Getting to H_2 under \$2: key milestones for achieving a hydrogen export industry at scale in Australia

Summary

The Australian Hydrogen Council (AHC) seeks to build on the November 2019 COAG *National Hydrogen Strategy* (NHS) to identify the key milestones to achieve a mature Australian hydrogen export industry by 2030.

This paper explores how we might:

- Connect the National Hydrogen Strategy's (NHS) 'measure of success' as a world top three hydrogen exporter with the Deloitte scenarios created for the NHS.
- Connect Deloitte's scenarios with the 'H_2 under 2' stretch target[1] announced by the Australian Government as part of its Technology Investment Roadmap.
- Connect the 'H_2 under 2' stretch target with required projects and investment needs.

In this paper we put forward a case for testing with stakeholders. This case currently covers export markets and we need domestic analysis to complete the picture.

We propose that on current estimates the NHS *Targeted deployment* scenario appears to represent a minimum success case for the scale-up of the Australian hydrogen export industry. This scenario could see A\$2/kg by 2040.

Later than 2040 will likely mean that Australia will be outcompeted and will miss out on export opportunities. Even A\$2/kg by 2040 might be problematic: Japan has indicated it is seeking hydrogen production costs at around \$2/kg post-2030 and Korea has proposed around A\$1.7-2/kg by 2030.

If we want Australia to be a top three global exporter, the AHC proposes we aim for A\$2/kg by 2030. This target is ambitious but will greatly improve our ability to compete.

Australia would need to accelerate the development of commercial scale projects to get there, which means a minimum of 10ktpa (volume of hydrogen production) per project in the next few years (the equivalent of around 100MW electrolyser scale for green hydrogen projects). Later in the decade projects should be at a minimum of 50ktpa, and closer to 100ktpa.

Looking at numbers of projects, our analysis suggests that Australia would need at least ten very large scale (over 50ktpa, closer to 100ktpa) projects proceeding at current costs to reach 'H_2 under 2'

[1] 'H_2 under 2' means a production price of A\$2/kg (excluding liquefaction, storage and shipping).

by 2030. The number will be much larger than ten if we were to replace large scale with 10-50ktpa size projects.

Reaching ‘H_2 under 2’ requires significant investment over the next ten years to get multiple projects underway – this is likely to billions of dollars rather than millions. It also relies on significant reductions in the power costs for green hydrogen projects.

1 The NHS and where we might be by 2030

The hydrogen export opportunity for Australia is significant. The International Energy Agency and World Energy Council have identified the potential for Australia to become one of the largest hydrogen producers in the world in meeting the clean energy needs of energy-intensive countries in the Asia-Pacific region.[2]

A 2018 report for ARENA suggests the potential demand for imported hydrogen in China, Japan, South Korea and Singapore could reach 3.8 million tonnes by 2030, representing an A$9.5 billion export opportunity.[3] Modelling based on more recently projected export volumes in the NHS estimates a ~A$55bn export market opportunity is possible by 2050,[4] if Australia can successfully achieve ‘H_2 under 2’, or an A$2/kg hydrogen production price[5] before this time.[6]

The NHS has recognised the economic value of the hydrogen export opportunity in one of its four key measures of success by 2030, as seen in Figure 1. It states the ambition for Australia to be among the top three exporters of hydrogen to Asian markets by 2030.[7]

Additional measures of success relating to hydrogen export in the NHS include the following:

- Australia becomes a destination of choice for international investors in hydrogen.
- Australia has major offtake or supply chain agreements in place with importing countries.
- Australia demonstrates its hydrogen capability in all aspects of the supply chain.
- The cost of clean hydrogen continues to decrease due to technology developments and scale achieved in the development of a hydrogen export industry, facilitating domestic use applications including the integration of hydrogen into energy market structures e.g. gas network blending, power generation and mobility.

[2] Australian Government Department of Industry, Science, Energy and Resources (2019) ‘The Australian resources sector - significance and opportunities’, in *Australia’s National Resources Statement*, February, https://www.industry.gov.au/data-and-publications/australias-national-resources-statement/the-australian-resources-sector-significance-and-opportunities
[3] ACIL Allen consulting (for ARENA) (2018), *Opportunities for Australia from Hydrogen Exports*, August, p. 52, https://arena.gov.au/knowledge-bank/opportunities-for-australia-from-hydrogen-exports/
[4] Based on A$2/kg landed price in Japan multiplied by 2050 export volumes under Deloitte *Energy of the future* scenario reflecting corrections published in erratum.
[5] It is important to note that presenting price/cost forecasts is an inherently difficult balancing act. Presenting too low a forecast deters investors whilst too high a forecast deters customers. When discussing production costs, we need to be clear about which cost components are included and excluded. For example, the production cost of hydrogen can be quoted as just the gas exiting an electrolyser, which excludes the considerable costs associated with liquefaction and storage.
[6] Export value estimate is in 2020 real terms.
[7] COAG (2019) *Australia’s National Hydrogen Strategy*, November, page 71, https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

Figure 1: Key measures of success for a hydrogen industry in Australia by 2030 from the NHS

Source: COAG Australia's *National Hydrogen Strategy*, November 2019 – page xiii.

The 2019 Deloitte report commissioned for the NHS presents four scenarios for hydrogen development over a thirty-year time frame to 2050.[8] These are shown in Figure 2 over the page.

Three of the four scenarios represent a version of the case for the scale up of the Australian hydrogen export industry.

The three scenarios are as follows:

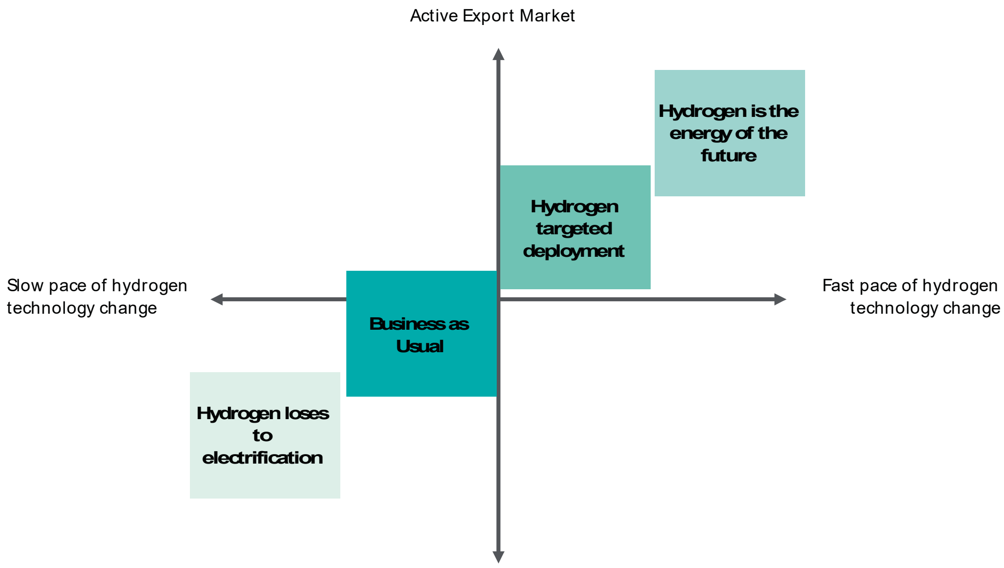
- The *Energy of the future* scenario, referred to as scenario 1 in the NHS report, represents a highly optimistic outlook for hydrogen in Australia. It is characterised by thriving export and domestic markets. In this scenario, it is assumed that Australian supply chain costs decline rapidly over time, foreign governments that cannot cost competitively produce hydrogen choose to import hydrogen and domestic government policies stimulate hydrogen uptake in all possible sectors of the economy. The scenario also assumes there is high consumer acceptance of hydrogen use. A summary of the assumptions behind this scenario is provided in Appendix A.
- The *Targeted deployment* scenario, referred to as scenario 2 in the NHS report, represents a moderately optimistic outlook for hydrogen uptake. It envisages an active export market where countries adopt a targeted approach to developing hydrogen in sectors that maximise economic value and benefits e.g. decarbonising steel manufacturing. Under this scenario "drivers behind Australian production mirror those of global demand, where steep reductions in technology costs and large proportions of end-use market share captured by hydrogen encourage a rapid expansion in Australian hydrogen production".[9] A summary of the assumptions behind this scenario is also provided in Appendix A.
- The *Business as usual* scenario, referred to as scenario 3 in the NHS report, sees growing hydrogen demand internationally. However, under this scenario, Australia is unable to capture a significant share of the export market due to a lag in technological improvements across the

[8] Deloitte (2019) *Australian and global hydrogen demand growth scenario analysis*, COAG Energy Council – National Hydrogen Strategy Taskforce, November, pp. 48-56, http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-australian-and-global-hydrogen-demand-growth-scenario-analysis-report-2019_1.pdf

[9] Ibid., p. 6.

hydrogen value chain, resulting in minimal reductions in technology costs. Australian exports never really get off the ground and are outcompeted by other countries, reaching only 1 million tonnes by 2050.

