrogen to East Asia by 2030, worth an estimated $2.2bn, which may grow further to over $5.7bn by 2040.[16]

Case Study 4 – Meeting Japanese demand

Kawasaki Heavy Industries has partnered with the Australian Federal and Victorian State Governments for the development of a grey hydrogen production facility in the Latrobe Valley, as part of a greater trial project to export hydrogen from Australia to Japan.

In December 2019 Kawasaki debuted the world's first liquefied hydrogen carrier, which will have storage capacity for 1,250 cubic meters of hydrogen at 1/800 of its original gaseous volume, having been cooled to -253 degrees Celsius.

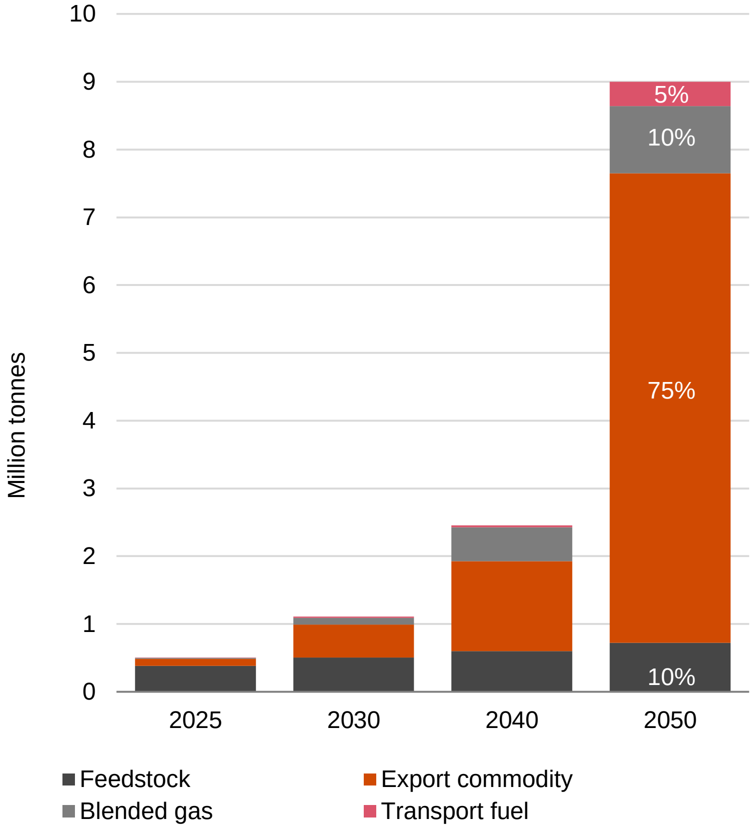
In combination, these two projects are laying the groundwork for future mass production and export of green hydrogen from Australia.

The need for a domestic market

If Australian hydrogen supply is to meet forecast demand levels, further investment in the industry will be required to overcome existing cost constraints. Not only does hydrogen offer the opportunity of being a valuable export commodity, as seen in the graph beside, its potential uses in domestic markets (including blending into gas networks and as a leading fuel in the transportation sector) support the prioritisation of its domestic adoption.

Establishing a viable domestic market should lay the foundation for improved production economics and attract private capital to support innovation, all of which can be supported by domestic government policies. Such an approach was also used by the LNG production industry in its infancy, using domestic markets to secure economic efficiencies before launching into global export markets, and should be replicated with hydrogen. Further, a focus on hydrogen adoption in domestic applications should provide a path to sustained reduced carbon emission reductions in Australia.

Australia's hydrogen end uses[17]



Case Study 5 – High-speed rail with zero carbon emissions

Australian high-speed rail projects, such as the proposed Consolidated Land and Rail Australia (CLARA) project, connecting Sydney and Melbourne gives the opportunity to explore innovative hydrogen deployment options to revolutionise infrastructure with a 50 to 100 year life expectancy.

Hydrogen's ability to power heavy transportation haulage is its defining advantage over electrification or battery storage, with development of hydrogen powered trains already progressing in Europe. In progressing the CLARA project, the Federal Government has an opportunity to underwrite domestic hydrogen production by requiring, or viewing favourably, submissions to include hydrogen powered trains.

The CLARA project is expecting the submission of developed business cases in 2020, with the rolling stock provider to be confirmed but expected to include options from Japan, France, Germany or China, all nations which have demonstrated a willingness, both in rhetoric and in practice, to develop hydrogen rail technology.

With Australia's regional rail network largely still to be electrified, switching to hydrogen-powered trains may have a competitive advantage in a shorter timeframe than for most other applications.[12]

[15] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. xvi
[16] Acil Allen, Opportunities for Australia from Hydrogen Exports, 2019, p. iii, PwC analysis
[17] COAG Energy Council, Hydrogen for Transport, 2019, p. 36

2. Driving down costs of production

As emerging sectors and international opportunities increase, the demand for clean hydrogen, production will scale-up, reducing costs and attracting further investment

Production scale and supply chain integration are the keys to driving down costs

1. Without government support, short-term losses are likely to be endured across the supply chain while the cost of producing green hydrogen remains more expensive than the competition.
2. Relying on alternatives to grow the technology, such as use of grey hydrogen or investment in CCUS technology is likely to be needed to drive down costs across the supply chain.
3. Strategic investment today will be for the benefit of the sector as a whole and deliver a first mover advantage to those willing to take a long-term view.
4. Industry leaders will need to address supply chain gaps through acquisitions, joint ventures and organic growth, rather than wait for the market to develop for them.

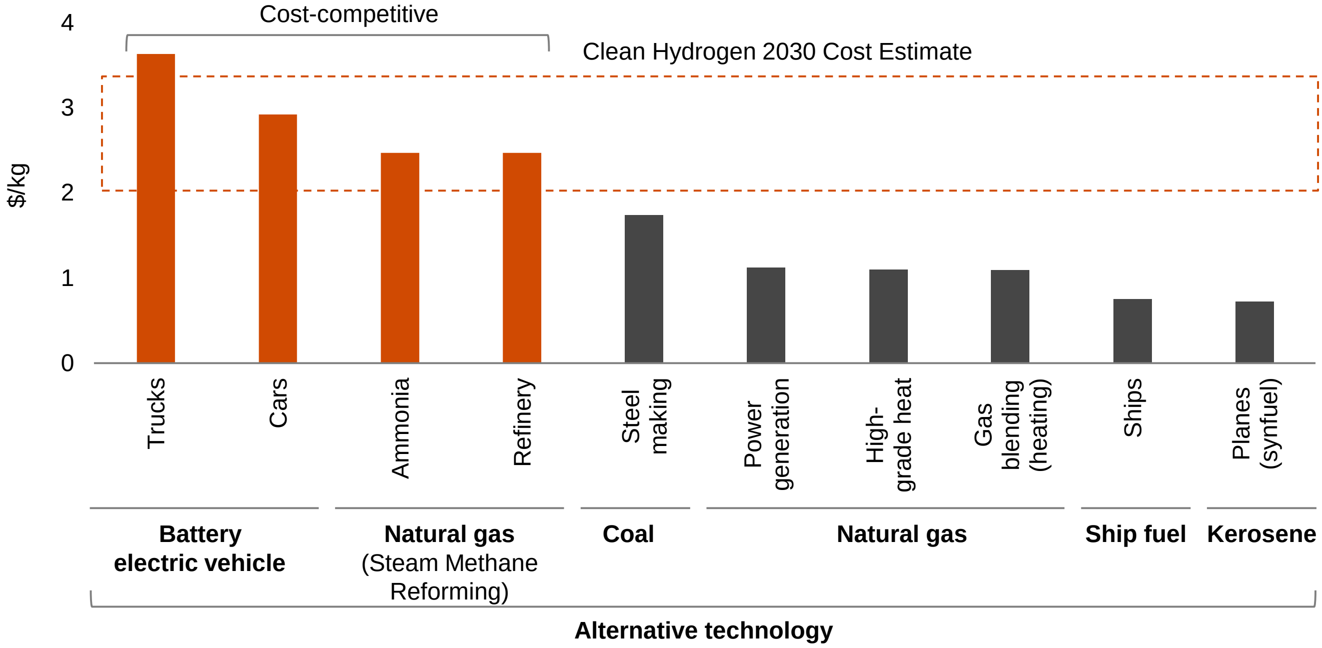
Playing the long-game: focusing on the end-goal of clean hydrogen

