Hydrogen for Transport

Prospective Australian Use Cases

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Executive summary

The Hydrogen for Transport opportunity

The Australian transport sector is under increasing pressure to reduce carbon emissions, whilst also managing a fuel supply chain that relies heavily on foreign import partners.

Transport in Australia equates to a significant proportion (approximately 18%) of the country's total greenhouse gas emissions. Due to ongoing population growth, these emissions have been steadily rising with the increase of cars on our roads and freight trucks in transit. Coupled with this, the transport fuel supply chain is highly reliant on overseas partners – Australia currently imports 90% of its liquid fuel. These two challenges present an interesting dichotomy for the industry, incentivising research and development into new technologies that can address one, or both, of these issues.

Hydrogen is one technology that has the potential to provide a reduction in greenhouse gas emissions as well as a more reliable, domestic fuel supply. Hydrogen fuel cell electric vehicles (FCEVs) are an emerging zero-emission alternative for the transport sector, which offer a variety of benefits.

The benefits of Hydrogen for Transport

There are three primary reasons why Hydrogen should be investigated as an alternative fuel source:

Fuel Security: Hydrogen is a fuel source that can be produced through chemical processes (e.g., electrolysis). This presents the opportunity to create a fuel supply chain wholly within Australia. The ability to reduce reliance on overseas supplies of liquid fuels, and hence increase local fuel security.

Air Quality and Emissions: Fuel cell technology produces no direct emissions, and this has the prospect to reduce air pollution, which is currently contributed to by petroleum and diesel-powered transport. Furthermore, hydrogen that is derived from renewable energy sources (so-called 'green hydrogen'), presents the opportunity to introduce a carbon-neutral fuel source into the transport energy mix.

Use and range: Hydrogen transport technology offers a similar user experience to incumbent technology, including the driving experience, driving range, and refuelling time. These characteristics make hydrogen technology attractive as a substitute to incumbent technology in a broad set of applications.

The purpose of this report is to provide independent advice on prospective use cases and models for the uptake of hydrogen in Australia's transport sector.

Understanding risks and overcoming barriers

Hydrogen for Transport is a relatively nascent opportunity, particularly in Australia. As with any emerging technology, this presents a number of risks and barriers that need to be navigated in order to unlock the benefits the technology can provide. The key challenges that need to be overcome are described below.

Fuel and refuelling infrastructure: the ability to refuel hydrogen vehicles will be one of the important pillars underpinning the success of any pilot, trial, or commercial roll-out. The end-to-end supply chain is complex and requires consideration for a number of factors, including: location of refuelling site; location of fuel supply; type of fuel (e.g., "green hydrogen"); and security of fuel source. The location of refuelling sites, and their ability to be accessible, will be of particular importance for the initial pilots and trials within Australia.

Vehicle supply: Globally, there are only a few models of hydrogen fuel cell vehicles that are in production and available for purchase. This includes some seven models of passenger vehicles, and slightly more variants of buses and trucks. The availability of fuel cell vehicles in Australia is further restricted, by the availability of Right Hand Drive (RHD) variants. Most manufacturers are focusing their initial efforts on developing a Left Hand Drive (LHD) variant, simply due to the relative size of the market (including the USA, Canada and most of Europe). This has meant that while markets such as America have already sold several thousand FCEVs to consumers, the Australian market will not have hydrogen vehicles available for out-right purchase until 2020.

Cost competitiveness: FCEV technology is generally more expensive to purchase than both incumbent technology (e.g., petrol or diesel combustion engines) and alternatives such as Battery Electric Vehicles (BEVs). This is largely driven by the high cost of production, which is ultimately due to the limited number of suppliers currently manufacturing FCEVs. As more manufacturers enter the market, these costs are expected to reduce, as demonstrated by BEVs.

FCEVs are currently one of the most expensive technologies when compared to diesel and other alternatives. In the longer term, estimates suggest that the technology will become comparable or even cheaper than these alternatives from a whole of life cost perspective, if infrastructure is highly utilised. This is most true for long-haul applications, where hydrogen offers lower fuel cell costs than battery costs in BEVs, and lower operation and maintenance costs than diesel trucks.

A critical step in the implementation of this technology will be the trials, demonstrations and pilots that can bring the Hydrogen for Transport vision to life.

The methodology used for this study

This study explores the Hydrogen for Transport opportunity, and the likely success of pilots and trials, through a four-step approach, as shown in Figure 1.

The following pages walk through these steps and summarise the findings from each stage of the methodology.