Figure 2: NHS scenario map prepared by Deloitte



Source: Deloitte (2019) *Australian and global hydrogen demand growth scenario analysis*; COAG Energy Council – National Hydrogen Strategy Taskforce, November, p.48.

The AHC believes that there should be a minimum success case, so that there can start to be common ground on what is needed to have a meaningful hydrogen export industry. On current estimations, Deloitte's *Targeted deployment* scenario appears to be a suitable minimum success case for hydrogen in Australia.

However, the *Energy of the future* scenario might be a better ambition, to be more consistent with the NHS 'measure of success' to be in the top three exporting nations by 2030.

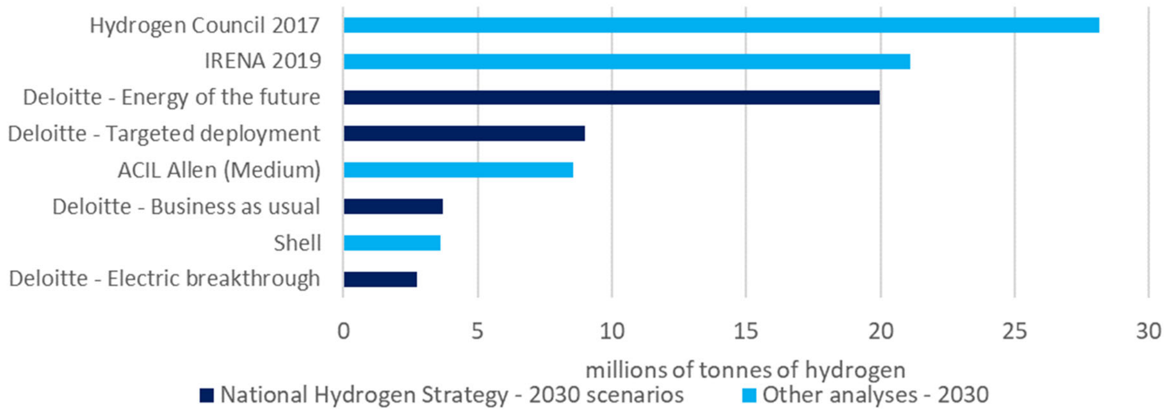
We are still testing these views, and how they might connect to 'H_2 under 2', which was developed separately as a policy goal to the modelling by Deloitte.

As a starting point – and until the evidence suggests otherwise – we suggest that Deloitte's *Targeted deployment* scenario might roughly equate with 'H_2 under 2' by 2040, and that the *Energy of the future* scenario might equate with A$2/kg by 2030. This paper starts to develop the logic to explore this, using current public data and a proposed export project milestone map.

The AHC is also working on a trajectory outlining the major milestones required to scale up the domestic hydrogen market. Ideally, we will be able to combine the two documents to arrive at clear policy and project requirements to build the Australian hydrogen industry.

As a last point, it is useful to understand how the Deloitte scenarios compare with other estimates/scenarios of global hydrogen demand. Figure 3 shows the variation in global hydrogen demand between different studies, including the four scenarios that Deloitte prepared for the NHS. This shows that the *Targeted deployment* scenario has around the same demand as the ACIL Allen medium case, which might mean that neither the *Targeted deployment* nor *Energy of the future* scenarios are excessively optimistic.

Figure 3: Comparing 2030 global hydrogen demand growth estimates



Source: Adapted from COAG (2019) *Australia's National Hydrogen Strategy*, November, p. 24, reflecting the corrected demand estimates in *the May 2020 Deloitte erratum.*

2 The hydrogen export opportunity

So what does a hydrogen export industry mean for Australia?

The resources and mining sectors are pillars of the Australian economy, representing over 8%of Australia's gross domestic product (GDP) and accounting for 73% of Australia's goods exports from 2018-2019.[10] Since the mining boom of the mid-2000s, the resources sector has delivered considerable economic wealth, job creation, wage increases, investment and tax revenues to Australians. Maintaining the success of the mining and resources sectors is critical to Australia's future prosperity.

The resources and mining sectors are also carbon intensive, both in their processing of raw materials as well as end-use products.

As countries look to deliver on the emissions reduction targets of the Paris agreement by incorporating cleaner fuels into their energy mix, the decline in demand for fossil fuels such as coal and natural gas threatens the Australian resources sector. There will also be increasing pressure for metals to be mined and extracted in a way that minimises carbon emissions.

While the short to medium-term outlook for Australian coal and natural gas exports remains optimistic, the long-term threat posed by decarbonisation commitments across the world must not be ignored if Australia is to ensure its continued economic success.

---

[10] See Australian Government Department of Industry, Science, Energy and Resources (2019) 'The Australian resources sector - significance and opportunities', in *Australia's National Resources Statement*, February, https://www.industry.gov.au/data-and-publications/australias-national-resources-statement/the-australian-resources-sector-significance-and-opportunities; also, Australian Government Department of Industry, Science, Energy and Resources (2020) *Resources and Energy Quarterly*, March, https://publications.industry.gov.au/publications/resourcesandenergyquarterlymarch2020/documents/Resources-and-Energy-Quarterly-March-2020.pdf

The export of hydrogen provides Australia not only with an economic growth opportunity, but a way to evolve the resources and mining sectors and provide economic resilience in a decarbonising world. Hydrogen also provides tangible opportunities for Australia to decarbonise its domestic energy system, including power generation, manufacturing and transport.

Australia is particularly well-positioned to play a key role in the hydrogen export market with its abundant renewable resources, existing bilateral trade relationships with Japan, Korea and China and low sovereign risk.

However, the window of opportunity will not exist forever. Competing hydrogen producers across the globe seek a share of the export pie and scaling up hydrogen production in their respective countries to supply the Japan, Korea and China markets as soon as 2025.[11] These competitors include Brunei, Qatar, UAE and Norway, and in the longer-term, market entrants such as the United States, Brazil, Chile and New Zealand.

Many of these countries enjoy the inherent strengths that Australia has for hydrogen production, including abundant renewable resources, access to low-cost gas for blue hydrogen production, depleted oil wells that can be utilised for carbon capture and storage, large areas of land for solar installations and proximity to key hydrogen export markets.

Japan and South Korea have been identified as the most promising export markets for Australian-produced hydrogen in the next decade, with both countries having published detailed road maps that highlight the need for imports to meet their domestic hydrogen targets. Both Japan and South Korea are energy-constrained domestically due to poor natural resources and renewables, necessitating imports to meet their hydrogen aspirations.

Apart from Japan and South Korea, China could also potentially become a major hydrogen export market for Australia, as identified in the Deloitte report delivered for the NHS and the 2018 ACIL Allen ARENA *Opportunities for Hydrogen* report.

