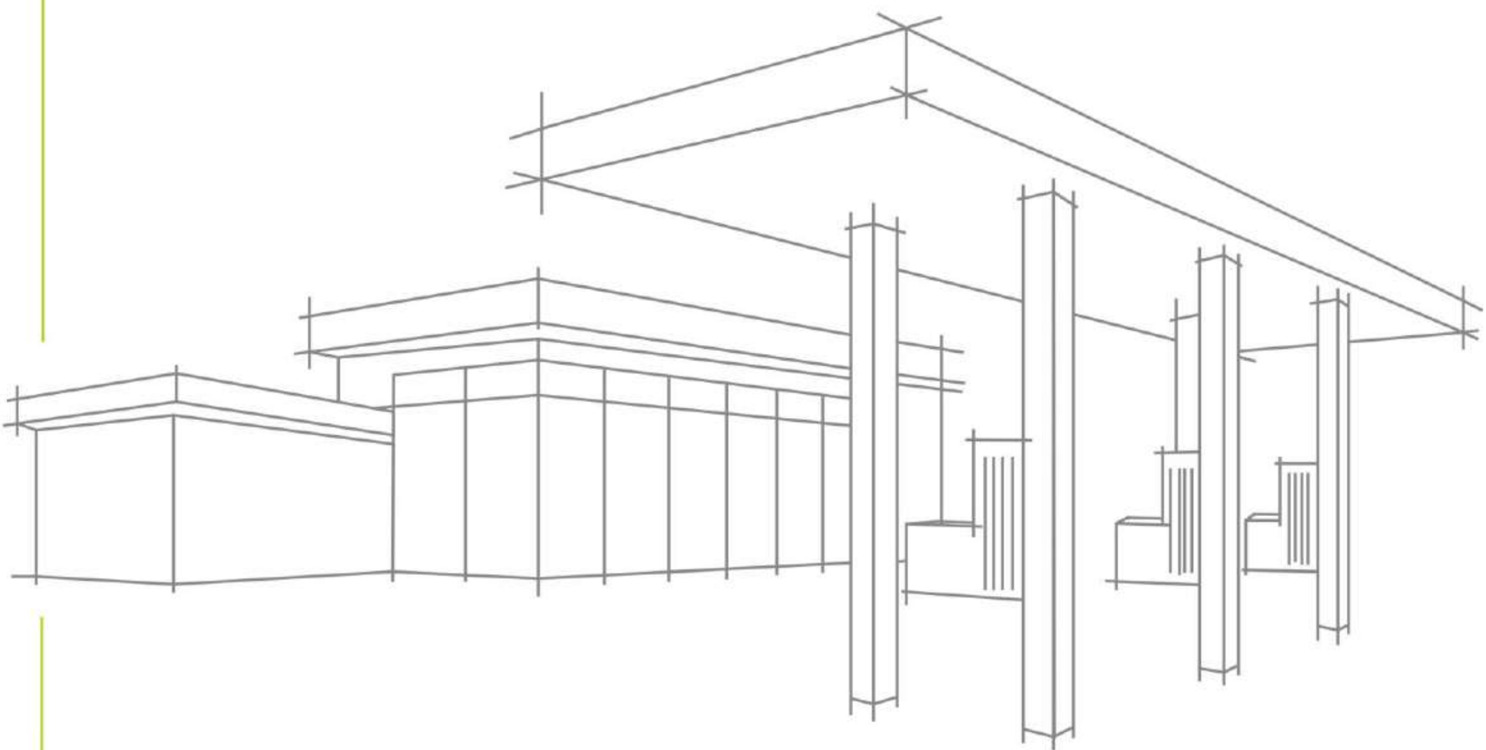
WHITE PAPER

LOW EMISSION VEHICLES, AN AUSTRALIAN PERSPECTIVE PART 2



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WHITE PAPER

Low Emission Vehicles, An Australian Perspective - Part 2

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Document Control

REVISION	DATE	PREPARED BY	REVIEWED BY	COMMENTS
A	07-Nov-22	K. Sharp	J. Rowell	For Internal/ External Use

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AT A GLANCE

Green hydrogen offers huge potential to help Australia decarbonise. However, the production of green hydrogen requires significant supplies of renewable electricity. There are not only many competing uses for green hydrogen, but also for new renewable electricity assets that may influence the role hydrogen plays in reducing transport emissions within the timeframe of net zero by 2050.

- Electricity generation produces 33% of greenhouse gas emissions in Australia. The government wants to increase renewable electricity generation for the national grid from 29% to 82% by 2030.
- Over 500,000 tonnes of hydrogen, currently generated from fossil fuels, is used for industry that needs to be replaced with green hydrogen.
- There are industrial applications where green hydrogen can reduce the use of fossil fuels in manufacturing.
- There are several mature, commercially available emission reduction technologies that will compete for road transport.
- Long haul transport is one of the more suitable applications for hydrogen requiring a smaller network of strategically located hydrogen refuelling facilities.
- The capital cost of hydrogen production equipment and vehicles is currently expensive and in short supply.
- There is a lack of hydrogen refuelling stations in Australia today is a significant impediment to the sale of hydrogen vehicles.

This article presents some of the key considerations and challenges to assess when preparing strategies and planning for hydrogen developments.

1.0 INTRODUCTION

This white paper is the second of a two-part series looking at low emissions vehicles currently on offer in Australia and which, in the current energy mix context, represents the lowest emission option in the most cost effective and feasible manner. Part 1 of the white paper focused on electric vehicles and hybrid vehicles. Part 2 will discuss the use of hydrogen for fuel cell electric vehicles (FCEVs).

2.0 HYDROGEN

There has been a lot of publicity about hydrogen over recent years. Australia's national hydrogen strategy and roadmap highlights numerous opportunities for us to be a hydrogen superpower. Before looking at the application of hydrogen to trucks and light passenger vehicles, we will set the scene with its current use, methods of production and competing potential applications.