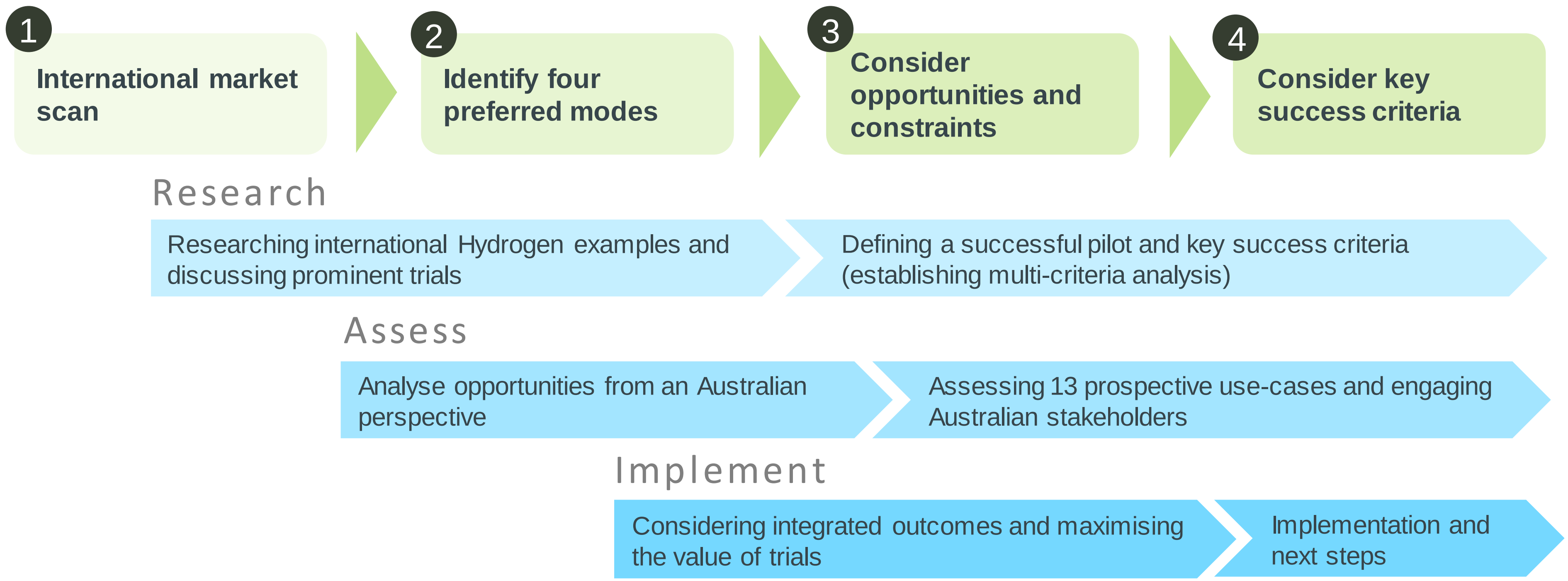


Figure 1: Summary of assessment approach

Step 1 - Learning from best practice

International markets, particularly in the USA and Europe, are further progressed in their adoption of hydrogen technology. This study presents international research and opportunities to translate these learnings into Australian demonstrations, pilots, or trials.

While some of these technologies have reached full commercialisation, such as hydrogen fuel cell cars, others are still in relative infancy. These projects on the global stage have been used to evaluate the maturity and prospect of technologies across 10 transport modes, that span the three sectors of Private, Public, and Commercial & Industrial transport.

Step 2 - Assessing opportunities for Australia

Based on the likelihood of short-term (2 - 5 year) success in the Australian market, using international examples to assess the maturity of each case, four transport modes have been selected for further analysis. The modes found to present the best opportunities for further development were fleet vehicles (cars), passenger buses, material handling equipment and goods vehicles.

Through this study, 13 hypothetical projects of varying sizes, across these four transport modes, have been assessed to understand the best prospects for the industry and Australia. Different project sizes have been chosen in order to understand and illustrate the implications of project scale for overcoming barriers and unlocking value across different types of pilots, demonstrations and trials.

Key success criteria have been developed to support the assessment of each of the projects. The criteria were developed with consideration for:

- The likely users of each hypothetical trial
- The operational characteristics (such as refuelling behaviour)
- Preferred locations and geographical catchments for undertaking the pilot
- Preferred partners to procure, invest and operate the pilot
- The components required to undertake the pilot (primarily relating to the number of vehicles required and the associated refuelling infrastructure)
- Indicative time to implement the trial
- Indicative capital costs to undertake the project

Step 3a - What defines a successful pilot?

A pilot or trial of an emerging technology can have a number of factors that determine whether it is a success within the market.

Technology pilots are undertaken for a number of reasons. For example, a new technology may be piloted to prove the operational performance and test the user experience. Alternatively, the pilot may aim to create end user awareness and encourage broad adoption of a new technology.

This study acknowledges that there are often multiple outcomes that a technology demonstration is trying to achieve and highlights some key learnings from around the globe that the Australian industry can leverage as it scales up the roll out of hydrogen pilots and trials.

The following criteria were used as the basis for assessment of the proposed pilots:

- The ability for the project to advance the strategic interests of Australia's hydrogen economy
- The ability of the project to grow the use case beyond the life of the trial
- The competitiveness of the hydrogen use case compared to both the incumbent technology and alternative technologies
- The ability to procure and implement the relevant trial technology
- The ability for the project to influence the perception and behaviour of the use case audience

Step 3b - Learning what Australia thinks

Informing the recommendations has been an extensive market sounding exercise with a variety of stakeholders. This has included fuel retailers, Original Equipment Manufacturers (OEMs), mining companies, industry associations and technology experts. Stakeholders are, in general, excited and receptive to the Hydrogen for Transport opportunity. Based on previous participation in pilots and trials, stakeholders suggested a number of important implementation aspects to consider:

- Understanding and communicating the key success criteria
- Effectively partnering with industry, creating commercial interest and engaging with the end user
- Influencing procurement and operational outcomes

The general consensus among stakeholders is that the development of hub-based infrastructure will be the easiest pathway to getting momentum with the technology. Furthermore, introducing hydrogen transport options, particularly in commercial situations, needs to be cognisant of the end user's 'core business' and the risks that need to be mitigated.