However, in our view, it is unclear as to whether China will emerge as a net importer or exporter of hydrogen due to China having the domestic capability to produce grey hydrogen from its considerable coal deposits and blue hydrogen using steam methane reforming (SMR).[12] Producing hydrogen from domestic coal and renewables is also attractive to China from an energy security perspective, given its current reliance on imported oil and gas for their energy needs. The hydrogen export opportunity in China will be assessed as the industry evolves over time.

2.1 Japan

Historically, Japan has been characterised by poor energy self-sufficiency due to a lack of natural resources, relying on overseas fossil fuels for 94% of its primary energy supply.[13] In addition, 98% of Japanese vehicles utilise oil-based fuels, 87% of which are sourced from the Middle East.[14] Natural disasters have also impacted Japan's energy security in the past, including the earthquake and resulting tsunami that shut down the Fukushima nuclear power stations in 2011. Energy security concerns, coupled with Japan's ambition to meet its Paris agreement emission reduction targets, makes hydrogen an attractive clean fuel for Japan's energy future.

[11] ACIL Allen consulting (for ARENA) (2018), *Opportunities for Australia from Hydrogen Exports*, page 15.
[12] Lewis, S (2020) *Green Shoots: A Growing Hydrogen Economy Webinar,* S&P Global Platts.
[13] METI (2019) *Japan Basic Hydrogen Strategy.*
[14] Ibid.

In 2016, Japan clearly stated its intention to build a hydrogen economy, when Japan's Ministry of Economy, Trade and Industry (METI) declared that by 2020 there would be approximately 40,000 hydrogen fuel-cell vehicles (FCVs) on Japan's roads, along with 160 refuelling stations and 1.4 million residential fuel cells, known as Ene-Farms.[15]

Large Japanese utilities are already engaging with potential suppliers across the globe, including companies in Australia, to secure long-term offtake agreements for hydrogen product from 2025 onwards. For example, in April 2020, Woodside announced it had signed an agreement with Japanese utilities JERA, Marubeni and IHI to undertake a joint study examining the large-scale export of blue hydrogen as ammonia.[16] The end-use for the ammonia is to decarbonise existing coal-fired power generation in Japan.

2.2 South Korea

Like Japan, Korea has poor natural resources and has been historically been dependent on liquefied natural gas and oil imports to meet its energy needs. Korea sees hydrogen as a key pillar of its transition to a cleaner energy mix and to decarbonise carbon intensive areas of the economy including transportation, power, industrial energy use and feedstock.

In 2018, South Korea delivered its *Hydrogen Economy Revitalization Roadmap*, which includes plans to produce FCVs and other technologies to realise a hydrogen-powered society.[17] The government has set a target of manufacturing 6.2 million FCVs domestically by 2040 and plans to introduce FCVs to the public transport system, as well as provide subsidies for infrastructure development.[18] Australian energy companies are presently engaging with potential project partners. For example, Woodside has announced that it has joined a Korean consortium called Hydrogen Energy Network (HyNet), which plans to build and operate 100 hydrogen refuelling stations in Korea.[19] Most discussions are commercial-in-confidence and unable to be shared publicly at the present time.

3 'H$_2$ under 2' - the A$2/kg target

In his keynote address on the 28th February 2020 at the CEDA *Future Direction in Energy Technologies* event, Energy and Emissions Reduction Minister the Hon. Angus Taylor presented the 'H$_2$ under 2' objective. He stated his aspiration that Australia would eventually be able to produce hydrogen "at or under $2 per kilogram…the point where it competes with alternatives in large-scale deployment across our energy system".[20] This stretch target has been reinforced in the Technology Investment Roadmap discussion paper released in May 2020.

[15] Japan Government Ministry of Economy, Trade and Industry (2019) https://www.meti.go.jp/english/press/2019/0312_002.html
[16] Woodside (2020) 'Woodside joins Japanese consortium to study exporting carbon neutral hydrogen', https://files.woodside/docs/default-source/media-releases/woodside-joins-japanese-consortium-to-study-exporting-carbon-neutral-hydrogen.pdf?sfvrsn=a10aae6d_2
[17] Hydrogen Korea Study Team (2018) *Hydrogen Roadmap Korea*: *A vision, roadmap and recommendation to develop Korea's hydrogen economy* http://www.h2eva.org/download.php?file=20181112_visualization_of_key_results.pdf
[18] Hosokawa (2019) 'South Korea targets hydrogen economy, from cars to cities,' *Nikkei Asian Review,* November 4, https://asia.nikkei.com/Business/Business-trends/South-Korea-targets-hydrogen-economy-from-cars-to-cities
[19] Woodside (2020) 'Making headway with hydrogen', https://www.woodside.com.au/news-and-media/stories/story/making-headway-with-hydrogen
[20] Taylor (2020) Keynote Address at CEDA Future Direction in Energy Technologies Event, Hon. Angus Taylor, Minister for Energy and Emissions Reduction.

It is important to consider what 'H_2 under 2' means: does the A$2 cover the production of hydrogen only or does it contain additional elements such as liquefaction, storage and transport and costs? For this analysis we assumed that the $2 is the production cost only.

The 'H_2 under 2' goal also needs to be connected with the export and domestic opportunities.

3.1 Connecting 'H_2 under 2' with the export market opportunity

The Bloomberg New Energy Finance (BNEF) 2020 *Hydrogen Economy Outlook* report suggests countries like Australia with best-in-class renewables and hydrogen storage could potentially deliver renewable hydrogen to **local large-scale users at A$2.5/kg by 2030.**[21]

Table 1 shows BNEF's figures, where we can see that prices then fall to A$1.2/kg by 2050.

Table 1: BNEF delivered price forecasts for hydrogen in 2030 and 2050 by country group

Year	Country characteristics	Power cost assumption, US$/MWh (A$)	Delivered hydrogen price, US$/kg	Delivered hydrogen price, A$/kg	Countries
2030	Countries with best-in-class renewables and hydrogen storage	US$21/MWh (A$30/MWh)	1.6	2.5	Australia, US, Brazil, Scandinavia and the Middle East
	Countries with large-scale industrial users in established industrial clusters with local supply chains	US$28/MWh (A$40/MWh)	2.0	3.1	China, India, Western Europe
	Japan and Korea with poor renewable resources	US$47/MWh (A$67/MWh)	3.0	4.6	Japan and Korea
2050	Countries with best-in-class renewables and hydrogen storage	US$12/MWh (A$17/MWh)	0.8	1.2	Australia, US, Brazil, Scandinavia and the Middle East
	Countries with large-scale industrial users in established industrial clusters with local supply chains	US$17/MWh (A$24/MWh)	1.0	1.5	China, India, Western Europe
	Japan and Korea with poor renewable resources	US$33/MWh (A$47/MWh)	1.5	2.3	Japan and Korea

Source: Modified from BNEF *Hydrogen Economy Outlook* 2020, p. 47.[22]

The A$2.5/kg figure is a delivered price, so it includes more than just hydrogen production cost. However, it is a delivered price to **domestic** large-scale industrial users, factoring in pipeline transmission costs, compression costs and hydrogen storage in salt caverns. Using this figure to estimate a landed price in Japan or Korea results in a landed price closer to **$3.5-$4/kg** (see Box 1 and Appendix B for shipping estimates). We do note however that the BNEF estimates assume both

[21] BNEF (2020) *Hydrogen Economy Outlook: key messages*, March 30, pp. 4-5. This is broadly consistent with CSIRO's (2018: 52) *National Hydrogen Roadmap* projection of a target hydrogen production price, suggesting it could A$2-3/kg by 2025 and 2030 (noting the CSIRO estimate excludes liquefaction, storage and transport).

[22] Notes: Original forecast numbers in US$ and converted to A$ using 1 USD = 0.7 AUD. Indicative delivered hydrogen price for countries with best-in-class renewables estimated by applying a 20% reduction as per BNEF analysis.

ambitious power price reductions and the success of salt caverns for storage. Salt caverns are geographically limited in Australia and to date unproven in their ability to successfully store hydrogen with minimal leakage.[23]

We now look at how these estimated prices compare with what we know about the Japanese and Korean import price appetites.