2.1 Hydrogen Uses Today

Hydrogen is used today primarily as a feedstock for chemical production, particularly ammonia for fertiliser, and oil refining. Global hydrogen demand reached 94 million tonnes in 2021, [1] with 99% of production via steam reforming of natural gas (SMR) and other petroleum fractions. Existing hydrogen production via this method is actually a major source of greenhouse gases (GHG) and responsible for more than 900 million tonnes of CO2 emissions per annum. So, when looking to expand the use of hydrogen, it is critical to consider the feedstock, technology, energy source and associated emissions.

In Australia, approximately 536,000 tonnes per annum of hydrogen is generated on site for industrial processing.

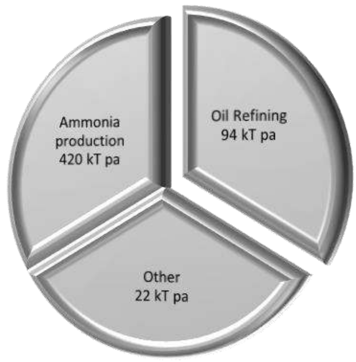

Figure 1: Historical Major Australian Hydrogen uses [2]

2.2 Hydrogen Production Colours and Intensity

Hydrogen can be made from a wide variety of feedstocks. These include fossil sources such as coal, methane and petroleum fractions, renewable sources such as biomass and the electrolysis of water using renewable electricity. Variations include the addition of carbon dioxide capture and storage and or utilisation technology (CCS or CCSU) and the source of the electricity used which directly impact the overall GHG footprint.

Whilst carbon capture and sequestration (CCS) technology can significantly reduce emissions, it does not capture all the carbon dioxide and is not as low emission as green hydrogen. In addition, not all CCS projects have been successful in achieving their performance targets.

The range of technology and feedstock methods are commonly classified with colours for simplicity as indicated in

Figure *2*. Indicative emissions for each technology are also shown.

The most common production technologies are based on steam methane reforming with or without carbon capture (grey / blue) and the electrolytic splitting of water to produce hydrogen and oxygen using 100% renewable electricity (green).

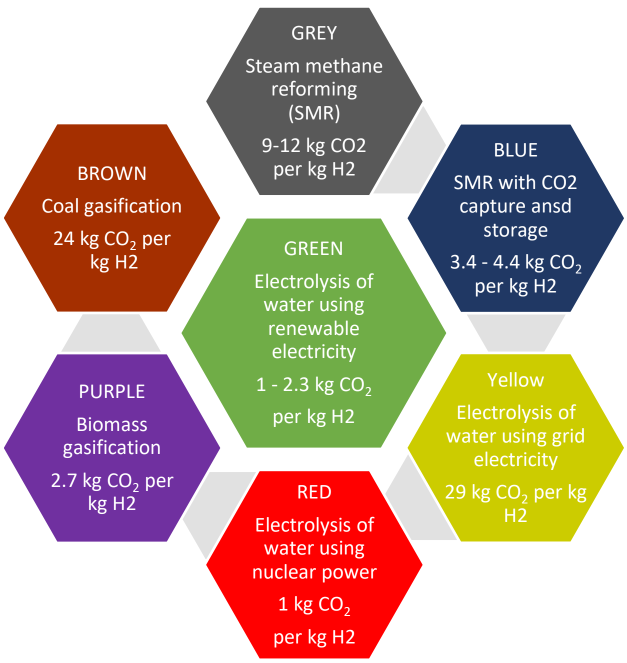

Figure 2: Hydrogen production emissions [3] [2] [4] [5]

Note emissions from electrolysis using power from the electricity grid can vary greatly and produce much higher emissions with the yellow figure quoted being based on the Germany grid mix in 2017 with 30% renewables. This is not dissimilar to Australia where 29% of electricity [6] is generated from renewables.

2.3 Hydrogen Properties

Hydrogen safety is very well understood by the process industries, however when compared to existing flammable fuels stored at a service station, hydrogen has very different properties which require careful consideration when planning an installation. Most petroleum product vapours are heavier than air. A liquid spill of petrol will quickly evaporate into vapour forming a flammable gas mixture. Vapours tend to disperse at ground level and accumulate in low lying pits. In contrast hydrogen is 14 times lighter than air and rises quickly if there is a leak.

	Vapour Density Rel to Air	Energy (MJ/kg)	Storage Pressure (Bar g)	Refuelling Pressure (Bar g)	Flash Point (°C)	Auto ignition Temp (°C)	Minimum Ignition Energy (µJ)	LEL (%)	UEL (%)	Gas Group
Petrol	4	44	0	3	-40	232	250	1	8	IIA
LPG	1.52	46	12	12	-104	490	260	2.4	9.6	IIA
Hydrogen	0.07	120	200-900	350-700	N/A	560	17	4	77	IIC

Figure 3: Hydrogen properties compared to conventional fuels

Hydrogen also has a much higher energy density meaning you do not need to store as much mass on site to refuel the same number of vehicles. A typical Hyundai Nexo hydrogen FCEV tank stores 6.4kg of hydrogen versus a small internal combustion engine (ICE) conventional Hyundai Tucson passenger vehicle tank storing 40kg of petrol to provide a similar range of approximately 660km.

Whilst petrol and diesel are typically installed in underground tanks, and LPG stored in either underground or above ground tanks, hydrogen is always stored in above ground storage with both steel and composite tank construction options. Hydrogen can also be stored and transported as a liquid; however, it must be cryogenically cooled to -253°C. Storage as a compressed gas is more popular and most vehicles store it in this form. Due to the high pressures, tanks are typically small diameter cylinders for strength.

Notably hydrogen has a much lower ignition energy (14x) and a ten times wider explosive limit concentration range. As such it has its own equipment hazardous area certification gas group (IIC). Care must be taken with the location of hydrogen equipment on existing sites as all existing electrical equipment represents an ignition source. Even hazardous rated service station dispenser electronics present an ignition source as they are typically designed and approved for gas group IIA for petrol and LPG not IIC for hydrogen.