It is seen as important to have a publicly visible rationale that highlights the reasons the trial was chosen over a business as-usual operation or alternative technology. In particular, trials which can effectively coordinate multiple stakeholders, and communicate their reasons for joining the project, have been reported to have a high chance of success.

At this stage of maturity, the transport market still needs to be won over with the financial and operational benefits of hydrogen technology. Stakeholders would like to see hydrogen 'play to its strengths' in terms of industrial and commercial applications.

Finally, stakeholders want to see trials, demonstrations and pilots replicate real life performance. The transport market is focused on understanding considerations such as refuelling times, training requirements, maintenance costs, and OEM availability, which can be proven and explored through initial trials in real operational situations.

Step 4 – What we recommend

Based on international research, stakeholder dialogues and our multi-criteria assessment, there are four key recommendations:

Trials of effective scale: In general, trials costing less than A$5 million do not have a large enough addressable market, or strategic impact to be considered effective. Investment within the A$20-A$100 million range allows for a substantial enough size of fleet to have sufficient impact and learnings. For example, a bus investment is not considered effective until it can support an end-to-end route.

Since the technology is relatively nascent, commercial-operating entities are keen to understand the operational performance of a hydrogen fleet, rather than an individual vehicle, and whole of life costings (regardless of whether government assistance is provided for capital costs). Furthermore, trials will need to be publicly visible and well-integrated into a 'business as usual' setting to be effective.

Focus on back-to-base opportunities: From a performance perspective, the highest scoring opportunities offer high utilisation of refuelling infrastructure. This includes government fleets, bus corridors and logistics hubs.

Integrate the approach: A vertically-integrated industry trial is preferable to enable the capital investment for refuelling infrastructure to be distributed across multiple modes**.** This could occur within activities such as mining, logistics, urban transport or intra-city freight. From an industry perspective, however, the procurement of hydrogen FCEVs will need to be incentivised by government policy.

This study identifies four opportunities that enable integrated systems and cross-sector development:

- A dedicated hydrogen transport corridor for passengers and freight vehicles
- Transitioning bulk material handling in mining and heavy industry to hydrogen
- Transforming personal mobility around local hydrogen hubs established in communities
- An end-to-end hydrogen-powered supply chain that integrates hydrogen production, transport and logistics

Partner for success: A commercial model that is underpinned by a partnering arrangement (e.g., with a manufacturer, end user, and refuelling infrastructure provider), with appropriate risk sharing between the entities, will encourage the best outcomes for initial trials.

A manufacturing partner is key for initial trials due to the limited availability of hydrogen vehicles among traditional OEMs. For this reason, we recommend that trials consider as many avenues as possible regarding the procurement of hydrogen technology. Either 'non-traditional' OEMs or opportunities for in-country manufacturing should be considered for initial non-passenger trial opportunities.