Policymakers should encourage investment in scaling-up pilot projects over the next 3-5 years that will help the industry develop, review, share and adapt, in order to support the business case for commercial deployment. The confidence of investors and consumers in the future of clean hydrogen will depend upon the experience gained from small-scale deployment and the feedback-loop generated from each successive investment.

Inevitably, this short-term investment across the sector may require initial reliance on increased production of grey hydrogen, to provide the fuel required to spur investment into end-use technology or export capability, as detailed in Case Study 4. While this would need to be carefully managed from a policy perspective, in our view this may represent a necessary first step in establishing a viable industry.

Innovation in hydrogen technology will drive cost competitiveness

Clean hydrogen is currently 2-3x more expensive than hydrogen produced from fossil fuels without CCS technology ($4-6/kg vs $1.5-$2.5/kg).[18] It is generally considered that to displace alternative technologies, clean hydrogen will need to be produced at a price range of $2.0/kg - $3.5/kg, although the ability to displace each specific use will depend on the ultimate end use and the efficiency of using hydrogen as an alternative:[19]



[18] IRENA, Hydrogen: A Renewable Energy Perspective, 2019, p. 28
[19] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. 6

2. Driving down costs of production

Electrolyser cost, operational efficiency and access to low-cost renewable energy will pull consumers toward cost-competitive green hydrogen

There are three main cost drivers on the pathway towards achieving cost competitiveness for green hydrogen:

1. **The capital cost of electrolysers**
2. **Electrolyser efficiency and usage**
3. **The cost of renewable electricity**

Driving down the capital cost of electrolysers

On the production side of green hydrogen, ongoing research and development focuses primarily on the cost, scale and efficiency of the electrolyser, as the most significant capital investment required for the production process.

Multiple electrolyser technology options exist, with differing technical and economic characteristics:[20]

	Alkaline electrolyser	Proton Exchange Membrane (PEM) electrolyser	Solid oxide electrolysis cells (SOEC) electrolyser
Description	A mature technology with relatively low capital costs	Relatively small size, offering flexible operation but greater reliance on previous electrode materials	Least mature option, expected to have lower materials costs (using ceramics), rely on steam electrolysis requiring higher heat source
Electrical efficiency (% LHV)	Current: 63% Long-term: 80%	Current: 56% Long-term: 74%	Current: 74% Long-term: 90%
Capex (AUD/kW)	Current: 740-2,080 Long-term: 300-1,040	Current: 1,640-2,700 Long-term: 300-1,340	Current: 4,200-8,340 Long-term: 750-1,640

Notes: LHV = Lower Heating Value, long-term refers to 2030-2050.

As project scale increases and production efficiencies are realised, the capital cost of electrolysers are expected to reduce by approximately 70% by 2030.[21] Whilst the average size for electrolyser installations globally was only 1.0MW from 2015-2019,[22] large-scale electrolyser projects are underway, notably across North-Western Europe, including Shell's development of the world's largest PEM electrolyser (10MW) in Germany and the Netherlands' ambitious 2GW electrolyser system being studied at Rotterdam harbour. Australia is also scaling-up with the planned Port Lincoln 30MW electrolyser and ammonia production facility in South Australia and continued investment in integrated hydrogen hubs.

The recently announced ARENA renewable hydrogen funding round will target projects involving the production of renewable hydrogen from electrolysers of 10MW or larger.

Improving electrolyser efficiency is essential

The cost of producing green hydrogen directly relates to the rate of efficiency at which renewable electricity can be converted to a unit of hydrogen, this efficiency depends upon two factors:

1. the conversion efficiency of the electrolyser, which will vary by electrolyser technology and development progress (currently approximating 75% and projected to peak at about 85% by 2030);[23]
2. the full load hours at which an electrolyser can utilise renewable electricity.

The full load hours depend upon the energy procurement strategy employed by the hydrogen production facility. The preferred energy procurement approach from a decarbonisation perspective is to pair the hydrogen plant with dedicated renewables capacity, which can be collocated to minimise transmission losses.

However, in the case of solar and wind, intermittent generation subject to seasonality may not result in load optimisation for achieving cost competitiveness. By contrast, security of supply can be achieved with grid electricity, however this will typically come at a higher cost to the hydrogen plant to secure a firm power supply contract and may result in greater complexity for ensuring the hydrogen's 'green' credentials, which will be subject to the prevailing grid generation mix.

Nations with the ability to harness year-round renewable energy with a high capacity factor, such as solar PV and onshore wind in Australia, will be at an advantage for producing green hydrogen.

[20] IEA, The Future of Hydrogen, 2019, p. 44, PwC analysis
[21] WEC, Hydrogen – Industry as Catalyst, 2019, p. 30
[22] IEA, The Future of Hydrogen, 2019, p. 45
[23] IEA, The Future of Hydrogen, 2019, p. 44

2. Driving down costs of production

Production of green hydrogen must be managed to ensure it benefits Australia and uses the country's natural resources wisely

The cost of renewable electricity

To meet the projected green hydrogen demand for exports from Australia of over 3.5 million tonnes in 2030 to Japan, the Republic of Korea, China and Singapore, CSIRO forecasts that a total wind and solar capacity of 15 GW to 17.5 GW would be required.[24] Any attempt to meet such demand without a coordinated strategy for installing the required renewable energy capacity would result in traditional fossil fuel-based generation being called upon to fulfil the renewables shortfall, nullifying the 'green' import credentials that are sought by aspiring clean hydrogen economies.