Hydrogen also burns with virtually an invisible flame, so the use of leak detectors and flame detectors is critical to being aware if there has been a leak and ignition onsite.

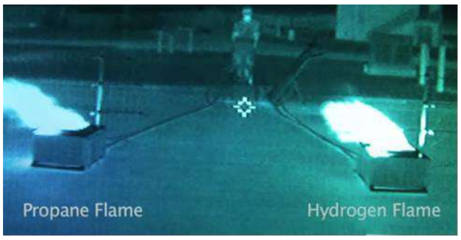

Figure 4: Hydrogen flame visibility

2.4 Hydrogen Competing Uses

There is a myriad of potential uses for hydrogen. Figure 5 shows additional uses for hydrogen graded according to the technical and commercial readiness of the application. Hydrogen represents the only option to reduce the use of coal in steel making and is already in use in Scandinavia. Gas blending, heating and transport hydrogen use rank much lower in readiness and have competition in the form of electricity / batteries. Forklifts, trains, aviation, shipping, and trucking are all identified as potential markets.

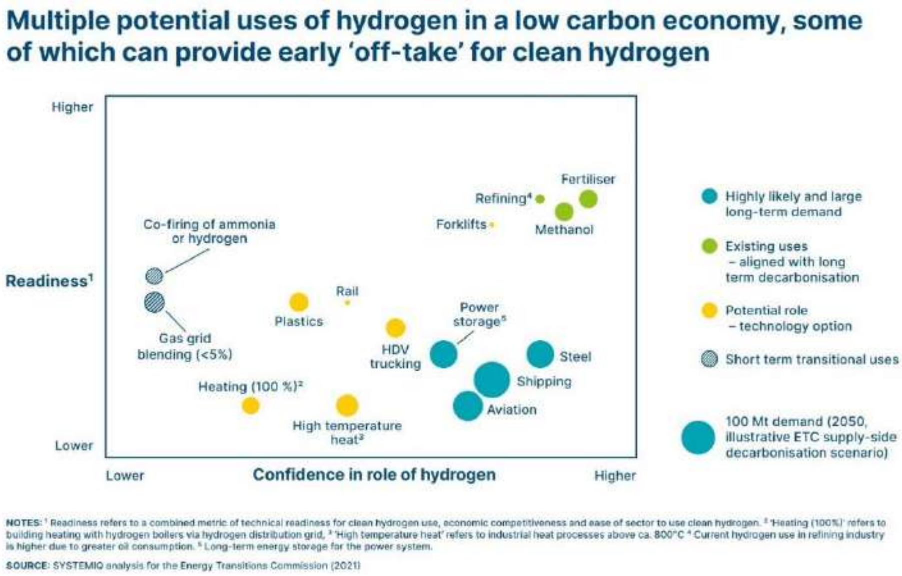

Figure 5: Likely roles of Hydrogen in a net zero future [32]

Whilst shipping and aviation are large markets, they are not technically feasible today. Hydrogen aircraft and ships do not exist yet and there is no firm timeline for their development.

At the recent Hydrogen Summit (September 2022) in Brisbane, Aurizon identified rechargeable battery technology as preferred for over 80% of their rail freight operations with only long-distance remote rail requiring hydrogen to supplement range.

These opportunities are not unique to Australia and there is worldwide demand with countries such as Japan and Germany seeking hydrogen exports from Australia.

To some degree the biggest risk to the growth of hydrogen use in Australia is the pursuit of the lucrative export market at the expense of Australia's own needs. This needs to be considered carefully as the development of Australia's natural gas export industry has reduced domestic supply and substantially increased gas costs.

Electricity generation is the biggest source of emissions in Australia responsible for 33% of all emissions [7] . The production of green hydrogen via electrolysis requires considerable extra renewable electricity, approximately 50kWhr per 1 kg [8] of hydrogen. An additional 30kWhr/kg (60%) is typically required to compress and transport gaseous hydrogen. Whilst renewable electricity generation has grown substantially over the last ten years; the net average percentage of renewable generation has only grown from 10% in 2010/11 to 27% in 2020/21.

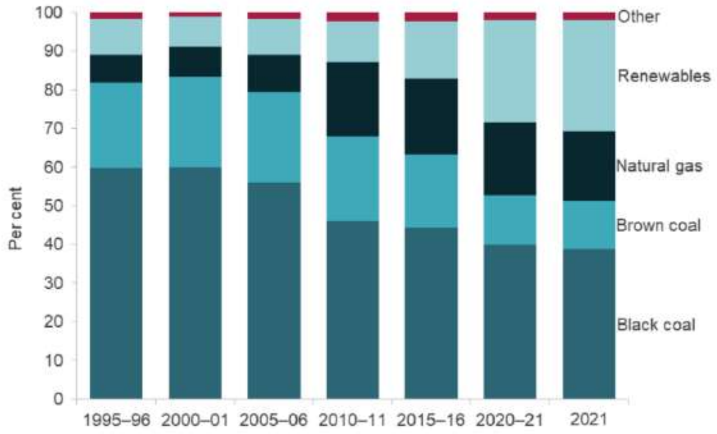

Figure 6: Australian electricity fuel mix [6]

With recent announcements quoting targets in the order of 82% renewables by 2030 [9], this will require increased expenditure and the installation of renewable generation assets at an accelerated rate consistently over the next eight years. Whilst this does not sound unreasonable in isolation, the growth of hydrogen will also compete for new renewable electricity assets.

To put this challenge in context, the Australian national electricity market had 65.2 GW of generation capacity in December 2021, [10] , producing 204 Terawatt hours (TWhr) of electricity in 2020/21.