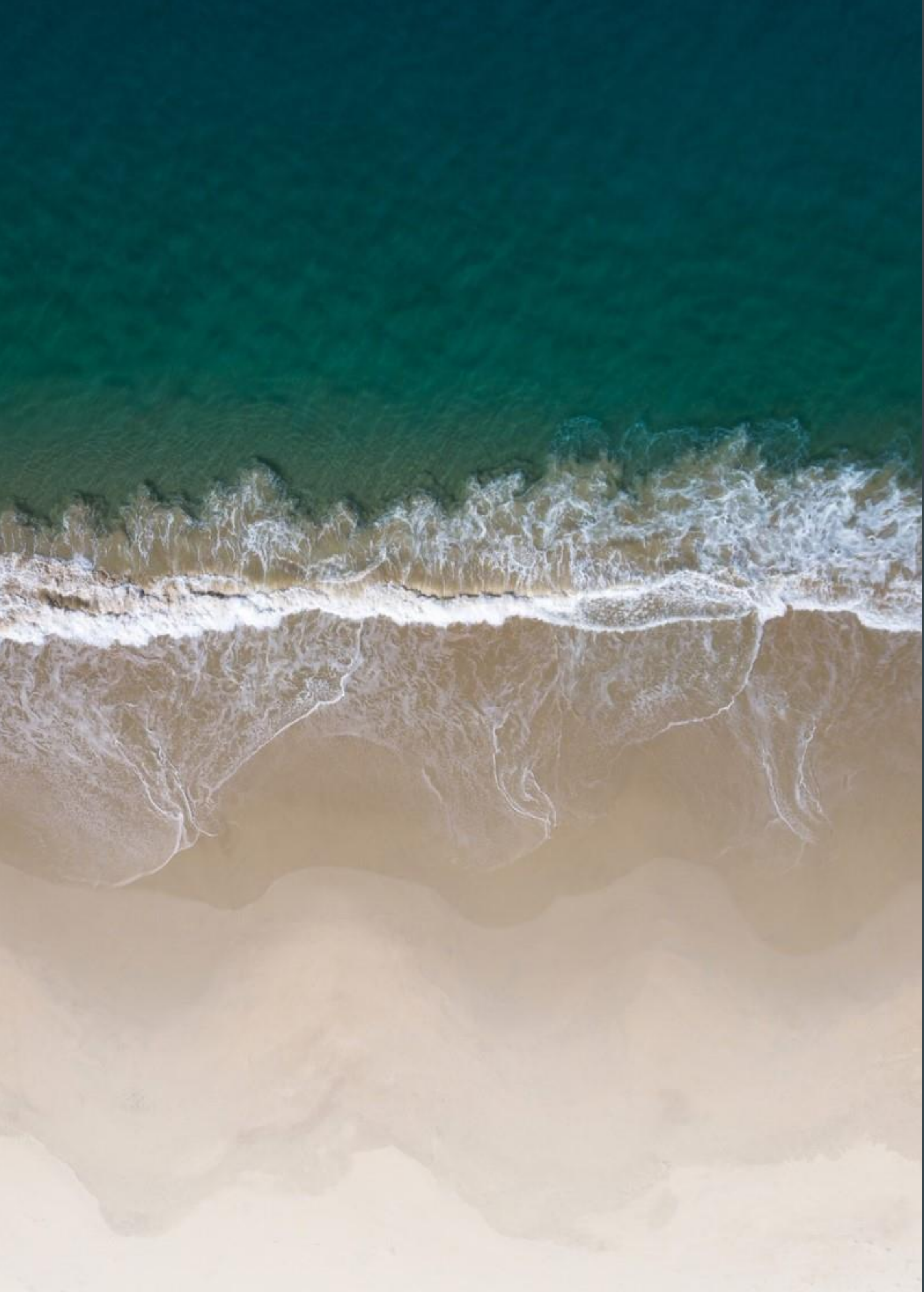
Next steps

Our analysis shows that buses, trucks and material handling are the most suitable transport modes for an initial pilot or trial.

The proposed next steps to support the implementation of a hydrogen transport trial should include:

1. Detailed cost-benefit analysis to validate the findings from this study, and the relative value of each pilot or trial
2. Integrate the pilots with a roadmap for implementation that supports the whole of economy view (including domestic use and export) of a hydrogen future, to inform investment priorities
3. Explore methods for procurement, including innovative commercial arrangements to incentivise private investment and maximise collaboration

With a fully developed hydrogen economy roadmap, key stakeholders (including government entities, end users, manufacturers, and investors) will have a clearer understanding of the end-to-end value proposition, enabling decision-makers to identify the projects which will facilitate strategic growth for a hydrogen economy in Australia.



CHAPTER 1

BACKGROUND AND INTRODUCTION

The opportunity to rethink transport in Australia:

The transport sector is a significant source (approximately 18%) of greenhouse gas emissions in Australia. These emissions have been steadily rising as population growth increases the number of cars on our roads and freight trucks in transit. The transport fuel supply chain is also highly reliant on overseas partners – Australia imports 90% of its liquid fuel.

Hydrogen in Transport

Australia's transport challenges can be addressed, in part, by the adoption of new technologies. Hydrogen is one such technology which promises to offer a low-emission, resilient supply chain transport solution.

A critical pathway for the implementation of this technology will be the trials, demonstrations and pilots which can bring the Hydrogen for Transport vision to life.

1. Background and Introduction

Purpose

Several Australian and global institutes and agencies, including CSIRO, the International Energy Agency and the World Energy Council, have identified Australia's potential to be one of the world's largest hydrogen producers. To realise this potential, the COAG Energy Council agreed in December 2018 to establish a dedicated Working Group, chaired by the Chief Scientist, to support the development of a clean, innovative and competitive hydrogen industry that establishes Australia as a major global player by 2030.

The Working Group has six work streams: hydrogen exports; Hydrogen for Transport; hydrogen in the gas network; hydrogen for industrial users; hydrogen to support electricity systems; and cross-cutting issues.

Following some initial analysis, and the development of a Hydrogen for Transport Issues Paper [1], the Working Group has engaged Aurecon to provide independent advice on prospective Australian use cases and models for the uptake of hydrogen in Australia's transport sector, and the resulting needs and priorities for refuelling infrastructure and transport demonstrations, pilots and trials.

Introduction to Hydrogen for Transport technology

Hydrogen fuel cell electric vehicles (FCEVs) are seen as an emerging zero-emission alternative for the transport sector with a variety of sustainability benefits. Coupled with this, FCEVs offer performance characteristics that align more closely to the end user experiences (e.g., range and refuelling times) of traditional combustion engine technology than existing Battery Electric Vehicles (BEVs).

The transport industry consumes around 20% of all petroleum and coal products in Australia, with a value of around A$9 billion per annum [2]. This presents as a sizeable opportunity for hydrogen, if the transport sector successfully converts to hydrogen as a major fuel source. There are, however, a variety of challenges that the Hydrogen for Transport industry must overcome to achieve significant maturity.

This study investigates options for Australian pilots and trials, of differing scales, with a feasible timeframe of 2 – 5 years. The transport sector includes road, rail, aviation, industrial and maritime sectors for both passenger transport and freight.

An Australian hydrogen economy

As part of the study, consideration has been made for how each project might be scaled beyond the initial pilot or trial timeline, and how the project may support broader hydrogen economy opportunities for growth and development. The COAG Energy Council is seeking to understand how Hydrogen for Transport can support the overall vision to build a clean, innovative and competitive Australian hydrogen industry that is a major global player by 2030.