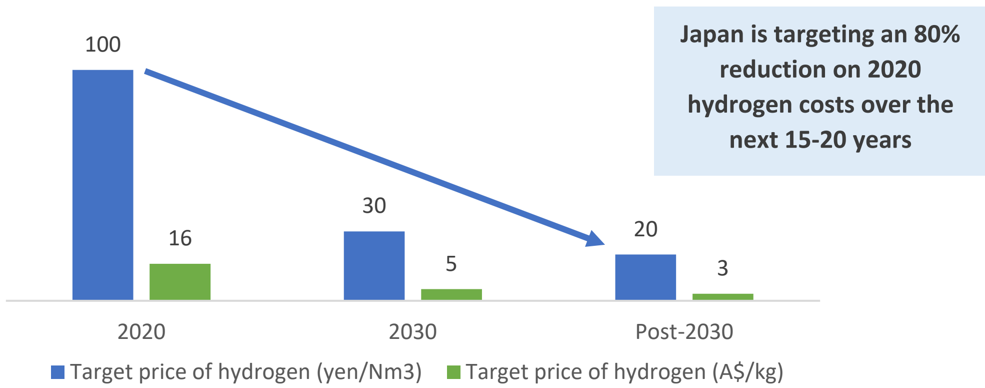
3.1.1 Producing hydrogen for the Japanese market

Over the next thirty years, Japan intends to import 5-10 million tonnes of hydrogen per year to meet its energy needs, highlighting the imperative for Australia to achieve competitive hydrogen production prices in order to supply the Japanese market.

Domestic hydrogen production in Japan is expensive due to the lack of natural resources and is currently estimated to be ¥100/Nm^3 or A$16/kg.[24] Japan's METI has indicated it is aiming to reach roughly a third of this hydrogen price by 2030 (~A$5/kg) and a fifth of this price post-2030 (~A$3/kg) to make it economically viable for hydrogen to replace fossil fuels in its domestic energy system.[25]

Figure 4 shows these targets, which it should be noted are not definitive but a starting point for commercial negotiations. When assessing price targets, exchange rate fluctuations should also be taken into consideration.[26]

Figure 4 - Japan METI hydrogen price targets



Source: *Hydrogen and Fuel Cells in Japan* report published October 2016 - page 16. Author Jonathan Arias, EU-Japan Centre for Industrial Cooperation.

The prices advised by Japan are the landed prices of hydrogen, which include all processing at the production end and the transport to Japan. Using numbers from the Victorian HESC project (see Appendix B), we have broken these prices down in Table 2 (see also Box 1).

[23] BNEF (2020) *Hydrogen Economy Outlook: key messages*, March 30, p. 3, https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

[24] Arias (2019) 'Hydrogen and Fuel Cells in Japan', https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf, p. 16.

[25] METI (2019) *Japan Basic Hydrogen Strategy*.

[26] Japanese price targets are converted from yen/Nm^3 to A$/kg using a long-term exchange rate of 1 Australian dollar = 74 yen, 1USD to 0.7 AUD, and a conversion factor of 11.9 Nm^3 per kilogram of hydrogen.

Table 2: Summary of Japan's hydrogen landed price targets (rounded to zero decimal places)

Cost/price	2020, ¥/Nm^3	2020, A$/kg	2030 Target, ¥/Nm^3	2030 Target, A$/kg	Post-2030 Target, ¥/Nm^3	Post-2030 Target, A$/kg
Cost of hydrogen produced	100	16.2	24	4	14	2
Shipping cost*	N/A	N/A	6	1	6	1
Landed price	N/A	N/A	30	5	20	3

*Note that for simplicity the shipping cost is assumed to remain fixed at ~A$1/kg.

Table 2 shows that the 2030 target of A$5/kg hydrogen price is based on hydrogen **produced at A$4/kg**. The post-2030 hydrogen production price target is A$2/kg.[27]

3.1.2 Producing hydrogen for the Korean market

Korea is aiming for 20% of its energy mix in 2050 to be based on hydrogen (excluding hydrogen used as an industrial feedstock). Korea has indicated that a hydrogen economy is fundamental to achieving a 40% reduction in carbon emissions by 2050 relative to 2015 emission levels. Korean estimates are for hydrogen demand to grow from 3mtpa in 2020 to 17mtpa by 2050 and demand to exceed the volume of product that can be produced domestically.[28]

Like Japan, Korea will rely on imported hydrogen to meet its targets. The Korean expectation appears to be that hydrogen landed from Australia will be cheaper in the long-term than hydrogen produced domestically via electrolysis and steam methane reforming with carbon capture and storage.

The 2018 *Hydrogen Roadmap Korea* presents considerably more aggressive import price targets compared to Japan, suggesting a production price of **~A$1.7-2/kg by 2030** and A$1/kg by 2050. (Calculations are shown in Box 1.) However, as previously noted these targets are not prescriptive but are starting point for commercial negotiations with exporters.

[27] The A$2/kg may well have originated from the Japanese expectation and/or from the HESC project cost breakdowns. We are presenting here to connect these numbers explicitly.

[28] Hydrogen Korea Study Team (2018) *Hydrogen Roadmap Korea*: *A vision, roadmap and recommendation to develop Korea's hydrogen economy* http://www.h2eva.org/download.php?file=20181112_visualization_of_key_results.pdf

Box 1: Japan and Korea hydrogen landed price and implied production price calculations

Japan METI Landed Price Targets		
Nm^3 hydrogen to kg hydrogen conversion factor	Nm^3/kg	11.9
Japan hydrogen landed price - 2030	yen/Nm^3	**30**
Japan hydrogen landed price - 2030	yen/kg	357
Japan hydrogen landed price post-2030	yen/Nm^3	**20**
Japan hydrogen landed price post-2030	Yen/kg	238
Currency Assumptions		
Yen to AUD		0.0136
Yen to USD		0.0092
USD to AUD		1.43
Japan hydrogen landed price 2030	A$/kg	**4.85**
Japan hydrogen landed price post-2030	A$/kg	**3.23**
Korea Landed Price Targets		
Assumed production cost in Australia - 2030	US$/kg	1.20
Assumed landed cost from Australia - 2030	US$/kg	2.20
Assumed production cost in Australia - 2050	US$/kg	0.70
Assumed landed cost from Australia - 2050	US$/kg	1.20
Production Cost in Australia - 2030	A$/kg	**1.71**
Landed Cost from Australia - 2030	A$/kg	**3.14**
Production Cost in Australia - 2050	A$/kg	**1.00**
Landed Cost from Australia - 2050	A$/kg	**1.71**
Implied shipping cost - 2030	A$/kg	1.43
Implied shipping cost - 2050	A$/kg	0.29

3.2 Domestic use

The main alternative that hydrogen will need to compete with in the Australian energy system is natural gas. A$2/kg hydrogen converts to approximately A$14/GJ in energy-equivalent terms using the higher heating value (HHV) of hydrogen.[29] At this price however, hydrogen is competitive with diesel used in heavy vehicle transport and remote power generation, assuming an average diesel price of A$1.5/L which is approximately A$40/GJ.[30]

In contrast, a hydrogen price of A$14/GJ is high when directly compared to historical Wallumbilla netback prices, which provide an indication of natural gas prices on the east coast of Australia. From 2018-2019, the Wallumbilla netback price averaged A$8/GJ and peaked at A$15/GJ in Jan-Feb 2019.[31] Hydrogen will struggle to compete with natural gas as a substitute fuel at A$14/GJ, unless a carbon signal is factored into the cost of supply of natural gas.

