Hydrogen vehicle refuelling infrastructure

Priorities and opportunities for Australia

EXECUTIVE SUMMARY

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CSIRO Australia's National Science Agency


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Executive summary

Introduction

This report is aimed at providing information around the opportunities and challenges for the deployment of refuelling stations for hydrogen-powered road vehicles in Australia, with particular regard to fuel cell electric vehicles (FCEVs). This report identifies priorities for action, including areas that would benefit from targeted research and innovation. Whilst battery electric vehicles (BEVs) are currently the leading means of decarbonising road transport, FCEVs are expected to play a significant role with heavy duty (HD) and linehaul freight transport, due to their ability to enable:

- much shorter refuelling times, being especially important where time-cost is of key importance
- payload maximisation, through avoiding a substantial negative impact of carrying large, heavy batteries
- greater range between refuelling stops.

Global context

There are five key overseas jurisdictions, each being major centres of automobile manufacturing, which have made, and are continuing to make, substantial progress in rolling-out hydrogen refuelling stations (HRSs). Germany, Japan, California, South Korea and China between them have around 600 HRSs, being over 80% of the world's total, that service close to 50,000 FCEVs. The progress in these jurisdictions has resulted largely from strategic partnerships and financial incentives from government, supported by the establishment of necessary regulations and standards to provide clarity for project developers.

The overseas experience has highlighted that how hydrogen is produced and distributed to HRSs has important implications for station location, design, scale, and cost and for the environmental benefits of hydrogen use in transportation. Geography, resources, local demand as well as government and industry objectives can be seen to be shaping station configurations. A variety of designs have been developed overseas, with no single preferred configuration emerging as yet. Onsite and offsite production, standalone facilities and additions to existing refuelling locations all continue to be developed.

Hydrogen refuelling station configurations and sizes

This report considers the Australian context and the merits of a range of HRS configurations across four sizes of stations defined by Maximum Daily Throughput of hydrogen:

- Small: 200 kilograms or 3.3 Heavy Duty FCEV fills
- Medium: 500 kg, 8.3 fills
- Large: 1,000 kg, 16.7 fills
- Extra-Large: 4,500 kg, 66.7 fills.

The HRS configurations are summarised below.

Table 1. Key configurations considered

<table>
<tr><th>Config'</th><th>Description</th><th>Production</th><th>Form</th><th>Distribution</th><th>Storage</th><th>Dispensing</th></tr>
<tr><td>1</td><td>Onsite production, electrolysis using grid electricity</td><td>Electrolysis using grid electricity</td><td rowspan="3">Gas</td><td>n/a</td><td rowspan="2">Gaseous storage</td><td rowspan="3">Gas compressor and dispenser</td></tr>
<tr><td>2</td><td>Onsite production, electrolysis using onsite renewables augmented by grid electricity</td><td>Electrolysis using behind-the-meter renewables</td><td>n/a</td></tr>
<tr><td>3</td><td>Offsite production, road transport of gas</td><td rowspan="3">Through any of:
- electrolysis
- reforming
- gasification or
- by-product</td><td>CGH_2 tube trailer</td><td>Trailer-swap or bulk delivery</td></tr>
<tr><td>4</td><td>Offsite production, road transport of liquid</td><td>Liquid</td><td>LH_2 trailer</td><td>Cryogenic tanks</td><td>Cryogenic pump and dispenser</td></tr>
<tr><td>5</td><td>Offsite production, pipeline transport of gas</td><td>Gas</td><td>pipeline</td><td>n/a</td><td>Gas compressor and dispenser</td></tr>
</table>

Legend: CGH_2 – compressed gaseous hydrogen, LH_2 – liquid hydrogen, n/a – not applicable

In relation to the configurations, key conclusions are:

Configuration 1, involving the production of hydrogen from an onsite (on HRS) electrolyser is the preferred configuration for pilot or 'proof of concept' projects, due to being self-contained (not reliant on an external supply chain for transport and production) and not requiring significant scale to service a modest number of FCEVs. It is also a solution where HRSs are very long distances from offsite production sources.