To that end, this study acknowledges that transport is but one of a number of specific topics that need to be considered when referring to the hydrogen economy in its entirety. Other facets such as producing hydrogen at scale, attracting hydrogen investment, community acceptance and safety, and industrial applications of hydrogen, are all pertinent to the broader outcomes.

Many of these considerations are interrelated, particularly as the scale of the pilot or demonstration reaches sufficient scale that it relies more heavily on the broader hydrogen system. For example, larger projects will require large-scale production and supply of hydrogen or need to be coupled closely with industrial applications of hydrogen.

This study acknowledges this through the investigation of differing scales of pilot or trial, and by including aspects relating to “strategic growth” as part of the assessment criteria.

Australian transport market

The size of the opportunity for Hydrogen for Transport relates to the size of the existing transport market and the size and value of existing vehicle fleets. As Figure 2 illustrates, when considering all modes, Australia has an approximately A$90 billion transport industry, including vehicle sales and revenue from transport services [3]. This presents significant scope for technological application.

Value: Largest mode types of the transport sector

Passenger vehicles are the dominant component of Australia's transport industry, particularly from a wholesale revenue perspective where more than a million vehicles are sold in the country every year. The country relies on sports utility vehicles (SUVs) and utility vehicles more than any other vehicle format.

Machinery is also a significant market segment from a wholesale perspective. Applications of this equipment are varied but relate to Australia's primary industries such as mining and agriculture, and downstream activities such as logistics and construction.

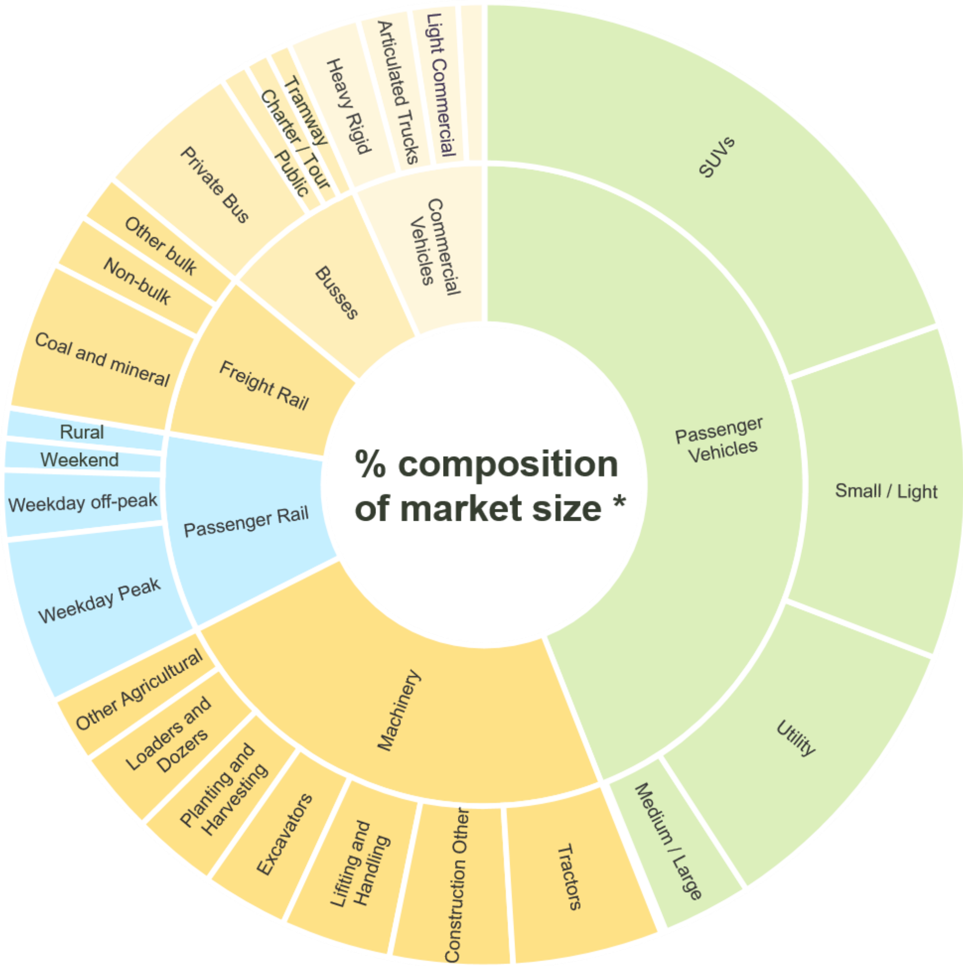


Figure 2: Market opportunity based on wholesale revenue

Emissions: Most carbon-intensive modes of transport sector

When considering the market in terms of emissions, transport accounted for around 23% of man-made greenhouse gas emissions globally in 2010 and has continued to increase since then, according to a report to the Intergovernmental Panel on Climate Change [4].

Australia's transport emissions are in line with the global proportion, projected to be responsible for around 20% of all Australian emissions in 2020 [5]. Figure 3 illustrates that, in terms of emissions, road-based transport modes make up over 75% of Australian transport emissions. Private passenger vehicles are the single largest mode in terms of their emissions contribution. Commercial vehicles are also significant greenhouse gas producers relative to the size of the Australian fleet.