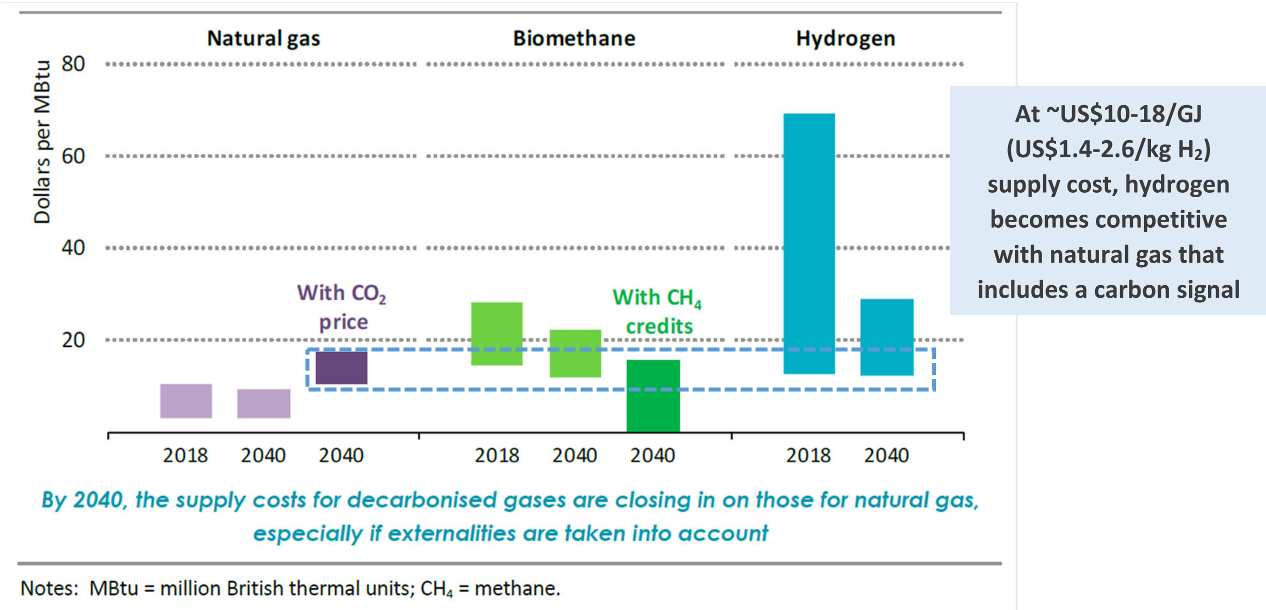
[29] Note that when fuels are converted to a $/GJ basis for comparison with natural gas, the higher heating value (HHV) is generally used. The HHV of hydrogen is 0.142 GJ/kg and implies A$14/GJ is equivalent to A$1.98/kg hydrogen. This approach differs from the National Hydrogen Strategy "Conversions and Units" page xiv, where the LHV (0.12 GJ/kg) is used, giving the metric A$10/GJ equals A$1.20/kg.

[30] Assumes an average diesel price of A$1.5/L and conversion rate of 1GJ = 27.7L. Source: https://www.globalpetrolprices.com/Australia/diesel_prices/

[31] Australian Competition and Consumer Commission (2020) LNG netback price series, https://www.accc.gov.au/regulated-infrastructure/energy/gas-inquiry-2017-2025/lng-netback-price-series

This echoes the supply cost analysis in the 2019 IEA *World Energy Outlook*[32] which identifies that hydrogen can substitute for gas by 2040, but only if the true cost of carbon is accounted for in the gas supply cost. Figure 5 provides the IEA's analysis.

Figure 5 – Supply costs of natural gas, bio-methane and hydrogen in the World Energy Outlook Sustainable Development scenario, 2019 and 2040



Source: IEA (2019) *World Energy Outlook*, p. 76 (with AHC supplement).

Box 2: Natural gas versus hydrogen

Natural gas burns relatively cleanly in terms of the carbon emissions produced when compared to coal and oil. It is also equally versatile and abundant as an energy source. For example, a newly built natural gas power station produces 50-60% fewer carbon dioxide emissions than the most efficient newly built coal-fired power station.[33] While historically coal was used more than natural gas, gas is now overtaking coal in many developed countries as a primary energy source due to its less polluting properties. It is one of the cheapest, low-carbon fuels to meet emission reduction targets and is considered by many to be a key transition fuel until cost reductions allow economies to be fuelled by renewables.

Although natural gas is cleaner burning than coal and oil, the combustion process still generates carbon emissions. There are also concerns associated with the leaking of methane, a greenhouse gas that is 25 times more potent than carbon dioxide, when gas is extracted from underground deposits.[34]

[32] IEA (2019) *World Energy Outlook*, p. 76, https://www.iea.org/reports/world-energy-outlook-2019.
[33] National Energy Technology Laboratory (NETL) (2010) *Cost and performance baseline for fossil energy plants, Volume 1: Bituminous coal and natural gas to electricity*, Revision 2, November, DOE/NETL-2010/1397, United States Department of Energy.
[34] Hope (2014) 'Explained: Fugitive methane emissions from natural gas production', https://www.carbonbrief.org/explained-fugitive-methane-emissions-from-natural-gas-production

Hydrogen has real potential to substitute for natural gas as it is just as versatile in its applications and can be manufactured in abundance rather than extracted from the earth. When hydrogen is made from sustainable water sources and renewable electricity, or from natural gas with appropriate carbon storage and offsets, it is a truly carbon-neutral fuel.

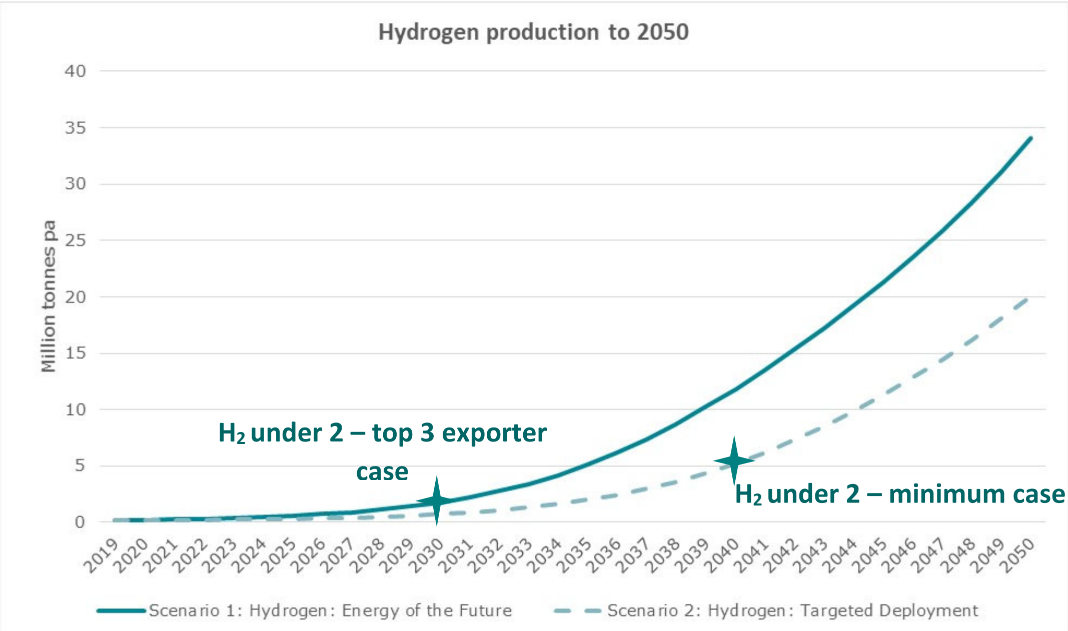
As discussed above, the BNEF 2020 *Hydrogen Economy Outlook* report suggests countries like Australia with best-in-class renewables and hydrogen storage could potentially deliver renewable hydrogen to local large-scale users at **A$2.5/kg by 2030.**[35] BNEF provides **a low case of A$2.11/kg** for delivered hydrogen costs to large-scale users in Australia.[36]

It is important to note, however, hydrogen does not reach these prices without significant funding.

4 Milestones to achieving an Australian hydrogen export industry at scale

Figure 6 shows the *Energy of the future* and *Targeted deployment* scenarios to 2050, with the suggested 'H_2 under 2' point for the minimum viable export case (achieved by 2040) and for the top three exporter case (achieved by 2030).[37]

Figure 6 – NHS scenarios 1 and 2 volume projections and H_2 under 2 scenarios



Source: data from Deloitte (2019) *Australian Global Hydrogen Demand Growth Scenario Analysis*.