Some of the projects already announced and under consideration are:

- ENGIE [11] to build an AUD $87 million 18MW solar farm and 10 MW electrolyser in Karratha, WA to produce hydrogen for Yara Pilbara Fertiliser's ammonia facility.
- AUD $38 million FEED study for a 500 MW renewable hydrogen plant at Incitec Pivot's [12] ammonia plant at Gibson Island, Brisbane producing 70,000 tonnes of hydrogen each year. The proposed plant would require the world's biggest electrolyser and 1 GW of renewable energy.

In addition, a number of export projects are already under consideration.

- The Asia renewable energy hub with up to 26GW of solar and wind generation (equivalent to producing over 90 TWhr/yr) to generate approximately 1.6 million tonnes of hydrogen per annum [13] [14]. The first 15GW stage is scheduled for final investment decision in 2025.
- The H2-Hub™ Gladstone project has a planned capacity of up to 3 gigawatts of electrolysis and up to 5,000 tonnes per day of green ammonia production using renewable energy.

To put it in perspective, to replace Australia's current industrial grey hydrogen with green hydrogen and to supply just the Asia renewable energy hub will require an additional 140 TWhr of renewable electricity generation. This represents six times the existing solar and wind generation and 70% more than our current grid capacity today.

3.0 TRANSPORT

The transport sector is Australia's third highest source of emissions at 19% [7]. Critically, unlike electricity generation, emissions from transport have been steadily increasing (up by 60% over the last 30 years excluding COVID).

Transport has been identified as one of the major potential markets for hydrogen but not all types of transport are viable today. Buses, trucks, and cars are available as fuel cell electric vehicles (FCEVs).; however, aviation and shipping are long term options at best.

In light of all the existing and potential uses of hydrogen, it is important to note that hydrogen is not the only option or even the most mature method to reduce road transport emissions in the short term.

Options to reduce emissions from Australia's 20 million commercial and passenger vehicle include biofuels or renewable fuels, E-fuel liquid fuels made from green hydrogen and carbon dioxide, hybrid vehicles (HEV or PHEV) which have both electric operation and internal combustion engines and battery electric vehicles (BEV or EV).

An attractive feature for both BEV and FCEV vehicles is the much publicised “zero emissions”, from the vehicle exhaust which significantly reduces smog and air pollution in major cities. However, this is a narrow perspective from a GHG perspective. Emissions are generated from these vehicles during the mining, transport, and processing of raw materials to the manufacture of batteries, solar panels, wind turbines, fuel cells and new cars. Life cycle assessment (LCA) is the accepted method worldwide to objectively compare technologies and considers all these factors. As illustrated in part 1 of this whitepaper, even a BEV charging at night with electricity generated using coal can have higher net LCA emissions than a convention petrol car. Figure 7 compares different fuel options from a LCA perspective and shows that similar emission savings are possible through many alternate renewable technology platforms.

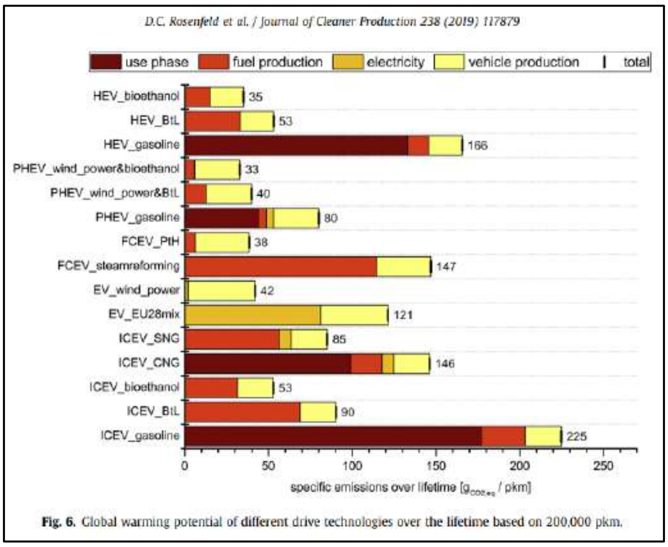

Figure 7: Advanced fuel LCA [43]
ICEV – Internal combustion engine vehicles
EV – battery electric vehicle, HEV- Hybrid electric vehicle.
PHEV – Plug in hybrid electric vehicle, BtL – biomass to liquid renewable fuel

4.0 PASSENGER VEHICLES

The majority of road vehicles are passenger vehicles. FCEV are not as efficient in their energy utilisation as BEV due to the comparative overall efficiencies as shown in Figure 8. The production, compression, and transport of sufficient green hydrogen to refuel a hydrogen car requires approximately 3-5x the electricity to charge a comparable BEV.

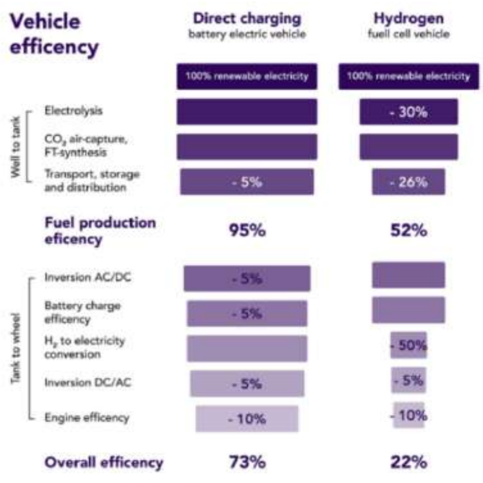

Figure 8: BEV vs. Hydrogen FCEV overall efficiency [1]

In return for this, FCEVs offer a range and user experience similar to an internal combustion car, refuelling in 3 minutes versus potentially hours for recharging. In part 1 of the white paper, we evaluated the cost to charge a Tesla Model 3 at a supercharger in Australia. Let's compare range and cost to see the difference. Both BEV and FCEV are much dearer options for the consumer, however FCEV are currently dearer than BEV to purchase and operate.