Whilst the short-term demand for hydrogen of any form to promote investment into end uses may lead to steady or increased emissions from grey hydrogen production, such investment will support downstream elements of the clean hydrogen supply chain that will reduce carbon emissions in the long-run when greater scale of green hydrogen electrolysis is achievable. This approach is evident in Case Study 4, in which hydrogen will be produced from brown coal and exported to Japan, with the potential to develop a carbon sequestration solution during commercialisation.[25]

With the cost of electricity estimated to contribute approximately 50%-70% to the Levelised Cost of Hydrogen (**LCOH**), achieving cost parity with grey hydrogen and alternative fuels will be heavily reliant on the availability of low-cost renewable electricity on a reliable basis. This will determine Australia's competitive advantage within a global clean hydrogen export market. Given the logistics cost associated with exporting hydrogen (shipping and handling cost expected to be around $1.5/kg by 2040), to achieve competitive parity with domestic production in Japan, it is expected that a price of approximately $20/MWh for Australia's renewable generation must be achieved.[26]

Creating hydrogen sustainably: preserving Australia's resources

Whilst the move towards green hydrogen represents a positive step for decarbonisation globally, the intensive water usage from electrolytic hydrogen production raises further considerations which will need to be addressed through a specifically Australian lens.

Water is consumed at a rate of 9 litres H_2O: 1kg H_2 in the electrolysis process, the same rate of water consumption as for hydrogen produced by coal gasification but double the rate at which hydrogen is produced from steam methane reforming, providing a further challenge in the move towards green hydrogen.[27]

As part of the National Hydrogen Strategy, the Australian Government developed a site identification tool, through which potential hydrogen production sites are identified based upon a number of assessment criteria. Whilst about 11% of Australia's land was identified as highly suitable for clean hydrogen production based on renewable energy production facilities, only 3% of land was considered highly suitable when proximity to water, ports, pipeline easements and electricity infrastructure is taken into account.[28]

Pressure on the use of fresh water supplies for hydrogen production can be eased by:

	Recycled water	Desalination	Flexible production
Description	• Harnessing recycled water for electrolysis; • Can result in reduction in logistics costs due to proximity of wastewater facilities to urban centres; • May achieve additional sustainability benefits through reduction in wastewater discharge to waterways and oceans.	• Could create a year-round source of demand for desalination facilities, reducing the marginal capital cost of investing in new desalination capacity; • Incremental operating cost of using desalinated water estimated at around an additional 5c/kg H2, not a material increase on the target cost of hydrogen production.[29]	• Subject production to water controls relative to activities deemed to have higher value in economic or social terms; • Curtailment of hydrogen production, would hinder the economics of clean hydrogen but could improve the sustainability, flexibility and perception of the industry.

[24] CSIRO, National Hydrogen Roadmap, 2018, p. 53
[25] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. xxi
[26] McKinsey, The hydrogen opportunity for Australia, 2019
[27] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. 12
[28] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. 10
[29] Jacobs, Hydrogen White Paper, 2019, p. 14

3. Developing the industry framework

Government bodies have an important role to play in overseeing the development of physical and regulatory infrastructure needed to support an emerging hydrogen industry

Private sector investment will look for confidence signals that a holistic supply chain is developing

1. Physical and regulatory infrastructure will need to develop in tandem with the hydrogen industry as it moves toward industrial-scale production;
2. Crossover with existing infrastructure in the form of transmission and distribution networks, shipping and renewable certification schemes provides an existing foundation to be adapted for the specifics of hydrogen;
3. Safety of hydrogen transportation, storage and appliances will be at the forefront of consumer engagement. International standards should be developed to grow confidence.

The shift to a clean hydrogen economy will not happen organically, nor can it be allowed to take place in isolation. Investors and consumers will require change to be facilitated by supporting infrastructure, in the form of physical means of storage, transport and utilisation, as well as 'soft' infrastructure in the form of regulation and certification to ensure that the transition takes place safely, efficiently and 'for the benefit of all Australians'.[30]
This requirement for supporting infrastructure will present further challenges and opportunities to the sector, many of which are being addressed at the early stages of development.

Transporting hydrogen domestically and internationally
As with the challenges presented by the transmission of renewable energy from rural generation sites to population centres, so too will green hydrogen require transport infrastructure that provides stability, minimises losses, is efficient and affordable. In the case of domestic transport for Australia, this will take the form of pipelines – either new-build or potentially adapted from existing gas pipelines – or storage and transport of hydrogen in the form of gas, liquid or fuel cells.

It has been estimated that the total domestic infrastructure investment required to store, transport and distribute hydrogen to take full advantage of Australia's opportunity to become the dominant East Asian exporter could be up to $80bn by 2030.[31] Approximately one quarter of this total investment would flow into the construction of Australia's hydrogen refuelling network, including the distribution and retail infrastructure, with the remainder being composed of liquefaction facilities, storage tanks, and distribution trucks.

For international transport, liquid hydrogen can be transported on ships, as proven with the launch of the world's first liquid hydrogen transport carrier by Kawasaki Heavy Industries in December 2019. Alternatively, molecular conversion, primarily from hydrogen to ammonia, can allow hydrogen to be transported on a wider array of existing carriers, at the expense of greater energy losses, with an existing ammonia transport industry already in operation.

[30] COAG Energy Council, Australia's National Hydrogen Strategy, 2019, p. 50
[31] Hydrogen Council, Hydrogen Scaling Up, 2017, p. 66

3. Developing the industry framework

Integrating hydrogen within our daily lives

Facilitating consumer uptake of clean hydrogen will require the roll-out of an array of supporting infrastructure, including hydrogen fuelling stations, hydrogen-compliant appliances such as boilers and stoves, and potential upgrades to gas distribution networks.

As discussed in section 1, the use of hydrogen and natural gas blending within Australian gas networks is already being trialled in South Australia. A study by the University of Queensland and COAG Energy Council found that two thirds of respondents actively supported the use of hydrogen in the home.[32]

Ensuring a safe transition

The same University of Queensland consumer survey found that safety was the main concern for consumers to be addressed as part of adapting to a hydrogen economy. The majority (77%) of those surveyed believe that there will be adequate safety precautions in place to keep risks under control.[33]

The public's faith in implementing these precautions lies in trust in government, research bodies and industry, to coordinate joint responsibility for a safe roll-out of hydrogen infrastructure, production and appliances.

Perceived safety issues or significant risk events will do far more to set back the successful roll-out of hydrogen in the long-term than the cost of structured engagement to establish a clear and widely-adopted set of regulations and guidelines in the short-term. In our view, relevant stakeholders should engage with governments as soon as possible to develop regulatory requirements, to ensure that the industry is not held back by a lagging regulatory environment.

Delivering true emissions reductions

Whilst a period of transition is expected to occur, during which there will be continued reliance on hydrogen produced from fossil fuel-based power to develop the whole supply chain, the selling point of hydrogen power is the role it can play in decarbonising industrial economies. A certification scheme will need to be developed to provide guarantee that hydrogen has been sourced from carbon-free renewable sources, or with a substantial degree of CCUS technology.