Configuration 2, being the same as Configuration 1, other than there being a source of behind-the-meter renewable electricity in addition to grid electricity to power the onsite electrolyser, is likely only attractive where there is significant space nearby for solar or wind generation and the installed renewable electricity is of a scale beyond that required for the HRS (e.g., for the purposes of export to the grid).

Configuration 3, which involves procuring gaseous hydrogen from an external production source and having it transported to the station in bulk compressed form, is likely the most effective configuration (in the midterm) as the scale of HRSs and supporting hydrogen production centres and transportation infrastructure is developed.

Configuration 4, which involves procuring liquid hydrogen from an offsite producer and having it transported to site for storage in cryogenic tanks has the potential to be an effective longer-term configuration as liquid hydrogen processes mature, due to liquid hydrogen being a much more concentrated source of energy than gaseous hydrogen, resulting in larger delivery payloads and hence reduced delivery costs.

Configuration 5, being a variant of Configuration 3 in that it uses a pipeline rather than road transport to deliver gaseous hydrogen to the HRS site, is likely only suitable for situations where otherwise un-utilised pipelines are available for use or where the HRS is situated in an industrial precinct that includes hydrogen production. Installing a purpose-built dedicated hydrogen distribution pipeline from a remote production source will likely involve a much greater cost than using road transport.

Cost implications

Significant investments in project development, scale, research and innovation are required to achieve commercially-viable prices at the dispenser that will be competitive with fossil fuels. Cost modelling presented in this report does not attempt to mirror any particular project that may currently be in development in Australia. Rather, it takes a forward-looking approach and assumes that the required investment in supporting infrastructure (e.g. compressing/filling equipment at offsite hydrogen producers) and assets such as Type III and Type IV tube trailers or Multi Element Gas Containers (MEGCs) has been made by industry participants, with those costs then recovered through charges to the HRS operators. The costs and cost components are presented in terms of Levelised Cost of Hydrogen (LCOH), being the average net present cost per kilogram of hydrogen over the project lifetime, calculated using a real discount rate of 7% (which may be lower than investment hurdle rates of some developers). In this report, as annotated by subscript, LCOH is alternatively used as a measure of the cost of hydrogen production ($LCOH_P$), cost of dispensed hydrogen ($LCOH_D$) and the contributory cost of component processes (transportation/distribution, compression, storage and filling (dispensing) – $LCOH_T$, $LCOH_C$, $LCOH_S$ and $LCOH_F$ respectively) at different pressures.

Our cost analysis does not include:

- the cost of the HRS site (too variable an input to meaningfully average)
- any necessary civil works, such as hardstand, drainage or installation of utilities
- any necessary upgrades to grid power supply and connections.
- commercial profit margins
- corporate overheads.

The LCOH figures presented are to provide a comparative analysis of the alternative business models and allow focus on those costs components which are most material to the development of HRSs. Our analysis does not quantify the alternative risk profiles that may be applicable to each project configuration. In addition, it is noted that the most significant contribution to $LCOH_D$ across all considered configurations is the cost of electricity (whether the hydrogen is produced onsite or transported from an offsite production site). For some scenarios (of configuration and scale) electricity comprises close to 50% of the overall $LCOH_D$. This report does not attempt to contemplate the wide range of electricity price scenarios that may eventuate in the future as Australia's energy market transitions towards net zero emission targets, rather it assumes a central AEMO price path. The $LCOH_D$ of all modelled scenarios will rise or fall in line with future electricity price outcomes.

For **Configuration 1**, the modelled dispensed cost of hydrogen on a levelised cost basis ($LCOH_D$) is in the range of $11.60 (Small HRS) to $8.59 (Extra-Large HRS) per kilogram, with the cost of producing the hydrogen ranging from 51% to 43% of the $LCOH_D$. In turn, the electricity to power the onsite electrolysers comprises around half of the hydrogen production cost.