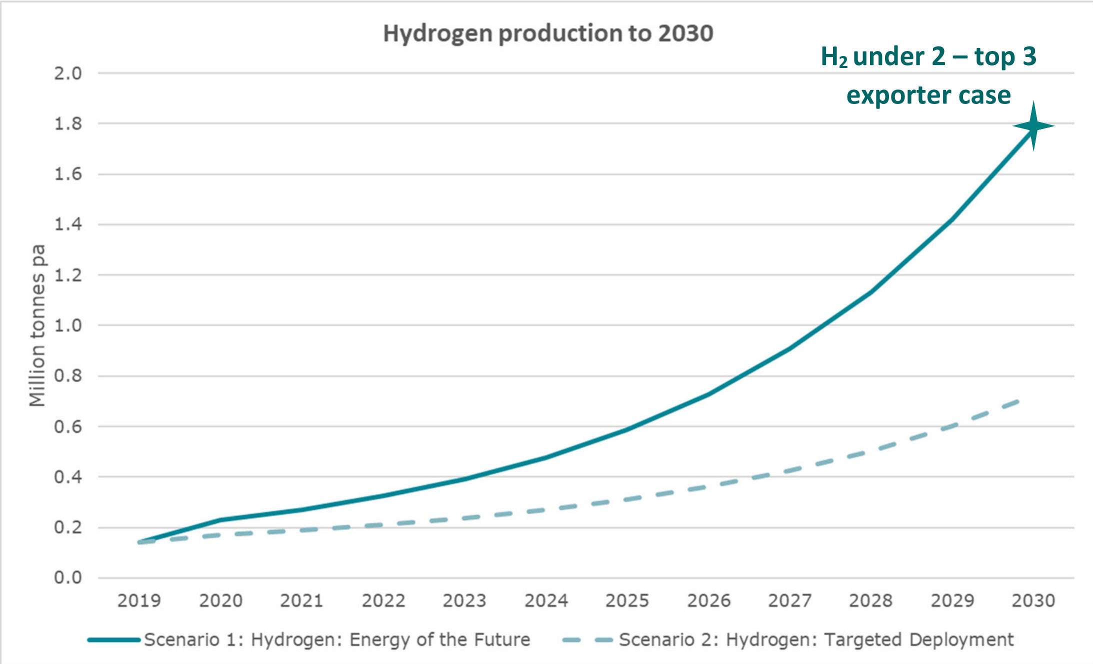
[35] BNEF (2020) *Hydrogen Economy Outlook: key messages*, March 30, pp. 4-5, https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

[36] Ibid., p. 5. The estimate is based on:
- Use of a large-scale alkaline electrolyser with capex of $135/kW in 2030.
- Storage costs assume 50% of total hydrogen demand passes through storage, and a salt cavern is used. Compression and conversion costs are included in storage.
- Transport costs are for a 50km transmission pipeline movement.

[37] Appendix C provides the full dataset.

Figure 7 shows the same data but only to 2030. This allows us to see the trajectory more easily.

Figure 7: NHS scenarios 1 and 2 volume projections to 2030



Source: data from Deloitte (2019) *Australian Global Hydrogen Demand Growth Scenario Analysis*.

The data shown in Figure 6 and 7 are total numbers for hydrogen production – that is, they cover both export and domestic production. **AHC is currently sense testing these scenarios with stakeholders.**

Table 3 shows these totals and the export portion of each of the two Deloitte scenarios, with example project numbers and sizes[38] to meet the forecast production volumes. This table shows that getting to the different scenario totals can be based on a mix of project sizes. The costs are provided for illustration only and are based on current industry views.[39]

Table 3: Examples of project combinations and costs to meet Deloitte scenarios

H2 production	**Electrolyser equivalent**	**Energy of the future Export - 970ktpa**		**Targeted deployment Export - 474ktpa**		**Energy of the future Total - 1777ktpa**	**Targeted deployment Total - 724 ktpa**
10ktpa	100MW					20	18
50ktpa	500MW		8	8	4	12	3
100ktpa	1GW	10	6	1	3	10	4
Total H2 volume (ktpa)		**1000**	**1000**	**500**	**500**	**1800**	**730**
	Projects	10	14	9	7	42	25
	Cost (m)	$ 10,000	$ 10,800	$ 5,800	$ 5,400	$ 22,200	$ 10,300
	Gap	$ 2,500	$ 2,700	$ 1,450	$ 1,350	$ 5,550	$ 2,575

[38] The table shows electrolyser sizes for comparison – projects are not assumed to be green. We arrive at the MW figure from the production figure by assuming a capacity factor of 59%.

[39] We have assumed around $250m, $600m and $1,000m for project sizes 10ktpa, 50ktpa and 100ktpa respectively.

Looking at numbers of projects, our analysis suggests that Australia would need at least ten very large scale (over 50ktpa, closer to 100ktpa) projects proceeding at current costs to reach 'H_2 under 2' by 2030. The number of projects will be much larger than ten if we were to replace large scale with 10-50ktpa size projects.

The project sizes will also change over time as we build scale. The early part of the decade will be about developing smaller projects, building to much larger ones by 2030. We would expect the best results will come from a minimum of 10ktpa (volume of hydrogen production) per project in the next few years (the equivalent of around 100MW electrolyser scale for green hydrogen projects). Later in the decade projects should be at a minimum of 50ktpa, and closer to 100ktpa.

The timing will also affect project costs, where we would assume greater efficiencies as experience grows.

Further, timing will influence the 'gap' referred to in Table 3, which is the funding gap that might need to be filled by government to get to commercial outcomes. We have used an average of 25% of the total cost, which is based on recent experience that shows public funding attracts another three times the amount in private funding (see Box 3). The funding required by government will vary with time, which is not shown here. We might expect a larger gap in the early stages of the industry's development, reducing to zero as the industry becomes commercial.

Using the average of 25% over ten years we can see that the funding gap to get Australia to the point of being a top three exporter **could be in excess of $2 billion**.

Box 3: Co-investment required

The Hydrogen Council's 2020 *Path to hydrogen competitiveness* report (supported by McKinsey analysis) estimates that **US$70bn (A$100bn)** of investment in hydrogen is required across the globe by 2030 to meaningfully activate the global hydrogen economy.[40]

Although US$70bn (A$100bn) by 2030 seems sizable, the report notes that this accounts for less than 5% of annual global spending on energy. In comparison, support provided to renewables in Germany totalled roughly US$30 billion (A$43 billion) in 2019.[41]

BNEF analysis goes further, estimating that **US$150 billion (A$214 billion)** will be needed globally until 2030 to bridge the cost gap between hydrogen **and the cheapest fossil fuels**, not just the cheapest low-carbon alternative.[42] Post-2030, BNEF proposes that policy measures such as carbon signals, rather than a pure funding approach, will be necessary to drive the further adoption of hydrogen.

Public investments and policies to fill the gap can then **unlock several times their value** from the private sector. For example, the RBA notes that the CEFC and ARENA 'have directly invested around $8.5 billion in clean energy-related projects since inception. They estimate that this investment has encouraged a further $25 to $30 billion of additional private sector investment'.[43] [44]

---

[40] Hydrogen Council (2020) *Path to hydrogen competitiveness: a cost perspective*, p.66, https://hydrogencouncil.com/en/path-to-hydrogen-competitiveness-a-cost-perspective/

[41] Ibid.

[42] BNEF (2020) *Hydrogen Economy Outlook: key messages*, March 30, pp. 4-5, https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

[43] De Atholia, T., Flannigan, G. and S. Lai (2020) 'Renewable energy investment in Australia', Reserve Bank of Australia https://www.rba.gov.au/publications/bulletin/2020/mar/pdf/renewable-energy-investment-in-australia.pdf.