Hydrogen pricing is not established yet as there are no retail sites selling hydrogen to consumers, but anticipated pricing is often quoted in the order of AUD $10-15/kg. The comparison uses 80kWhr/kg (section 2.4 electrolysis plus compression) and $15/kg for hydrogen. Charging costs are based on commercial supercharger electricity rates (51c/kWhr), however charging at home is even cheaper. Considerable investment in R&D is currently being targeted to reduce hydrogen costs to AUD $2/kg, however at this time, this can only be achieved with the reforming of natural gas (SMR) which is not environmentally acceptable.

Table 1: Cost comparison of BEVs vs. FCEVs

LONG DISTANCE TRIP COMPARISON			
	Toyota Mirai [15]	**Hyundai NEXO [16]**	**Tesla Model 3 LR [17]**
MSRP (AU, pre-subsidy)	63,000	83,645	77,150
Energy carrier	5.6 kg H2	6.33kg H2	82 kWh
Electricity / Tank	448 kWhr	506 kWhr	82kWhr
Tested Range (km)	650	666	602
Cost to fill (AUD)	84.00	94.95	41.82
Relative cost ¢/km	13	14	7

One of the key concerns for consumers with both BEV and FCEV is range anxiety. A lot of work has already been completed by governments to establish a national supercharging network for BEV, and of course everyone who buys a BEV can charge it at home, albeit slowly. At this point in time there are only three or four hydrogen refuelling stations operating in Australia. This is challenging for the development of FCEV as consumers can only go to specific locations to refuel in a couple of major cities. In the short to medium term this is a huge challenge for passenger FCEV as consumers will not commit unless widespread refuelling is available. Conversely, establishing hydrogen refuelling facilities is expensive and has no return on investment without customers.

5.0 HEAVY TRANSPORT

Heavy transport truck fleets have very different utilisation to passenger vehicles. Vehicle utilisation is often 24 hours per day, 7 days per week with short breaks for drivers. Whilst renewable liquid fuels are still viable, battery electric operation has limited appeal, adding substantial weight for a large battery (reducing cargo capacity) and lengthy recharge times (reducing utilisation).

Interstate trucks move a lot of Australia's freight and refuelling requirements are predictable. The Hyzon HYMAX 46 tonne prime mover made in Melbourne will travel 680km on 70kg of hydrogen [18], and would only have to refuel once between Melbourne and Sydney or Sydney to Brisbane.

So, truck fleets can get by with much fewer hydrogen refuelling facilities which can be much more easily developed on large country allotments with minimal adjacent sensitive uses (residential etc). Within major cities, return to base fleets have the option of establishing a central refuelling facility where all trucks can refuel once per day.

However, hydrogen trucks are expensive with an Australian manufacturer Hyzon still at small scale with a prime mover at approximately AUD $850,000, well above the price of a conventional prime mover based on a recent presentation at the 2022 Hydrogen Connect Summit. Supply is increasing with Foton announcing that they are ramping up production in China, predicting capacity to supply 1,000 primer movers per year to Australia by 2024.

Without a national refuelling network, sales of trucks which only operate on hydrogen will be limited. Importantly governments are being proactive with Victoria and NSW [19], co-delivering the Hume Hydrogen Highway initiative.

They are investing $10 million each in grant funding to support:

- The design and delivery of at least 4 refuelling stations along the Hume Highway between Melbourne and Sydney.
- Approximately 25 hydrogen-powered long-haul heavy freight vehicles to adopt zero-emission technology, such as fuel cells.

6.0 HYDROGEN INFRASTRUCTURE

Hydrogen production and refuelling equipment is still very expensive and often suffers from lead times greater than 12 months.

Hydrogen electrolysers vary for alkaline and PEM construction, however data from 2020 shows costs are in the order of USD $840,000 / MW [20]. For this investment a 1 MW electrolyser can produce 15-20 kg of hydrogen per hour. A continuous supply of renewable electricity is critical to fully utilising these assets. Without energy storage, renewable solar and wind power may only provide power for 8 hours per day limiting production.

US DOE 2020 data for 111 new service stations [21] found a median capital cost of USD $1.9 million adjusted for equivalent costs in 2016. Adjusting this with the current July 2022 CEPCI and exchange rate equates to AUD $4.6 million.

None of the sites in the comparison produced hydrogen onsite. The median throughput was 1,500 kg/day with smaller sites (43%~) storing and receiving hydrogen in gaseous form and the remainder in liquid form. Hydrogen gas sites with a single dispenser were cheaper at AUD $3.4 million (adjusted) versus liquid hydrogen sites varying from AUD $4.6 – 10.2 million (adjusted) with one to two dispensers. Transporting liquified hydrogen reduces the amount of deliveries by a factor of 7 however it adds significant capital cost and requires more energy. Capital costs for a hydrogen liquefaction plant vary from USD $50 million for a 6,000 kg/day plant up to USD $800 million for a 200,000 kg/day plant [22]. Liquefaction energy requirements are in the order of 22-43 kWhr / kg of hydrogen.

Current world production of electrolysers is in the order of 8GW per year [23] with many manufacturers' looking to increase production. Whilst no hydrogen equipment is currently manufactured in Australia, Fortescue Future Industries (FFI) [24] are constructing the largest electrolyser manufacturing plant in the world in Gladstone with a capacity to produce 2 GW of electrolysers per year.

This will help to address electrolyser supply limitations in Australian and potentially reduce costs, however this is still well short of the demand to satisfy the current list of proposed projects. The potential generation from the proposed Asia energy hub could support operating over 10GW of electrolyser capacity operating 24 hours per day. This represents 5 years of production from the proposed FFI plant.

With the costs and the safety issues associated with hydrogen, it is not likely we will see hydrogen refuelling at home similar to the existing capacity to charge battery electric vehicles. Hence the traditional service station concept will be the likely way forward. Government support is critical to develop the industry. The Queensland Supercharging Highway has been key in establishing a network of superchargers to support the take-off of BEVs.