Thus, for onsite production, whilst there should be focus on reducing the costs of procuring and installing electrolysers, there should be equal or greater focus on improving electrolyser power efficiency in response to escalating electricity prices. Focussed consideration should be given to optimising the flexibility of the electrolyser plant, and time-of-day load management to reduce input electricity costs.

Second to the cost of hydrogen production, is the cost of onsite hydrogen compression with, similar to the electrolysis, around 50% of $LCOH_C$ being the cost of grid electricity input. Compressor costs benefit greatly from economies of scale with $LCOH_C$ reducing from $2.32 per kilogram for a Small HRS to $0.58 per kilogram for an Extra-Large HRS.

Modelling of **Configuration 2** provides similar, but higher cost outcomes, as Model 1 due to the cost of establishing onsite renewable electricity (assumed to be solar photovoltaic). Whilst on a marginal cost basis, solar electricity is much lower cost than grid electricity, this is outweighed by the capital cost of installing the solar array. The use of onsite (or otherwise behind-the-meter) electricity is likely best suited where there is a wider proximate electricity need (e.g. where the HRS might be part of an energy hub or where it is intended to export power to the grid).

Configuration 3, based on the modelling, is the best solution for most scenarios where round-trip delivery distance is less than approximately 600km. It is premised on the availability of compressed hydrogen transport vehicles and hydrogen producers that have the capacity, infrastructure and willingness to sell to HRS operators. Whilst there are Type I tube trailers (230 bar pressure) currently available in Australia, tube trailers with higher pressures and higher capacities (Types III and IV) can play a substantial role in improving the economics of the offsite production model.

Configuration 4 (transporting liquid hydrogen from remote production facilities) is expected by many industry stakeholders to be an attractive future option for HRSs with high throughput, due to the potential to transport and store larger volumes of hydrogen at a lower cost. This is borne out by our financial modelling, with a $LCOH_D$ of dispensed hydrogen as low as $6.65 per kilogram for an Extra-Large HRS. Thus, liquefaction, and transporting, storage and dispensing of liquid hydrogen present as areas of great interest for commercial and industrial research and innovation.

Other findings

The table below sets out some of the key observations and findings in this report, along with the associated opportunities.

Table 2. Summary of other observations and findings

Key observations / findings	Opportunities	Report reference
Industry initiatives and business models		
1. Those overseas jurisdictions that are much more developed than Australia with their roll-out of HRSs have utilised major public sector – private sector partnerships and consortia to provide a collective approach to stimulating demand, promoting research and development, sharing risks and achieving initial scale to allow supply chain cost reductions.	Incorporate learnings from overseas to expedite infrastructure development in Australia. Incentivise international technology partnerships. Further develop Australia's Hydrogen Hubs' strategy to incorporate a wider scope of stakeholders in mobility projects, especially from fuel retailing and vehicle manufacturing. Governments to investigate the potential to found / support the creation of sector partnerships/consortia in the Australian market.	3.1. 3.2
Offsite versus onsite hydrogen production		
2. Centralised offsite production and distribution of hydrogen to HRSs is likely to be the dominant future model due to cost efficiencies with scale and the avoidance of needing to accommodate onsite production when selecting sites.	Governments and developers should focus on the enablers of larger scale HRSs utilising hydrogen supplied by centralised offsite production facilities.	8.2.1, 8.2.3
3. To date, onsite production of hydrogen is currently the supply model of the existing early HRSs and those currently being planned/ developed in Australia, due to it being self-contained and not dependent on transporters and external producers of hydrogen.	Continue to develop onsite production as an early-stage approach, and as a prototype for remote locations that may be long distances from offsite production sites, and that may have less neighbourhood constraints to accommodating larger scale onsite production.	2.5
4. Modelling shows that incorporating the use of purpose-built behind-the-meter renewable electricity, scaled to the size of the HRS, adds to the cost of onsite hydrogen production versus fully relying on grid-supplied electricity.	Consider co-locating HRSs with existing large-scale renewable electricity sources where possible (having regard to established freight routes) and /or if new renewable electricity was to be utilised, it being of a scale beyond that needed for servicing the HRS.	8.2.2
Pressure and form of hydrogen		
5. Currently most Heavy Duty and Medium Duty FCEVs (overseas) use hydrogen at 350 bar pressure. However, a number of vehicle manufacturers are now flagging a transition to 700 bar, especially for long haul transport – initially aiming at 1,000km range.	The cost of onsite storage at 700 bar is significantly higher than that of storage at 350 bar, thus this is an area that would benefit from focussed research and innovation, including continued research into the optimisation of cascade storage.	A1.1, 5.4.2
6. Liquefaction, and transport and storage of liquid hydrogen, to be dispensed as a gas presents as an opportunity to greatly improve distribution and storage capacities. However, transport and storage of liquid hydrogen at low volumes is currently very expensive compared to compressed hydrogen.	Promote focussed research and innovation to enhance the technology and processes for liquefaction, and transport and storage of liquid hydrogen.	5.2.2
7. Long-haul vehicle manufacturers are flagging future use of onboard liquid hydrogen as fuel, which will greatly increase the hydrogen energy that can be carried in vehicle tanks, thus increasing range and limiting the impost of the tank volume.	Dispensing technology is developed, but field experience is limited. Demonstration trials are necessary.	5.5.4, 5.5.5