Australia has the opportunity to play a leading role in shaping a future certification of origin scheme, in which it will likely be in Australia's interest given the vast wealth of renewable energy sources relative to that of its export targets. To be adopted at an international level, there will need to be a coordinated agreement upon standards, carbon-free qualification and transparent origination for exported hydrogen.

[32] University of Queensland, The Australian public's perception of hydrogen for energy, 2018, p. 34
[33] University of Queensland, The Australian public's perception of hydrogen for energy, 2018, p. 6

4. Using policy to support the industry

The emerging industry will seek confidence from policy commitments at a State and Federal level, as well as heeding lessons learned from the LNG and renewable energy markets

Governments will rely on market competition and deliverability to back projects with significant social and economic value

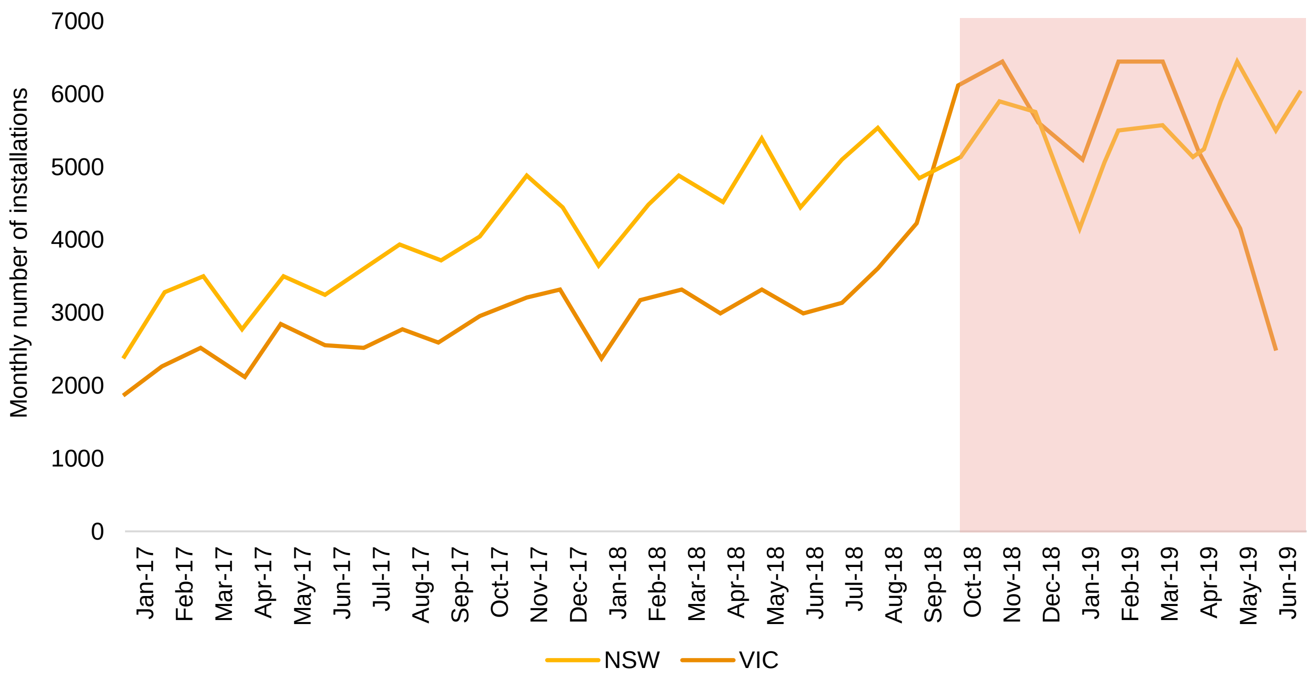
1. Government grant, subsidy and low-cost finance schemes should be deployed strategically to projects that are considered to offer the greatest benefit from a whole-of-industry perspective;
2. Procurement strategies that focus on the hydrogen industry to identify gaps within the supply chain and create a competitive environment should be adopted for transport and power applications;
3. Government should view this decade as the essential period for catalysing the hydrogen industry through targeted support, with a view to stepping back from a liberalised sector when private sector capital can be attracted through the feasibility of viable projects.

While incumbent technologies and consumption patterns benefit from existing technologies, research and development and infrastructure, effective government policy can both shape demand, provide funding for development in the absence of private capital and encourage further investment to enable commercialisation.

History shows that effective policies address key structural or behavioural levers

The technical, financial and political challenges hindering development of the North West Shelf Liquified Natural Gas (NWS LNG) project in the early 1970s are well documented,[34] with development only secured as a result of clear policy directives at both State and Federal levels. More specifically, new federal policies provided confidence to investors and tax incentives to reduce the cost of development, while demand was secured by the Western Australian government entering into a 'take or pay' gas supply contract and providing funding for key infrastructure. These policies supported development of the first (domestic) stage of the NWS LNG project, establishing a foundation for expansion that has led to Australia becoming the world's largest LNG exporter[35] and the LNG export industry significantly contributing to Australia's GDP.

Government policy can also shift consumption to achieve strategic outcomes, with a prominent example being the implementation of financial support packages from Australian state governments leading to Australia having the highest uptake of rooftop solar globally.[36] However, policies must adapt to changing markets to ensure sustained success. As evidenced by the graph below, rooftop solar installations in Victoria declined significantly when the financial support scheme reached its threshold cap (and only recovered after the cap was enlarged).[37]



[34] Engineers Australia, Nomination of the North West Shelf Project For an Engineering Heritage Australia Heritage Recognition Award, 2017
[35] Reuters, Australia grabs world's biggest LNG exporter crown from Qatar in November, 2018
[36] Australian National University, Australia: the renewable energy superstar, 2018, p. 2
[37] Australian Energy Council, Solar Report – Quarter 3, 2019, p. 4

4. Using policy to support the industry

The emerging industry will seek confidence from policy commitments at a State and Federal level, as well as heeding lessons learned from the LNG and renewable energy markets

This same principle is also observed in large-scale renewable development markets both in Australia and globally, where rebates and incentives support investment. For example, the Production Tax Credit (PTC) and Solar Investment Tax Credit (SITC) schemes in the United States, which provided tax credits for qualifying investment, resulted in significant investment in wind[38] and solar[39] technologies.

Consumption patterns can also be shifted through the imposition of penalty schemes. The European Union (EU) continues to provide a coordinated approach to emission reduction policies, with member states issuing directives that penalise the usage of specified fuels and energy sources. The EU's recent decision to exclude gas-fired power from its criteria for sustainable investment will likely have significant capital allocation implications.[40] Such policies are seen to be effective, as investment markets suggest that corporate consumers usually respond to preserve their profitability and reputation.[41]

Finally, the effectiveness of government policy is also determined by the clarity and intent of policy communications. Within the Asia-Pacific region alone, clear statements from Japan, Singapore, Korea and China regarding the ambition to consume green hydrogen, facilitate global supply chains and develop relevant technologies have garnered significant global interest from scientists, investors and other governments. Clarity of policy intent demands attention from other governments, financial investors and corporates that either produce relevant products (e.g. car manufacturers) or those looking to create adjacencies in a hydrogen powered economy (e.g. refuelling station network operators).