Currently the number of FCEV refuelling stations available to the public in Australia in early 2022 is three. This includes ActewAGL in NSW, Toyota Hydrogen Centre in Victoria, and BOC in QLD. [25]

ARENA grants and the Future Fuels Fund are being used to stimulate investment in FCEV refuelling infrastructure. One example is the VIVA Energy AUD $43.3 million New Energies Service Station in Geelong, which is expected to be available for use in early 2024. It will incorporate a 2-MW electrolyser, 150kW in EV charging facilities and 15 heavy hydrogen vehicles. [26]

Privately funded projects are also under development such as the Hydrogen Fuels Australia facility at Truganina, Victoria [27] which is expected to be operational in 2023. The facility will include a 640kW twin-axis solar array, 432kW alkaline electrolyser, 95kW hydrogen fuel cell, 300kW/307kWh battery storage and commercial vehicle refuelling.

A comprehensive list of projects under development is available on the CSIRO HyResource web site.

7.0 PRACTICAL ISSUES FOR RETROFITTING HYDROGEN TO EXISTING SERVICE STATIONS

There are over 500 hydrogen service stations worldwide. Whilst Australia is still developing standards for hydrogen service stations, countries such as the USA, Europe and the UK have well established standards and experience. Examples are NFPA 2, EIGA 15/21 and the Energy Institute Guidance on hydrogen delivery systems for refuelling of motor vehicles, co-located with petrol fuelling stations.

Australia has approximately 7,000 conventional service stations of which approximately one quarter have been designed by TfA. Most Australians live in major cities, and this is where many of the service stations are located.

Metropolitan service stations present a number of challenges. The first is the limited space for solar panels and thus limited ability to generate hydrogen onsite. Based on the typical roof area of a metropolitan site, approximately 340kWhr per day of solar electricity could be generated based on a weighted average of Melbourne, Sydney, and Brisbane. This could generate only 7kg of hydrogen per day, enough to refuel one car and hence for most metro sites, onsite production using onsite solar is simply not viable.

This means that onsite storage will often be required as per Figure 9 which shows a hydrogen trailer being parked on site as storage rather than build permanent bulk storage. This concept allows quick swapping of the hydrogen storage on site without extended deliveries on site. In either case hydrogen must be transported to site. Offset power purchase agreements combined with an onsite electrolyser are a potential alternative option.

Figure 9: NREL Hydrogen concept layout [42]

Gaseous hydrogen is expensive to transport with a typical hydrogen road tanker carrying only 340 kg of hydrogen versus a conventional fuel tanker which can carry 32,000 kg of petrol. Whilst a 5 kg hydrogen refuelling of car can be done in 3 minutes, almost as quickly as a 50-litre fuelling of a petrol vehicle, a road tanker only provides enough hydrogen to refuel roughly 70 cars versus 850 petrol cars comparatively. This means there would be 12 times as many road tanker deliveries based on gaseous hydrogen for the same number of vehicles.

Transport of liquid hydrogen is much cheaper with a tanker carrying ~2,000kg of hydrogen (Figure 10). This works much better logistically requiring only twice the number of deliveries comparatively. However, hydrogen liquification requires expensive additional plant at the production facility for cryogenic cooling to -253°C. It also adds substantial processing cost consuming a lot of additional energy equivalent to 0.4 kg of hydrogen to liquify every 1 kg of hydrogen [28].

This brings us to the issue of space and available land. Hydrogen station designs typically include bulk storage, compression/pumping, high-pressure buffer storage, precooling unit, and dispensers, but vary depending on individual site design configuration. The minimum footprint of a hydrogen equipment enclosure is in the order of 10 x 15m plus separation distances excluding the area for the hydrogen dispenser. In many cases there is simply insufficient space on existing metropolitan service stations, so the retrofitting of hydrogen may simply not be practical. Acquiring new sites to dedicate to hydrogen is likely to be more practical in metropolitan areas.

Figure 10: Liquid hydrogen -253°C

Retrofitting hydrogen to large truck stop sites and regional service centres is likely to be much easier. Many are surrounded by open land where solar panels could be installed with space onsite for hydrogen production, storage and refuelling without impacts on sensitive uses. Major truck routes need fewer refuelling points as they are largely dictated by mandatory breaks for drivers with trucks having a much larger range than cars.

Dedicated hydrogen refuelling facilities for trucks in the country are also much easier to establish given large allotments of land can be acquired without adjacent sensitive uses which are much easier to develop for both production and refuelling.

Hydrogen refuelling dispensers are not compatible with existing conventional diesel and petrol dispensers which are generally approved for different gas groups and should be kept well apart (~5m).

Figure 11: Different canopy designs

In addition, hazardous zones for hydrogen are very different to petrol as the hydrogen rises. The upper photo in Figure 11 shows a canopy designed for good hydrogen ventilation, allowing the hydrogen to quickly rise without accumulating under the canopy. The lower photo shows an existing truck stop canopy design which may not be suitable for hydrogen. The risk of hydrogen accumulation within the canopy structure needs to be considered when planning to retrofit hydrogen to existing site. Existing lighting is unlikely to be hazardous rated to gas group IIC and could be a potential ignition source.

8.0 THE CLEAN HYDROGEN LADDER

An interesting summary and representation of the potential options and priorities for hydrogen has been presented by Liebreich Associates as shown in Figure 12. Whilst this chart proposes a potential hierarchy for hydrogen implementation, hydrogen is already selectively being used for all these applications.