This composition highlights the opportunities that exist within the private, freight and commercial sectors to apply hydrogen technology and mitigate greenhouse gas emissions.

While hydrogen as a fuel has a carbon intensity dependent on its manufacturing process, it is possible to produce low-emission hydrogen through electrolysis from renewable electricity. Currently, only 2% of global hydrogen production is produced by electrolysis. The other 98% of hydrogen is produced from fossil fuels, through methods such as steam methane reforming and coal gasification [6].

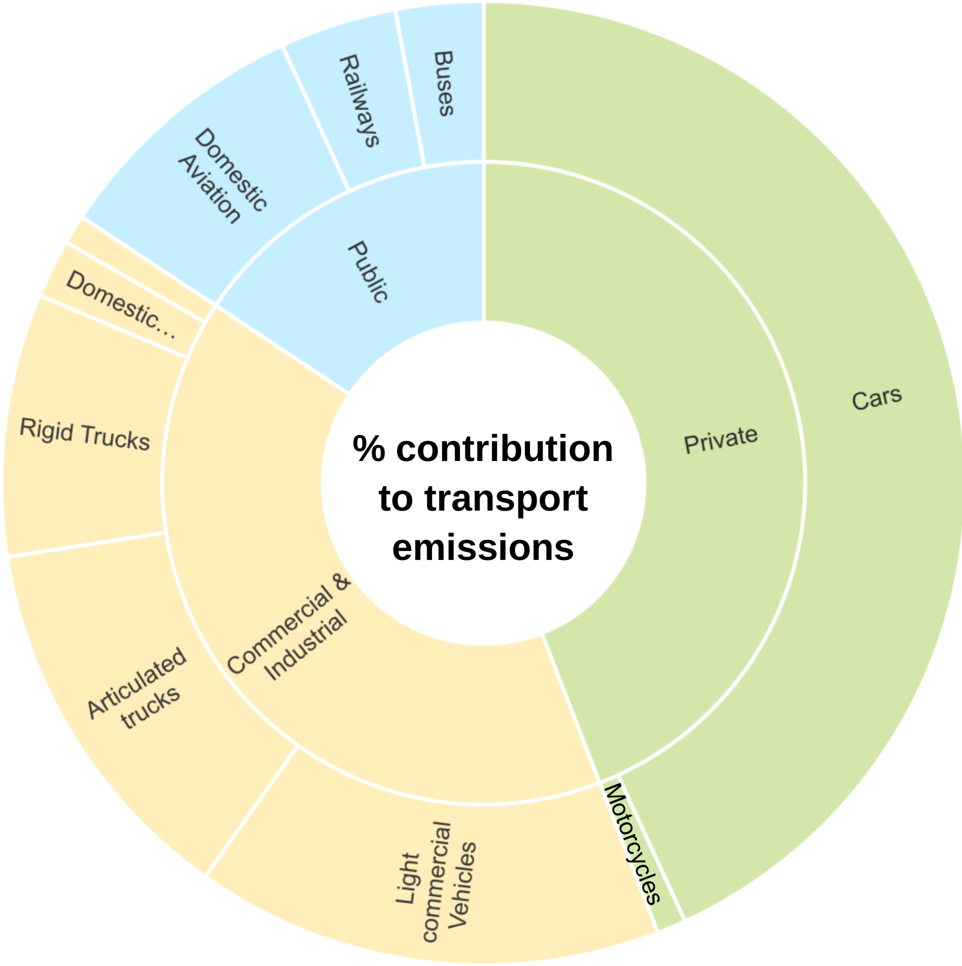


Figure 3: Emissions of transport by mode (total 102 Mt CO_2 equivalent)

Market sounding

As part of the process of developing this report, Aurecon engaged with a range of stakeholders who are part of, or have links to, the transport industry, to gather their insights and perspectives on hydrogen. The stakeholder group encompassed Original Equipment Manufacturers (OEMs), fuel retailers, hydrogen distributors and commercial end users. All stakeholders have been anonymised within the body of this report, and it should be noted that the conclusions and recommendations contained within this document do not necessarily reflect the views of the organisations that were consulted as part of the market sounding.

Benefits of the opportunity

Using hydrogen to fuel transport is likely to provide a number of benefits to Australian industries and transport users. As presented in the Working Group's Hydrogen for Transport Issues Paper [1], there are considered to be three primary reasons why Hydrogen should be investigated as an alternative fuel source:

1. **Fuel Security:** Hydrogen is a fuel source that can be produced through chemical processes (e.g., electrolysis). This presents the opportunity to create a fuel supply chain wholly within Australia. The ability to reduce reliance on overseas supplies of liquid fuels, and hence increase local fuel security.

2. **Air Quality and Emissions:** Fuel cell technology produces no direct emissions, and this has the prospect to reduce air pollution, which is currently contributed to by petroleum and diesel-powered transport. Furthermore, hydrogen that is derived from renewable energy sources (so-called 'green hydrogen'), presents the opportunity to introduce a carbon-neutral fuel source into the transport energy mix.

3. **Use and range:** Hydrogen transport technology offers a similar user experience to incumbent technology, including the driving experience, driving range, and refuelling time. These characteristics make hydrogen technology attractive as a substitute to incumbent technology in a broad set of applications.