Recent State and Federal support is preparing Australia's hydrogen industry for commercialisation

Following adoption of the National Hydrogen Strategy, the Federal Government committed $70m to ARENA for electrolyser projects and $300m to the CEFC's new 'Advancing Hydrogen Fund' to support emerging hydrogen technologies,[42] increasing the Federal Government's hydrogen funding commitment to over $500m. ARENA has already provided in excess of $43m of funding across 23 projects,[43] investigating the commercial feasibility of green hydrogen at scale (including efficiency of electrolysis), the introduction of hydrogen into domestic gas networks and potential transportation applications.

The $70m ARENA renewable hydrogen fund will focus on production of renewable hydrogen from electrolysers of 10MW or greater, a significant step-up in scale of production.

Policy announcements from State Governments[44] have also sought to support early stage development and commercialisation projects, but in addition they have announced consumption policies to support future production, such as commitments on blending hydrogen into gas networks and procuring hydrogen powered public sector transportation. As the NWS LNG project's success highlights, consumption-focused policies are still required (in addition to development grants) while an industry is in its infancy.

…but much more is needed over the coming decade to cement Australia's position in a global green hydrogen economy

The hydrogen industry must address key issues throughout the supply chain to deliver long-term, sustainable success. While government policies must continue to support ongoing development of new technologies that will improve the economics of production, new policies addressing consumption, infrastructure and regulation will also be needed.

Financial support from ARENA and CEFC must be extended to encourage technological development and support pilot programs transition to commercialisation to meet future demand. While private sector capital will ultimately be required to ensure a sustainable industry, proponents of technology development should demand government support to provide the required funding for the industry while in its infancy, laying a foundation for future private capital.

[38] Department of Energy, The Production Tax Credit is Key to a Strong U.S. Wind Industry, 2014
[39] SEIA, Solar Investment Tax Credit, 2020
[40] AFR, Europe's heavy blow against natural gas, 2020
[41] AFR, The carbon tax that will work, 2020
[42] Department of Industry, Australia to be a world leader in hydrogen, 2019
[43] Refer Appendix A for a listing of all projects
[44] Refer Appendix B for a list of state government policy announcements

4. Using policy to support the industry

Stimulating consumer demand for hydrogen will play an integral role in scaling-up production and reducing costs

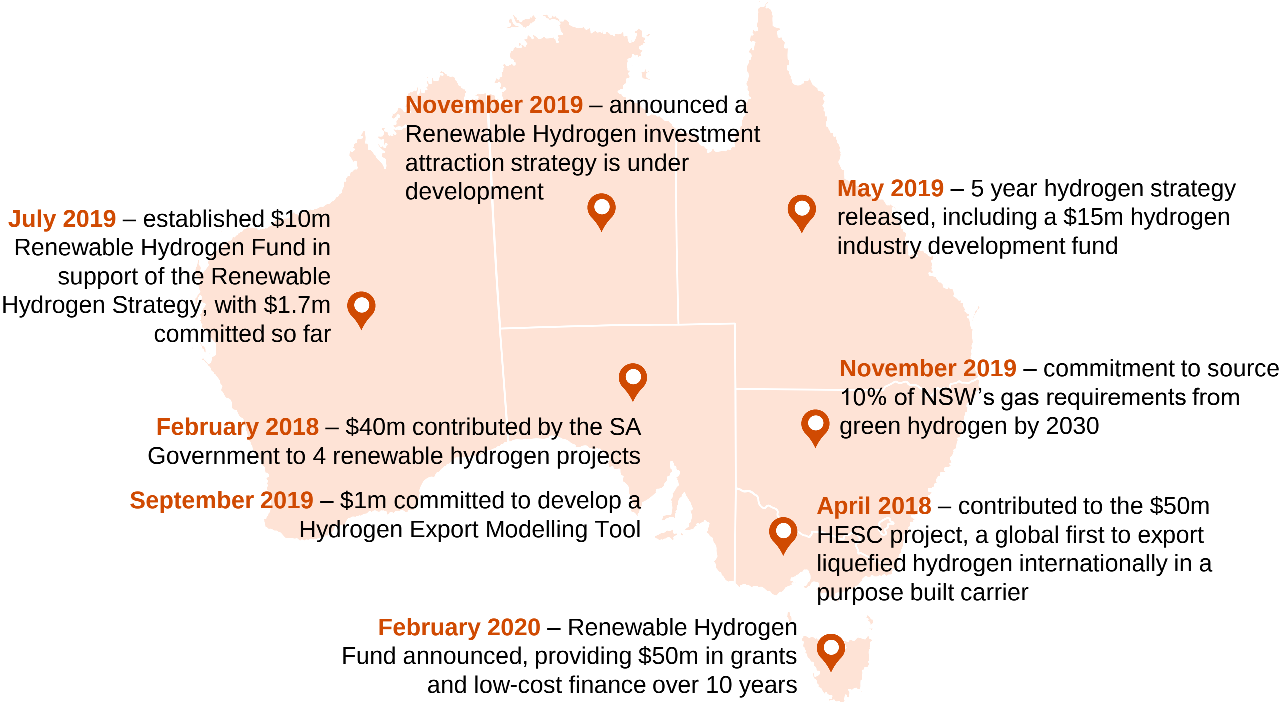
Targeted consumption policies must also be implemented to maximise the return on investment of grant funding and to further invest in consumption capabilities and required infrastructure.

Consumption can be effectively channelled by financial incentive schemes that target producers (e.g. feed-in tariffs) and key consumers (e.g. subsidies to offset higher costs), and governments should collaborate with industry participants to design different schemes that address key requirements. Governments should also pursue initiatives to support their own ideological and consumption policies. For example, the implementation of emissions targets will divert consumption to greener fuels (including, but not limited to, hydrogen) and targeted procurement policies, such as mandating that new transport/vehicle fleets be hydrogen powered, will both pursue changes to existing consumption patterns and further support elements of the supply chain. The effectiveness of these policies will require a coordinated approach across State and Federal Governments, particularly as specific policies may be better implemented at different levels of government.

As noted above, a growing hydrogen industry will require significant investments in key infrastructure to support production, storage and transportation. Governments should consider implementing tax credit/offset schemes to encourage private sector investment in the short term and to the extent necessary infrastructure fails to attract sufficient private capital, governments should invest themselves. While the NWS LNG project evidences the benefits of government policies that encourage and provide infrastructure investment, significant shortcomings in electricity infrastructure investment in the Eastern states highlight the damaging effects of policy inaction and an uncertain investment outlook.