[44] If we take advice from the Hydrogen Council across two recent reports, a similar expectation of the ratio of public to private funds emerges: the 2020 report says around US$70 billion is required from government, and in a 2017 report the Council states that 'building the hydrogen economy would require annual investments of [US]$20 to 25 billion for a total of

Table 4 on page 17 of this paper shows an export timeline and milestones, based on industry views and the summary actions outlined in the 2018 CSIRO *National Hydrogen Roadmap.*[45] This timeline can be used for either *Energy of the future* or *Targeted deployment*.

Tables 3 and 4 are also being tested with stakeholders and will be further supplemented by domestic milestones. We are also considering what further analysis is required, and by when.

about [US]$280 billion until 2030' (p. 66). See Hydrogen Council (2017) *Hydrogen Scaling Up: A Sustainable Pathway for the Global Energy Transition*, November, https://hydrogencouncil.com/en/study-hydrogen-scaling-up/

[45] We have also referred to the 'hydrogen enablers' template used in the recently published *Roadmap to a US Hydrogen Economy.* See Fuel Cell and Hydrogen Energy Association (2020) *US Roadmap to a Hydrogen Economy*, https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf

Table 4: Hydrogen export timeline

	2020	2021	2022	2023-2024	2025	2030	2035	2040	2050
	Immediate next steps →			**Early scale-up →**		**Diversification →**		**Maturing →**	**Industry mature**
Key outcomes	Accelerated deployment of strategic funding for commercial scale blue and green H_2 export projects (~10ktpa+ scale of H_2 production per project, ~100MW electrolyser scale for green H_2 projects). Commercial scale H_2 projects incorporated into broader infrastructure programs intended to stimulate economic recovery. Strategic priorities developed for the next 3-5 years based on where the demand is now i.e. export markets in Japan and Korea (see LNG industry experience). Australian H_2 technology and knowledge monetised and built into relationship with offtakers.			Commercial scale projects (10ktpa+) reach FID in 2023/2024 and construction commences. 1-10ktpa+ scale projects (10-100MW scale green H_2 projects) ready to export to Asia in 2025. Cost to produce H_2 reducing as a result of learnings from feasibility studies and commercial scale projects.		Increasing efficiency gained from commercial scale export experience. Growing volumes of H_2 exported to Japan and Korea. New export markets emerge. H_2 from export used for diversifying domestic market end-use applications.		Export industry in Australia growing and approaching maturity. 100ktpa+ scale projects increase in number.	Export industry mature and at scale, like the LNG industry today. Australia a global leader in H_2 production.
Hydrogen production scale-up milestones	**Late-2020**: feasibility studies completed for first 1-10ktpa+ scale green H_2 electrolyser projects. Feasibility studies for first small to mid-scale blue H_2 projects.◊	**Mid-2021**: FID taken on first 10ktpa+ scale electrolyser projects. FID taken on first small to mid-scale blue H2 projects.◊	**2022:** Feasibility studies begin for first 100ktpa+ scale projects. This includes the first large-scale blue H_2 projects◊ as well as ~1GW scale electrolyser projects.	**2023/2024:** FID on first 100ktpa+ projects. FID on first large-scale blue H_2 projects◊ and 1GW scale electrolyser projects.	**2025**: First small to mid-scale 10ktpa+ projects online and exporting to Asia.	**2030:** First large-scale 100ktpa+ projects online and exporting to Asia.	**2035:** Expansion of smaller-scale and large-scale facilities to meet increasing demand in Asia. Australia is established as trusted H_2 export partner.	**2040:** H_2 export industry in Australia growing and approaching maturity. 100ktpa+ projects the norm.	**2050:** Export industry mature and at scale, similar to the maturity of the LNG industry.
Funding milestones	**From mid-2020**: ARENA H_2 funding allocated to kick-start feasibility studies and pre-FEED studies. ARENA provided further funds to mid-2022.	**Early 2021**: ARENA 2.0 (or alternative) legislation passed to fund renewable investment after mid-2022, with **A$>2bn in H_2 investment allocated**.	**Mid-2022**: ARENA 2.0 (or alternative) funds available.						

◊ Using SMR + CCS/offsets

Glossary

Term	Definition
AHC	Australian Hydrogen Council
ARENA	Australian Renewable Energy Agency
BNEF	Bloomberg New Energy Finance
FCV	Fuel cell vehicle
IRENA	International Renewable Energy Agency
METI	Japan's Ministry of Economy, Trade and Industry
ktpa	Kilotonnes per annum
Mtpa	Million tonnes per annum
Nm^3	Normal metres cubed, a volumetric measurement of the quantity of hydrogen
NHS	National Hydrogen Strategy (report released in November 2019)
SMR	Steam methane reforming

Appendix A

National Hydrogen Strategy *Energy of the future* and *Targeted deployment* Scenario Assumptions

See Deloitte (2019) *Australian Global Hydrogen Demand Growth Scenario Analysis*.[46]

Energy of the future

Key drivers and detailed parameters for Hydrogen: Energy of the future scenario

Key Drivers	Detailed Parameters
Highly positive future outlook for hydrogen uptake.	• Globally, stakeholders, governments and shareholders, see the role of hydrogen as important and it will continue to grow. • Investment potential and returns in the hydrogen sector are high for production, storage and transport facilities. • The useful cost of the use of hydrogen throughout the value chain is comparatively less expensive than alternatives.
Australian supply chain costs decrease rapidly.	• Production technology improves so that there are rapid declines in renewable energy, CCS and shipping and handling cost. • Utilisation technology improves and Australia industry rapidly changes, thereby driving quick technology learning rates, with the cost of new hydrogen production, transport and storage technologies decreasing. • The Australian hydrogen industry capitalises on the experience gained through the development of the existing LNG export industry. • There are no barriers to the use of hydrogen in distribution pipeline infrastructure as the maximum amount of hydrogen that can be mixed with natural gas is addressed through low-cost processes. • Piloting and trials of hydrogen deployment happen immediately with widespread deployment occurring several years prior to 2030.
Domestic government policies stimulate hydrogen uptake in all possible sectors of the economy including transport, industrial processes, and power generation and hard to abate industries (resources, chemical and steel manufacturing and agriculture sectors).	• Domestic policy removes barriers and streamlines processes, allowing for timely infrastructure investment and coordinating hydrogen generation with network resources. • Energy policies encourage coordination between the location of hydrogen facilities with generation and network resources.

[46] See https://www2.deloitte.com/content/dam/Deloitte/au/Documents/future-of-cities/deloitte-au-australian-global-hydrogen-demand-growth-scenario-analysis-091219.pdf, pages 51-52.

Most foreign governments that cannot cost competitively produce hydrogen choose to import it as it is cost effective to do so. Government policies aim for early and deep decarbonisation which promotes finding alternatives to traditional fossil fuels throughout the value chain, hydrogen being only one aspect of the overall strategy.	• Countries import hydrogen where they have insufficient land, CCS sites, water resources and renewable resources to enable clean hydrogen production. • Hydrogen is deployed to aid in meeting the objectives of government policies enacted for early and deep decarbonisation. • As a result of policy drivers, there is a change in energy mix that results in a decoupling between energy and economic growth. • Countries use hydrogen to decarbonise hard to abate sectors like resources, chemical and steel manufacturing.
Australia builds and maintains a strong competitive position relative to other exporting countries.	• Hydrogen infrastructure is built upon the experience gained in developing the LNG export industry. • Governments encourage investment throughout the value chain but particularly in relation to production. • Australia leads technological innovation and adoption providing a cost advantage relative to other countries.
Proliferation of hydrogen use internationally in transport including long-haul transport, municipal fleets and public transportation as well as industrial processes, power and heat.	• Passenger and long-haul vehicles (new) are almost all hydrogen powered. • Government policies in developed countries require all fleet vehicles purchased to be hydrogen-fuelled and governments actively invest in supporting infrastructure (i.e. fuelling stations). • In countries where solar and wind resources are abundant, hydrogen is used for domestic and commercial heating to replace natural gas. • Where solar and wind resources are not plentiful and the country imports hydrogen, hydrogen is used as the fuel for generators to produce electricity as well as for domestic and commercial heating. • Steelmaking processes are adapted in all countries that make steel to use hydrogen direct-reduction processing.
High-levels of consumer acceptance of hydrogen use.	• Hydrogen becomes the fuel of choice for consumers. • The majority of consumers (stages 1 through 4) adopt some form of hydrogen use. This is based on the 5 stages of technology adoption: innovators (stage 1), early adopters (stage 2), early majority (stage 3), late majority (stage 4) and laggards (stage 5). • The laggard group of technology adopters (stage 5) is adopting the most mature hydrogen technologies, including transport. • As a result of successful trials and community engagement both overseas and domestically, consumers are supportive of hydrogen use and no longer differentiate between hydrogen and other energy sources in terms of safety and technology acceptance. • Hydrogen production facilities can readily access suitable water resources.