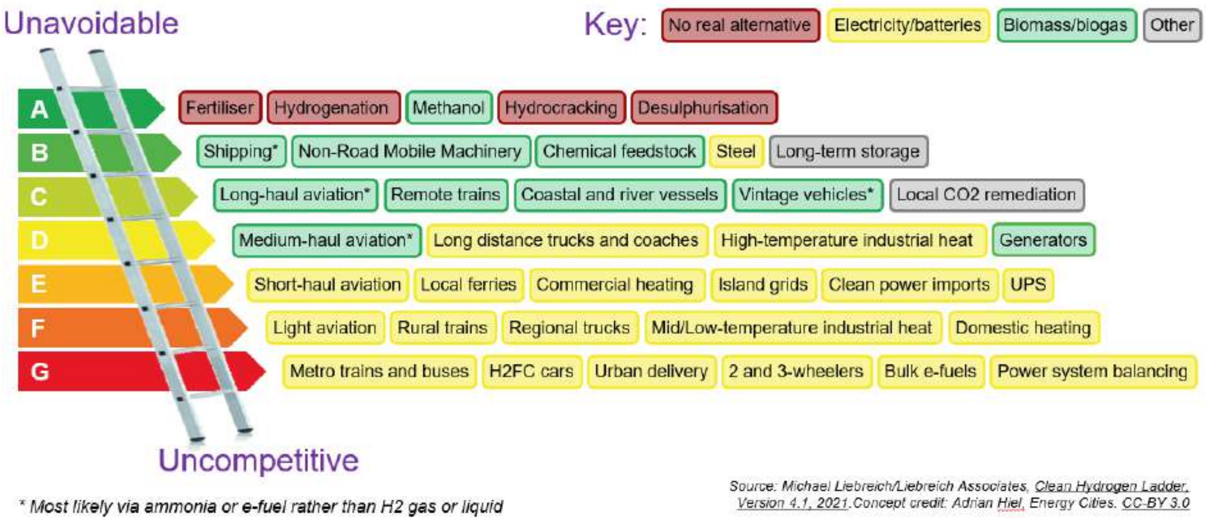

Figure 12: The competing uses for hydrogen [22]

Notably applications such as aviation are not viable for the foreseeable future as commercial hydrogen aircraft do not exist. Conversely truck fleets, coaches, trains, and taxis with 24/7 utilisation are already technically demonstrated and commercially and are much better suited to hydrogen than battery operation. A network of refuelling stations centred around back to base operations and strategically located on major highways will make it much easier and quicker to expand these applications.

9.0 CONCLUSION

The green hydrogen industry in Australia is in its infancy today. However, there is no doubt green hydrogen offers huge potential to help Australia decarbonise. There is already a lot of movement by private companies and government to help establish critical infrastructure.

- FFI's local manufacturing of electrolysers is a positive step, and we still need more electrolyser production ideally in Australia to keep up with the anticipated demand for green hydrogen.
- Government support for increasing grid renewables is already strong, though there will be competition for new renewable power assets, and therefore we still need more investment in renewable energy dedicated to hydrogen production.
- There is also wide government support for the strategic development of regional hydrogen refuelling facilities. The Future Fuels Fund and Victoria / NSW Hume Hydrogen Highway fund are good examples.
- Heavy vehicle and return to base fleets that have 24/7 utilisation and require fast refuelling times will be better suited to hydrogen than BEV, however this needs a well thought out supply and refuelling network strategy.
- Given the competition in the grid for renewable power, it may make sense for large regional sites to have their own onsite power generation, ideally with energy storage for overnight production

This article has presented some of the key considerations and challenges to assess when preparing strategies and planning for hydrogen developments. TFA Project Group have been working with both traditional and renewable bioenergy fuels including hydrogen for over 25 years. We can assist you to evaluate, identify and implement a hydrogen solution for your business.

10.0 REFERENCES

[1] IEA, “Hydrogen,” IEA, 2021. [Online]. Available: https://www.iea.org/reports/hydrogen.

[2] Advisian, “Australian hydrogen market study,” CEFC, 24 May 2021.

[3] *. A. R. A. H. R. D. a. D. H. Graham Palmer, “Life-cycle greenhouse gas emissions and net energy assessment of large-scale hydrogen production via electrolysis and solar PV,” *Royal Society of Chemistry Energy & Environmental Science,* no. August, 2021.

[4] A. A.-D. 2. I. ,. G. A. 3. S. J. M. 4. a. S. U. 5. Andi Mehmeti 1, “Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies,” *MDPI Environemnts,* vol. 5, no. 24, 2018.

[5] K. B. d. l. R. M. Hamacher, “Life cycle assessment of hydrogen from proton exchange membrane water electrolysis in future energy systems,” *Applied Energy,* vol. 237, pp. 862-872, 2019.

[6] E. E. a. W. Australian Government Dept of Climate Change, “Australian Energy Update 2022,” September 2022. [Online]. Available: https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202022%20Energy%20Update%20Report.pdf. [Accessed 10 October 2022].

[7] Australian Government, “Quarterly Update of Australia’s National Greenhouse Gas Inventory: Mar 2022,” Dept of Climate Change, Energy the Environment and Water, March 2022. [Online]. Available: https://www.dcceew.gov.au/sites/default/files/documents/nggi-quarterly-update-march-2022.pdf. [Accessed 11 October 2022].

[8] Foresion, M. Neagoe and P. Turner, “Supply Chains for Future Road Transport Fuels in Australia,” Foresion, 2022.

[9] M. Ludlow, “Times up for the great transition,” *Australian Financial Review AFR Weekend,* pp. 20-21, 15-16 October 2022.

[10] AEMO, “The National Electricity market Fact Sheet December 2021,” December 2021. [Online]. Available: https://aemo.com.au/-/media/files/electricity/nem/national-electricity-market-fact-sheet.pdf. [Accessed 10 October 2022].

[11] ARENA, “Australia’s first large scale renewable hydrogen plant to be built in Pilbara,” 16 September 2022. [Online]. Available: https://arena.gov.au/blog/australias-first-large-scale-renewable-hydrogen-plant-to-be-built-in-pilbara/. [Accessed 12 Oct 2022].

[12] ARENA, “Fortescue plans massive hydrogen electrolyser in Brisbane,” ARENA, 07 October 2022. [Online]. Available: https://arena.gov.au/blog/fortescue-plans-massive-hydrogen-electrolyser-in-brisbane/. [Accessed 7/10/2022 October 2022].

[13] “Intercontinental Energy Asian Renewable Energy Hub,” 2022. [Online]. Available: https://intercontinentalenergy.com/asian-renewable-energy-hub. [Accessed 11 Oct 2022].