As Case Study 3 suggests, direct government investment in hydrogen infrastructure can have significant flow-on benefits. This paper has highlighted that investment in hydrogen production/storage infrastructure would not only support the hydrogen industry, but would also support the renewable energy sector and provide additional stability to the electricity network, the intermittent use of electrolysers solely to capture surplus renewable energy production for storage and subsequent firming is unlikely to be financially viable given current capital costs.

Importantly, governments must work collaboratively with industry participants (who should also be proactive in their approach) and design policies that support the entire supply chain. These policies must be supported by public engagement that highlights both the future economic benefits of a sustainable hydrogen industry and its importance in helping reduce Australia's emissions. The transition to hydrogen will be challenging and at times may face opposition, but leadership from governments and the implementation of effective policies will provide a future environment in which the first steps can be taken.



Looking ahead to a decarbonised Australian economy fuelled by Hydrogen

At the start of this critical decade for hydrogen, we observe an industry in the early stages of development, taking the first steps towards realising its potential with a view to surpassing our reliance on carbon-emitting alternatives

At the start of this paper we asked you to imagine a planet that had significantly reduced its reliance on coal and oil, and was instead powered by a new hydrogen economy forged to replace fossil fuel usage. Today, we can be certain that the hydrogen economy is not only coming, but that we are accelerating towards a hydrogen reliant future.

This introductory overview to the industry highlights the market's strongest themes:

- ✓ Costs of producing green hydrogen are falling;
- ✓ Global demand for the production of green hydrogen from a variety of consumer sectors is rising;
- ✓ Early-adopters are pushing ahead with innovative and larger projects across the supply chain.

There will be challenges encountered as the industry pushes forward. To achieve the scale needed to meet the market benchmark for competitiveness of approximately $2.5/kg to $3/kg (down from current pricing of $6-8/kg), green hydrogen will require a successful transition from pilot projects to industrial-scale production.

This will not happen without leaders in the public and private sectors harnessing the momentum of pilot projects and hailing their successes. Collaboration and integration across the supply chain will also be needed to share innovation and cost efficiencies where possible.

Australia is fortunate to possess the fundamentals required for hydrogen production and be relatively closely located to international centres of demand, but success in creating a booming hydrogen economy will require decisive action and a coordinated approach from both the private and public sectors. We agree that the National Hydrogen Strategy's list of strategic actions are the right starting basis for this coordinated plan. We all have a role to play and an opportunity to share in the future success.

Private sector participants with existing capabilities across the potential supply chain are well positioned to make the first move, but should be supported by effective government policy that encourages the investment of private capital. Mandating the use of hydrogen powered buses and trains, utilising hydrogen for electrical grid stability and energy storage, and the blending of hydrogen into existing natural gas networks are all accessible applications that support government policy in the short-term, secure domestic demand and provide investors with an early exposure to invest in required infrastructure to support a growing hydrogen industry.

We recognise that accelerating markets takes more than innovation, it takes political will and alignment with investors and market participants. There is a need for market certainty, and simple policy initiatives targeting hydrogen adoption in mobility can have a strong effect in boosting the hydrogen mobility application.

Learning to crawl before hydrogen walks provides investors with the ability to focus on areas for investment that offer the greatest certainty for growth and establish the foundation for today's developing hydrogen powered economy to be a runaway success in the future.

Following this introduction to the sector, we will be looking ahead to identifying and supporting hydrogen investment opportunities through subsequent publications and industry engagement.

To speak to our team about how to invest strategically in hydrogen now to best capture the market, please contact one of our contributors to this paper.

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Appendix A: ARENA-funded hydrogen projects

ARENA is funding development projects to kickstart the Australian hydrogen economy

Project Name	State	Project partners	Project description	Total cost (A$m)	ARENA funding (A$m)
Jemena Power to Gas Demonstration	NSW	Jemena	Aims to support the long-term decarbonisation of Australia's energy market by demonstrating that hydrogen produced from excess intermittent renewable energy sources can be both stored in the gas distribution network and used as a clean fuel for hydrogen fuel-cell vehicles. Plans to source renewable energy and convert it into hydrogen via electrolysis, with the majority to be injected into the gas network, providing enough energy to meet the cooking, heating and hot-water requirements of approximately 250 homes. A smaller portion of the hydrogen will be utilised for electricity generation, with the remainder stored for use in an onsite Hydrogen Refuelling Station. A 500 kW electrolyser will be constructed in Western Sydney to produce hydrogen, which will see hydrogen stored in the Jemena Gas Network over the 5 year trial period to demonstrate how existing gas infrastructure can be repurposed.	15	7.5
Highly Efficient & Low Cost Photovoltaic-Electrolysis System	NSW	UNSW; Beijing Zhongchao Haiqi Technology Co; RayGen Resources; Shenzhen Kohodo Sunshine Renewable Energy Co	Aims to lower the cost of renewable hydrogen produced via PhotoVoltaic Electrolysis (PVE) by improving the energy efficiency of transition metal-based alkaline water electrolysers and the overall solar to hydrogen (STH) conversion efficiency of PVE systems. The current technology used to produce over 90% of hydrogen stock is by steam reforming of methane. The project will use an integrated PVE heat exchange technology and active and cost-effective catalyst materials to convert sunlight to hydrogen.	5.04	1.31
Toyota Ecopark Hydrogen Demonstration	VIC	Toyota Motor Corporation	Aims to demonstrate the technical and economic feasibility of producing, storing and using hydrogen sourced from renewable powered electrolysis for both stationary energy and transport energy uses. This constitutes phase 2 of a 3 phase plan to develop a Zero Emission Centre of Excellence, and includes the following deliverables: • demonstrating that a combination of on-site solar PV with battery storage and hydrogen production can provide the centre with a reliable and continual power supply • demonstrating that green hydrogen can fuel vehicles and supply electricity through the use of fuel cells • constructing a Hydrogen Education Centre to promote hydrogen innovation and education	7.37	3.07
Hydrogen to Ammonia Research and Development	VIC	CSIRO; Orica Australia; Grains Research and Development Corporation	Aims to develop an ammonia production process which is less energy intensive than the conventional (Haber-Bosch) process and does not contribute to any greenhouse gas emissions. The energy consumed by the conventional process is 10-15 kWh/kg. The proposed process will develop the technology to produce ammonia from renewable sources of energy with 25% less energy input per tonne of ammonia. A prototype ammonia producing reactor will be built to demonstrate the operation with electricity supplied by a solar PV.	2.83	1.17