Hydrogen: Targeted deployment

Key drivers and detailed parameters for Hydrogen: Targeted deployment scenario

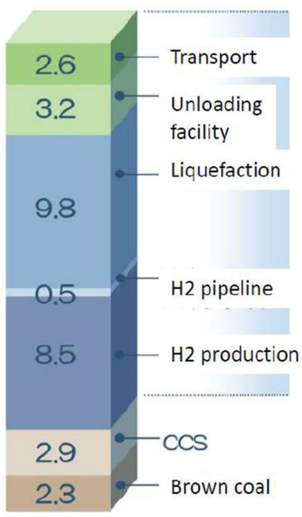
Key Drivers	Detailed Parameters
Moderately positive future outlook for hydrogen uptake.	• Globally, stakeholders, governments and shareholders view the role of hydrogen as important in targeted sectors. • Investment potential and returns for hydrogen in the targeted sectors are considered moderate with potential for growth. • The useful cost of the use of hydrogen for end-use in the targeted sectors is comparatively less expensive than alternatives.
Australian supply chain costs drop quickly for targeted sectors with cost decreases in related sectors occurring at a more moderate pace.	• Production technology improves so that there are moderate declines in renewable energy, CCS and shipping and handling costs. • Utilisation technology improves so that there are moderate declines in costs. • Uptake in targeted sectors resulting in rapid decline in supply chain costs. • There are improvements in the efficiency of balance of plant technology in mature production technologies. • Piloting and trials of hydrogen deployment happen immediately in the targeted sectors with widespread deployment in these sectors occurring several years prior to 2030. • Remaining sector deployment is more moderate and occurs after 2030.
Domestic government policies stimulate uptake in targeted sectors of the value chain and reduce non-price barriers to uptake in targeted sectors of the economy.	• Australian governments adopt policies to enable access for hydrogen deployment in targeted sectors. • Licensing and approval processes related to the target sectors are streamlined, allowing for greater ease in deploying hydrogen.
Most foreign governments that cannot cost competitively produce hydrogen choose to import it and set policies to incentivise hydrogen in particular sectors of the value chain where it is cost effective to do so. Governments adopt decarbonisation policies in addition to those previously announced with hydrogen	• Several developed countries, including Japan, South Korea, China and the United States adopt policies specifically targeting deployment of hydrogen in selected sectors. • The policies adopted by these nations support hydrogen uptake in selected sectors but at different levels of ambition, incentives and targets. • Countries import hydrogen where they have insufficient land, CCS sites, water resources and renewable resources to enable clean hydrogen production. • Hydrogen is deployed as one of the means to achieving decarbonisation objectives.

deployment being one aspect of the strategy.	
Australia can build new relationships or has trade relationships with those foreign governments that have set hydrogen targets.	• Australia already has strong trade relationships with early movers in the hydrogen import market – Japan, South Korea and China. • The Commonwealth Government actively pursues trade relationships with countries that have set hydrogen targets or are expected to set hydrogen targets. • Australian government agencies collaborate with industry participants to quickly build markets through the leveraging of existing relationships between those industry participants and stakeholders in international markets.
Australia faces competition in the export market including from other countries with similar competitive advantage.	• Australia's main competitors in the export market – the United States, Germany and Norway – adopt government policies that provide certainty for investors, reducing the risk of investment in these countries and increasing their attractiveness to international investors. • Australia's policies provide similar signals for international investment in the hydrogen sectors as its competitors. • Australia has a moderate share of the export market.
Proliferation of electrification technologies in relation to end-user applications in non-targeted hydrogen sectors.	• At the same time as hydrogen deployment in the targeted sector, electricity costs decrease globally given technological advancements. • Electrification, and other decarbonisation technologies, fulfil the decarbonisation challenge in the sectors where hydrogen is not deployed as these technologies are more compelling.
Moderate levels of consumer acceptance of hydrogen use.	• Consumers accept the use of hydrogen in targeted sectors of the value chain and the use of electrification technologies in non-targeted sectors. • A small segment of consumers, or innovators, accept and deploy hydrogen use in all sectors. • Early majority (stage 3) moving into late majority (stage 4) of consumers (based on the 5 stages of technology development) accept the use of hydrogen in the targeted sectors of the value chain. • In non-targeted sectors, consumer deployment remains with innovators (stage 1) and early adopters (stage 2) of technology. • Successful trials in the targeted sector and community engagement results in change in perception and community acceptance of hydrogen use. • Hydrogen production facilities can readily access suitable water resources.

Appendix B

Build-up of Japan's 2030 ¥30/Nm^3 landed price target

The estimated costs of the Australian Victorian Hydrogen Energy Supply Chain (HESC) project, which will export hydrogen made from brown coal in 2030, add up to Japan's 2030 ¥30/Nm^3 landed price target. It is unclear as to whether the ¥30/Nm^3 price target was developed from the HESC project cost stack or the cost stack was reversed engineered from the price target.



Source: Kawasaki Heavy Industries.

Source: Arias (2019) 'Hydrogen and Fuel Cells in Japan', https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf, p. 83.

Cost components of Japan's 2030 ¥30/Nm^3 landed price target

Components	Japan 2030 landed hydrogen price, yen/Nm^3	Japan 2030 landed hydrogen price*, A$/kg	% of total cost
Brown coal feedstock	2.3	0.37	8%
Carbon capture and storage	2.9	0.47	10%
Hydrogen production	8.6	1.38	29%
Hydrogen pipeline	0.5	0.08	2%
Liquefaction	9.9	1.60	33%
Cost of hydrogen produced	24.2	**3.91**	81%
Unloading facility	3.2	0.52	11%
Transport by liquid hydrogen ship	2.6	0.42	9%
Landed price	30	**4.85**	100%

Source: Arias (2019) 'Hydrogen and Fuel Cells in Japan', https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf, p. 83.

*Yen to A$ based on long-term exchange rate of 1 A$ = 74 yen.

AUSTRALIAN HYDROGEN COUNCIL

Appendix C

Deloitte Australian hydrogen export and domestic volume scenarios provided in the NHS report*

		2020	2025	2030	2035	2040	2045	2050
Total volumes								
Energy of the future	Mt	0.2	0.6	1.8	5.1	11.8	21.3	34.1
Targeted deployment	Mt	0.2	0.3	0.7	2.0	5.2	11.3	20.1
Business as usual	Mt	0.1	0.2	0.2	0.3	0.6	1.4	2.8
Domestic market volumes								
Energy of the future	Mt	0.2	0.3	0.8	2.0	3.9	6.0	7.8
Targeted deployment	Mt	0.1	0.1	0.3	0.5	1.1	1.8	2.7
Business as usual	Mt	0.1	0.1	0.1	0.2	0.3	0.5	0.9
Export market volumes								
Energy of the future	Mt	0.1	0.3	1.0	3.1	7.9	15.3	26.3
Targeted deployment	Mt	0.07	0.2	0.5	1.5	4.2	9.5	17.4
Business as usual	Mt	0.1	0.08	0.1	0.2	0.4	0.9	1.9

*Reflects updated numbers in the Deloitte erratum published May 2020.