[14] BP, “Renewable energy hub in Australia,” BPO, 18 October 2022. [Online]. Available: https://www.bp.com/en/global/corporate/what-we-do/gas-and-low-carbon-energy/renewable-energy-hub-in-australia.html. [Accessed 18 October 2022].

[15] “Cars Guide,” [Online]. Available: https://www.carsguide.com.au/car-reviews/toyota-mirai-83279.

[16] “Cars Guide,” [Online]. Available: https://www.carsguide.com.au/ev/hyundai-nexo-82996.

[17] “Tesla,” [Online]. Available: https://www.tesla.com/en_au/model3.

[18] Hyzon, “Hyzon motors,” 10 October 2022. [Online]. Available: https://www.hyzonmotors.com/vehicles/hyzon-hymax-series. [Accessed 10 October 2022].

[19] “Hume Hydrogen Highway,” Victorian State Government, October 2022. [Online]. Available: https://www.energy.vic.gov.au/grants/hume-hydrogen-highway. [Accessed 26 October 2022].

[20] R. D. e. a. Jonathon Yates, "Techno-economic Analysis of Hydrogen Electrolysis from Off-Grid Stand-Alone Photovoltaics Incorporating Uncertainty Analysis," 21 October 2020. [Online]. Available: https://ars.els-cdn.com/content/image/1-s2.0-S2666386420302241-mmc3.pdf. [Accessed 13 October 2022].

[21] U. D. o. Energy, "Hydrogen Fuelling Station Costs," 11 Feb 2020. [Online]. Available: https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf. [Accessed 13 Oct 2022].

[22] U. D. o. Energy, "DOE Hydrogen and Fuel Cells Program Record," 9 September 2019. [Online]. Available: https://www.hydrogen.energy.gov/pdfs/19001_hydrogen_liquefaction_costs.pdf. [Accessed 15 October 2022].

[23] Peter Ker, "Big hydrogen warns newcomers that electrolyser dreams won't come easy," Australian Financial Review, 24 October 2022. [Online]. Available: https://www.afr.com/companies/energy/big-hydrogen-warns-newcomers-that-electrolyser-dreams-won-t-come-easy-20221021-p5brv5. [Accessed 24 October 2022].

[24] F. F. Industries, "Construction commences on world-leading electrolyser facility in Gladstone, Queensland," 27 Feb 2022. [Online]. Available: https://ffi.com.au/news/construction-commences-on-world-leading-electrolyser-facility-in-gladstone-queensland/. [Accessed 12 Oct 2022].

[25] glpautogas.info, "Hydrogen Stations in Australia in May 2022," May 2022. [Online]. Available: https://www.glpautogas.info/en/hydrogen-stations-australia.html.

[26] C. Brauer, "Australian Government Moves Speed FCEV Commercialization," Global Fleet Management, 23 March 2022. [Online]. Available: https://www.globalfleetmanagement.com/10163977/australian-government-moves-speed-fcev-commercialization.

[27] "Hydrogen Fuels Australia Truganina HRS," CSIRO Hyresource, 7 October 2022. [Online]. Available: https://research.csiro.au/hyresource/hydrogen-fuels-australia-truganina-hrs/#:~:text=The%20project%20proponent%20is%20developing,grid%20and%20mobility%20end%2Duses. [Accessed 26 October 2022].

[28] U. B. a. B. Eliasson, "US Dept of Energy Alternative Fuels Data Center," [Online]. Available: https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf. [Accessed 10 October 2022].

[29] S. Newman, "2021 Tesla Model 3 Long Range Review," WhichCar.com.au, 28 March 2021. [Online]. Available: https://www.whichcar.com.au/reviews/2021-tesla-model-3-long-range-review.

[30] D. R. e. al., "Comparison of advanced fuels - Which technology can win from the life cycle perspective?," *Journal of Cleaner Production 238,* 2019.

[31] S. E. a. R. Australian Government Department of Industry, "Electricity generation," 2020. [Online]. Available: https://www.energy.gov.au/data/electricity-generation. [Accessed 23 February 2022].

[32] Energy Transitions Commision, "Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy," 2021.

[33] K. Senecal and F. Leach, Racing Towards Zero: The Untold Story of Driving Green, SAE International, 2021.

[34] A. Smart and W. P. Graham, "Possible Futures: Scenario Modelling of Australian Alternative Transport Fuels to 2050," CSIRO, 2011.

[35] R. W. Howarth and M. Z. Jacobson, "How green is blue hydrogen?," *Energy Science & Engineering,* 2021.

[36] M. Liebreich, *Clean Hydrogen Ladder,* 2021.

[37] Australian Hydrogen Council, "Hydrogen Decarbonization Pathways - A life-cycle assessment," 2021.

[38] Scania, "Electrification," 2022. [Online]. Available: https://www.scania.com/au/en/home/products/attributes/electrification.html.

[39] J. M. Howarth RW, "Energy Science and Engineering," 12 August 2021. [Online]. Available: https://doi.org/10.1002/ese3.956. [Accessed 29 September 2022].

[40] C. E. Council, "Clean Energy Australia Report 2022," 2022. [Online]. Available: https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2022.pdf. [Accessed 10 October 2022].

[41] LG, "LG Solar System Output Calculator," October 2022. [Online]. Available: https://www.lgenergy.com.au/calculator/suburb/dawes-point-nsw/2000. [Accessed 10 October 2022].

[42] N. B. P. N. N. Laboratory, “Introduction to hydrogen and fuel cell technologies and safety considerations,” H2 Hydrogen Safety Panel, 13 September 2018. [Online]. Available: https://h2tools.org/sites/default/files/IntroToH2FCandSafetyConsiderations_Sept2018.pdf. [Accessed 10 October 2022].

[43] D. R. E. Al, “Comparison of advanced fuels - which technology can win from the life cycle perspective?,” *Journal of Cleaner Fuel Production,* vol. 238, 2019.