Appendix A: ARENA-funded hydrogen projects

Project Name	State	Project partners	Project description	Total cost (A$m)	ARENA funding (A$m)
Enabling Efficient, Affordable & Robust Use of Renewable Hydrogen	VIC	University of Melbourne; UNSW; MAN Diesel & Turbo SE; Energy Power Systems; Continental Automotive Systems; Energy Australia	To demonstrate the performance and the value of highly efficient, reciprocating engines operating on renewable hydrogen. The project will commence with fundamental studies of hydrogen injection and combustion and the development of the first predictive tools for use in the design and optimisation of advanced hydrogen fuelled, reciprocating engines. Some of the chief innovations include new models for the oxidation of renewable hydrogen in advanced engines, predictive simulations of directly-injected hydrogen, demonstration of hydrogen fuelled engines with efficiencies exceeding 45% and an analysis detailing the role of hydrogen fuelled engines in the renewable hydrogen economy.	8.61	2.59
Feasibility Study for a Green Hydrogen and Ammonia Project	QLD	Queensland Nitrates (QNP); Neoen; Adivisan (Worley Group)	Aims to determine the feasibility of producing green hydrogen at commercial scale to produce ammonia at QNP's existing manufacturing plant in Qld. The proposed plant would produce 20% of the ammonia used by QNP, which is currently based wholly on hydrogen produced from natural gas. Ammonia production is currently the largest use of hydrogen globally, consuming about half the total production. QNP is to provide the market and business case analysis for green ammonia supply, and on-site plant experience; Advisian will complete overall process modelling, integration engineering, project management and environmental, social and regulatory approval work; Neoen will examine the renewable based electricity supply for the project.	3.89	1.91
Feasibility of Renewable Green Hydrogen	QLD	Dyno Nobel Moranbah; Incitec Pivot	Aims to assess the feasibility of producing renewable hydrogen and ammonia at Dyno Nobel's existing facility in Qld, to replace natural gas as the feedstock. This study will determine the scope and cost of the required plant upgrade, including updates to system design and technology, process safety, approvals, cost drivers, implementation timeframe and funding requirements.	2.67	0.98
Renewable Hydrogen Production and Refuelling Project	QLD	BOC Limited; ITM Power; QUT; Hyundai Motor Company	Aims to demonstrate renewable hydrogen production at a commercially viable scale, and help progress the commercialisation of hydrogen for vehicles. Proposal is to produce renewable hydrogen at Bulwer Island to service BOC's existing gas customers there (following the closure of the BP refinery) and to expand commercial activities to supplying hydrogen for transport. BOC currently produces hydrogen through steam methane reformation in Altona, Vic, and transports it to Bulwer resulting in 90 tonnes of CO_2 emissions. The plan is to install a 100 kW solar array and 220 kW proton exchange membrane electrolyser on Bulwer Island, as well as a hydrogen refuelling station in Brisbane to fuel hydrogen vehicles.	4.18	0.95

Appendix A: ARENA-funded hydrogen projects

Project Name	State	Project partners	Project description	Total cost (A$m)	ARENA funding (A$m)
ATCO Hydrogen Microgrid	WA	ATCO	Aims to explore integration of hydrogen supply with existing gas infrastructure by developing a Clean Energy Innovation Hub (CEIH). The CEIH incorporates the production, storage and use of green hydrogen, as well as the commercial application of clean energy in micro-grid systems. Solar panels capable of generating 300 kW of power will be installed, with 400kWh of energy stored in batteries and any excess utilised to power an electrolyser for hydrogen production. The hydrogen will be captured and injected into a micro-grid system at the Jandakot facility. Some of the challenges include optimising hydrogen storage solutions, blending hydrogen with natural gas and using hydrogen a direct use fuel.	3.53	1.79
Connecting the Power and Gas Grids	SA	AquaHydrex	The Connecting the Power and Gas Grids project started in July 2017 but was unable to proceed and ended in April 2018 without any ARENA funds spent. Aimed to design and build an electrolyser pilot plant and test it in partnership with Australian Gas Networks (AGN) as a demonstration of 'power to gas' injection of hydrogen into the natural gas grid. The pilot plant planned to use electricity from the grid to produce hydrogen from water through a 50 kW electrolyser, which would then be injected into the natural gas network.	12.21	5

Appendix B: Global hydrogen progress

All Australian states are committed to developing their hydrogen production capabilities, having announced millions of dollars in investment

Australian States

- In November 2019, NSW Energy Minister Matt Kean committed to sourcing 10% of NSW's gas requirements from green hydrogen by 2030. This target will build on Jemena's ARENA funded Western-Sydney hydrogen blending project[34] and may be supported by NSW's $100m clean-tech funding package.
- In January 2019, the NSW Minister for Transport announced that hydrogen fuel cell bus technology would be explored as part of the Future Transport 2056 Strategy.
- The Queensland Government released a 5 year hydrogen strategy in May 2019, included in which is a $15m industry development fund to support hydrogen projects, seeking to capitalize on its abundant natural renewable energy resources and proximity to Asia for transportation.
- $1m in funding was granted by the Queensland Government to the Southern Oil facility in Gladstone to develop a bio-hydrogen generation unit in June 2017, and a further $8.4m was provided in August 2018 by the Government, ARENA and industry players to support hydrogen production at the Queensland Government's Redlands Hydrogen Research Facility, where hydrogen has been produced and exported to Japan as a trial.
- The Queensland Government also intends to trial a FCEV fleet, which was a key contributor to BOC's decision to progress their $3.1m green hydrogen project on Bulwer Island in August 2019.
- Over $40m has been contributed in grants and loans by the South Australian Government in February 2018 to 4 renewable hydrogen projects in the state, including Neoen's 50MW Hydrogen Superhub and H2U's 30MW Port Lincoln hydrogen supply chain demonstrator.
- ARENA has announced the Renewable Hydrogen funding round, with the Expression of Interest process due to commence in April 2020. $70m grant funding will be available to projects that can produce renewable hydrogen using an electrolyser of 10MW or greater.
- A further $1m was committed in September 2019 by the South Australian Government to the development of a Hydrogen Export Modelling Tool to inform the establishment of renewable hydrogen export supply chains and assist infrastructure developers and investors.
- Western Australia announced ~1.7m of funding across 7 feasibility studies in January 2020, and are currently assessing applications for funding on capital works projects from their $10m Renewable Hydrogen Fund, established in support of the Western Australia Renewable Hydrogen Strategy in July 2019.
- Demand is being driven by the Western Australian government's goals to:
  - Export renewable hydrogen by 2022, and grow WA's market share in global hydrogen export to similar levels as its share in LNG exports today by 2040;
  - Blend renewable hydrogen in a WA gas network by 2022, and by 2040 blend 10% green hydrogen into all WA's gas networks; and
  - Utilise renewable hydrogen as a significant fuel source for regional transportation and mining haulage vehicles in the state by 2040.
- In April 2018 the Victorian Government contributed to the $50m HESC project, a global first in terms of scale which includes the transportation of liquefied hydrogen in a purpose built hydrogen carrier, with the aim of developing a commercial supply chain from Victoria to Japan by 2030.
- Workshops are currently being held with industry participants to develop the Victorian Hydrogen Investment Program (VHIP), with the aim of encouraging investment to meet the target of net zero carbon emissions in the state by 2050.
- The Tasmanian State government has announced a Renewable Hydrogen Fund, comprising $20m grant funding, $20m concessional loans, $10m worth of support services for hydrogen projects. The fund will be available for up to 10 years with the Expression of Interest process due to commence in early 2020.