Barriers and Risks

Hydrogen for Transport is a relatively nascent opportunity, particularly in Australia. As with any emerging technology, this presents a number of barriers and risks that need to be navigated in order to unlock the benefits the technology can provide. The Australian market is unique and has market characteristics which may assist or hinder the implementation of particular project types. Table 1 discusses some of the barriers and risks that will need to be managed for the technology to become more broadly implemented in Australia.

Subsequent sections within this chapter provide in-depth analysis of three fundamental hurdles that will need to be resolved for hydrogen to achieve significant maturity within the transport industry.

Table 1: Barriers and risks to Hydrogen for Transport

Barriers
Supply (vehicles + infrastructure)
The supply of vehicles and refuelling infrastructure is currently limited. Only a small number of manufacturers have committed to developing fuel cell technology for the Australian market in the short to medium term. Furthermore, Right Hand Drive (RHD) vehicles are less common than Left Hand Drive (LHD) vehicles – manufacturers are preferring to test their LHD concept before producing RHD vehicles. This is resulting in a lack of available vehicles to trial in Australia.
Relative Performance
A number of emerging technologies are currently being investigated to replace traditional combustion engines. Hydrogen solutions will need to compete with options such as BEVs, which are more progressed in the Australian market. The transport technology needs to offer superior performance than alternatives in at least one dimension such as power, range, operational behaviour and usability.
Risks
Market Preferences
Any new transport technology needs to win approval from end users who are comfortable with incumbent technologies. Australians are highly reliant on road transport (both for private and commercial applications). It can be unpredictable as to whether a technology will win hearts and minds of consumers (this is applicable to both individuals and enterprises).
Regulation and Policy
Technological development does not occur in isolation – the market structure, policy environment (e.g., incentives and integrated outcomes) will help or hinder opportunity development. Unclear or changing policy positions will affect market adoption.
Commercial Factors
Investing in an emerging technology needs to have a clear pathway ‘beyond the life of the trial’ – businesses and individuals need to feel confident they’re supporting the development of a mainstream transport alternative. While many businesses value their social licence – capital expenditure, operational costs and asset performance will be more pertinent long-term considerations.

How the key barriers affect this assessment

Fuel supply and refuelling infrastructure

There are four developed approaches to hydrogen fuelling (Figure 4). Industry consultation suggests that either decentralised electrolysis (the process of using electricity to split water to produce hydrogen), or hydrogen gas offtake from a centralised facility (producing hydrogen for other applications by one of a variety of methods, as discussed in the Hydrogen at Scale issues paper [7]) will be the most suitable refuelling options for Australia during the pilot and demonstrations phase of the Hydrogen for Transport opportunity.

Hydrogen refuelling infrastructure within Australia is very nascent with only a few live examples of the technology. Furthermore, these examples are mainly within the private sector and not readily available for public use, e.g., the hydrogen refuelling station at the Toyota Altona Site.

In most instances, the assessment of potential hydrogen trials and pilots has included the costs required to procure and implement hydrogen refuelling technology. The assessment however, leaves the technology used as deliberately generic – it does not specify whether the refuelling is centralised, decentralised or the delivery method of the hydrogen fuel, where applicable.

Our research suggests that the refuelling technology choice is mostly agnostic to the use case and more dependent on the geographical and supply chain constraints of each specific project. Table 2 and Figure 4 illustrate some of the considerations which will influence the refuelling technology choice. For the most part, however, these considerations are downstream of this study and therefore not considered in great detail when determining the relative strengths and weaknesses of each hypothetical project.

Table 2: Key considerations for choice of hydrogen refuelling technology

Location	• A centralised hydrogen supply chain relies on the availability of road transport (tanker trucks) to transport gaseous hydrogen to refuelling stations • Decentralised electrolysis can be based anywhere, but will require substantial site footprint for production and compression
Energy supply	• Creating green hydrogen requires readily accessible renewable energy sources • Decentralised electrolysis may be favourable on sites which have excess renewable energy production (e.g., rooftop solar at a warehouse, or a solar farm adjacent to a mine site) • Centralised production of hydrogen from gas or coal has a readily available fuel supply and around 70-90% of the CO_2 emissions can be captured [8]
Hydrogen supply	• Hydrogen is currently produced and used in industrial applications • Opportunities to interact with this supply chain would be advantageous, but most industries do not use green hydrogen