Key observations / findings	Opportunities	Report reference
Distribution of hydrogen to HRSs		
8. Road distribution of hydrogen utilising existing steel tube trailer technology is limited by capacity constraints. There is an overseas trend towards transporting in higher pressure Type III and Type IV carbon fibre cylinders that can transport hydrogen much higher volumes, with lower weight.	Explore Australia's access to Type III and Type IV tube trailers and consider a potential collective approach to acquisition of trailers for shared use of fuel companies / hydrogen distributors.	5.2.1
9. For the foreseeable future, transport of hydrogen directly to HRSs by dedicated pipeline will likely be difficult to justify in most cases, due to high capital intensity and relatively low demand of individual HRSs. However, there could be refuelling locations in industrial or port areas (e.g. hubs) that are suitable for direct pipelines, due to proximity to the supply source and/or having pre-existing pipelines that can be repurposed, although additional onsite compression will be required due to lower delivery pressures.	Explore use of new or repurposed pipelines for distributing pure hydrogen from production facilities to high demand facilities and/or delivery hubs (from which road transport could complete the deliveries). Undertake further research and technology development for the extraction of hydrogen from natural gas network blends.	5.2.3
Policies, standards and regulation		
10. Government policy can be a leading driver of the adoption of alternative fuels for road transport.	Consider targeting GHG abatement in transport as a priority within broader decarbonisation policies. Options include, enaction of emission standards (e.g. carbon intensity) for road vehicles, or incentive measures such as tax exemptions.	3.2, 3.3, 3.4
11. Australia currently lacks nationwide standards, regulations and planning processes for transport of hydrogen, HRS equipment and configuration, contributing to uncertainty, cost and investment uncertainty.	Align requirements of road regulators, work safety agencies, environment protection agencies and energy departments. Introduce a comprehensive set of standards/certifications for harmonised application across states and territories and a simplified, nationally consistent approach for certifying equipment manufactured overseas for use in Australia.	3.3
12. Regardless of the scale, onsite versus offsite production, and preferred location, developers and investors are seeking clarity of planning processes.	Develop clear, predictable and well-documented planning and environmental processes for siting of HRSs. Develop clear standard approach to assessing and mitigating risk – consider standard planning templates and distances per AS1940 and NFPA2, in particular for LH_2. Consider adopting international standards for equipment to simplify HRS development.	3.3, 6.1, 6.2, 6.3
Costs		
13. Compression, and associated cooling, is expensive in terms of both capital and operating costs.	Continue research into technology improvement and associated cost reductions. Focus on achieving sufficient scale to reduce unit costs.	5.3

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