Appendix B: Global hydrogen progress

Global hydrogen investment is gaining traction, with ambitious targets announced across East Asia and the European Union

Japan

- 2008 – The four year Fukuoka Hydrogen Town Project is announced, with 150 houses to have fuel cells installed, to run from 2009-12
- 2014 – Fourth 'Strategic Energy Plan' approved by Cabinet, stating that it is essential for Japan to formulate a roadmap towards the creation of a 'hydrogen society', including an outlook until 2030. In line with the Plan, METI published the 'Strategic Roadmap for Hydrogen and Fuel Cells'.
  - Aim to operate 40k FCVs by 2020, 200k by 2025, and 800k by 2030
  - Construct 900 refuelling stations by 2030
- 2017 – 'Basic Hydrogen Strategy' decided on, with the aim of reducing the cost of hydrogen from its present value of 100 yen/m3 to 30 yen/m3 by 2030, and eventually to 20 yen/m3 (ie reduce cost by 1/5.
  - Method of achieving this is to establish large scale hydrogen supply chains and establish the mass use of hydrogen as fuel for FCVs, power generation and industry, thereby taking advantage of economies of scale.
- 2018 – Fifth 'Strategic Energy Plan' approved by Cabinet, expanding outlook until 2050. Targets include:
  - Introduction of 5.3 million stationary fuel cells to households by 2030, up from 230,000 presently;
  - FCV and refuelling station targets as per the 2014 Plan;
  - 12,000 fuel cell buses and 10,000 fuel cell forklifts by 2030;
  - Develop commercial scale international hydrogen supply chains, procuring 300 kt of hydrogen annually by 2030, up from current level of 200 tpa
- 2019 – Japan and Australia sign a cooperation agreement to underpin future hydrogen export between the two countries

South Korea

- 2005 – Eco-friendly Hydrogen Economy Master Plan announced
- 2013 – South Korean Government subsidises the construction of 59 MW Gyeonggi Green Energy Park, the largest hydrogen fuel cell production facility in the world at the time
- 2015 – Government announces various hydrogen targets, including:
  - Increasing the number of FCEVs on the streets from current 50 up to 9,000 by 2020, and up to 630,000 by 2030 (approx 10% of all vehicles)
  - Government subsidies of approx US$23,000 per passenger FCEV (approx 1/3 of total vehicle cost) to encourage uptake
  - Increasing number of refuelling stations across the nation from 10 currently to 520 by 2030
- 2019 – Korea announced its 'Hydrogen Economy Roadmap', expanding its targets out to 2040, including:
  - Increasing number of FCEVs on the streets from 8,000 presently, to 67,000 by 2022, to 1.8m by 2030
  - Increasing FCEV production from having made 18,000 units presently, to 810,000 units by 2022, to 6.2m units by 2040
  - Halve the price of FCEVs sold on the market by 2025 by subsidising fuel-cell taxis and trucks and rolling out buses, thereby increasing production capacity
  - Increasing number of refuelling stations from 14 presently, to 310 by 2022, to 1,200 by 2040
  - Roll out 35 hydrogen buses in 2019, increased to 2,000 by 2022 and to 41,000 by 2040
  - Supply 15 GW of fuel cells for power generation by 2040
  - Halving the price of hydrogen from current levels by 2040, and increasing hydrogen supply from 130 kt per annum in 2018, to 470 kt in 2020, to 5.26 Mt in 2040
  - US$1.8bn fund created for investment in hydrogen until 2022 to kickstart this transformation
- 2019 – South Korea and Australia sign a letter of intent for the future export of hydrogen from Australia to Korea. Korea loosened its domestic regulations to allow for more rapid uptake of hydrogen.

Appendix B: Global hydrogen progress

China

- 2009 – subsidies for new-energy vehicles (including hydrogen) introduced
- 2015 – 'Made in China 2025' 10 year plan released, including New-Energy vehicles and equipment as a priority sector
- 2016 – 'Energy Saving and New Energy Vehicle Technology Roadmap' published by the Strategic Advisory Committee, which included the 'Hydrogen Fuel Cell Vehicle Technology Roadmap' as Chapter 4. Key targets include:
  - 5,000 FCEVs in service by 2020, up to 50,000 by 2025, and up to 1m by 2030
  - Over 100 hydrogen refuelling stations by 2020, over 300 by 2025, and over 1,000 by 2030
  - Over 50% of hydrogen production from renewable resources by 2030 (indicating that, especially in the near future, production will be mostly 'grey' hydrogen)
  - Technological progress in fuel cell systems, key materials and components, with a near 90% reduction in fuel cell stack costs in 2025 when compared to 2015 prices
  - Subsidies of approx US$22,000 per passenger FCEV (approx 30% of total vehicle cost)
- 2018 – there are currently 2,000 FCEVs in service in China, mostly buses

Singapore

- 2004 – Early trial of 6 hydrogen FCVs conducted
- 2010 – hydrogen FCV bus trialled at the Youth Olympic games
- 2019 – The Prime Minister's office issued a tender for a 'Consultancy Study on Hydrogen Imports and Downstream Applications for Singapore', awarded to KBR and Argus consulting firms in September. Hydrogen is an attractive option, as it can replace LNG as a fuel for power stations while eliminating 60% of Singapore's emissions.

European Union

- 2006 – Germany – 'National Innovation Programme Hydrogen and Fuel Cell Technology' (**NIP**) established.
- 2008 – The 'Fuel Cells and Hydrogen Joint Undertaking' (**FCH JU**, a public-private partnership between the European Commission, European industry and research organizations) is established. The current phase (2014-2020) has a total budget of EUR 1.33 billion to support R&D and demonstration activities in Hydrogen and Fuel Cell activities in Europe.
- 2017 – The Hydrogen Law (**HyLaw**) project is established, bringing together 23 countries across the EU with the aim of boosting market uptake of hydrogen technologies by providing a clear view of the applicable regulations whilst calling on policy makers to remove legal barriers.
- 2018 – Germany – world's first hydrogen train begins operation
- 2018 – France – 'Hydrogen Development Plan' released, targeting:
  - Increasing FCEVs from current 250, to 5k by 2023, to 20-50k by 2028
  - Increasing heavy hydrogen vehicles to 200 by 2023, and 800-2k by 2028
  - Increasing refuelling stations from20 currently, to 100 by 2023, to 400-1k by 2028.
  - Increase the percentage of green hydrogen consumed in France from 5% currently, to at least 10% by 2023, to 20-40% by 2028.
  - Development of hydrogen storage capabilities for renewable power
- 2019 – Germany – target of 1.8m FCEVs by 2030, and 1,000 refuelling stations. The German Government announced in July 2019 that 20 new research laboratories will receive EUR 100 million a year to test Hydrogen technologies. Germany's gas industry aims to build 5 GW of power-to-gas capacity by 2025, and 40 GW by 2050.
- 2020 – Germany – draft national hydrogen strategy has been circulated for internal cabinet review, to be released later in the year

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Thank you

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