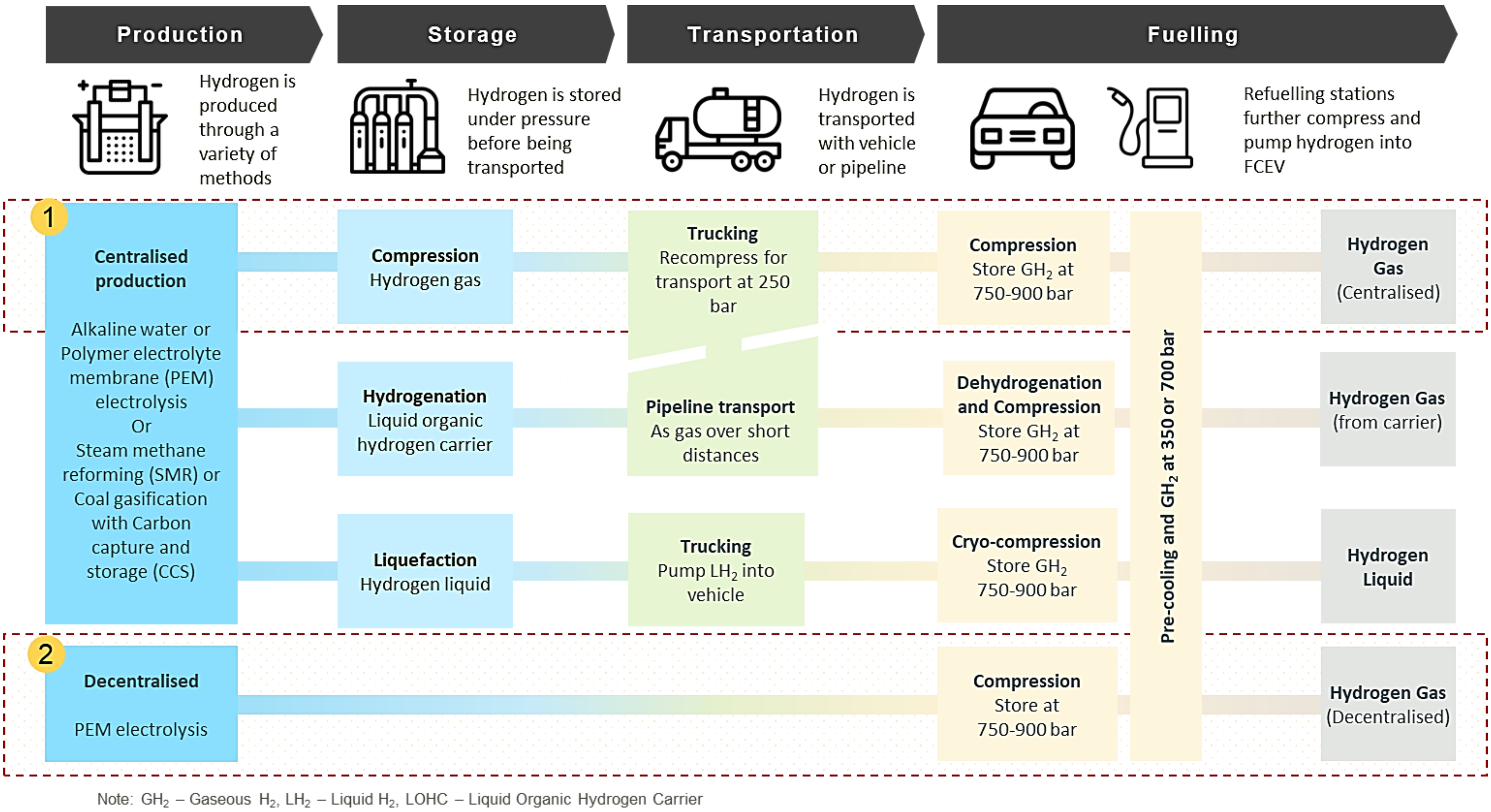


Figure 4: Hydrogen (as a transport fuel) production pathways

The supply of fuel cell electric vehicles

Globally, there are only a few models of hydrogen FCEVs that are in production and available for purchase. This includes some seven models of passenger vehicles, and slightly more variants of buses and trucks.

The availability of such models in Australia is further restricted, however, by the availability of RHD variants. Most OEMs focus their emerging technology on LHD markets, simply due to the relative size of the market (including the USA, Canada and most of Europe). This has meant that while markets such as America have already sold several thousand FCEVs to consumers, the Australian market will not have hydrogen vehicles available for out-right purchase until 2020, although there are some currently available for lease.

The issue is equally prevalent for buses, trucks and light commercial vehicles. The main bus and truck manufacturers (e.g., Ford, Daimler, Van Hool, Nikola and Hyundai) have also started their Fuel Cell (FC) vehicle supply in LHD markets, although the UK has been able to incentivise the supply of some RHD vehicles for its trials.

Australia has previously overcome such supply issues with specialist cars by converting LHD vehicles to RHD. However, this can cost up to 75% of the original vehicle cost [9] and may not be possible on larger vehicles, such as buses and trucks.

Another option to increase supply of hydrogen vehicles, particularly for modes with long-life assets, is to convert Internal Combustion Engine (ICE), battery electric or diesel electric vehicles. This usually requires replacing the existing engine, battery or generator with a hydrogen FC and, for ICE vehicles, an electric drivetrain. While this is possible, it is expensive and is likely to be most effective in large vehicles such as trucks or buses [10].

Some companies, however, are removing the FC from the equation all together, looking at the use of hydrogen carriers, such as ammonia, in existing ICEs. Any such technologies are yet to be made commercially available, but it is a route being considered particularly for heavy industry.

The cost competitiveness of FCEVs relative to incumbent technologies and alternatives

FCEV technology is generally more expensive to purchase than both incumbent technology (e.g., petrol or diesel combustion engines) and alternatives such as BEVs. This is largely driven by the high cost of production, which is ultimately due to the limited number of suppliers currently manufacturing FCEVs. As more manufacturers enter the market, these costs are expected to reduce, as demonstrated by BEVs.

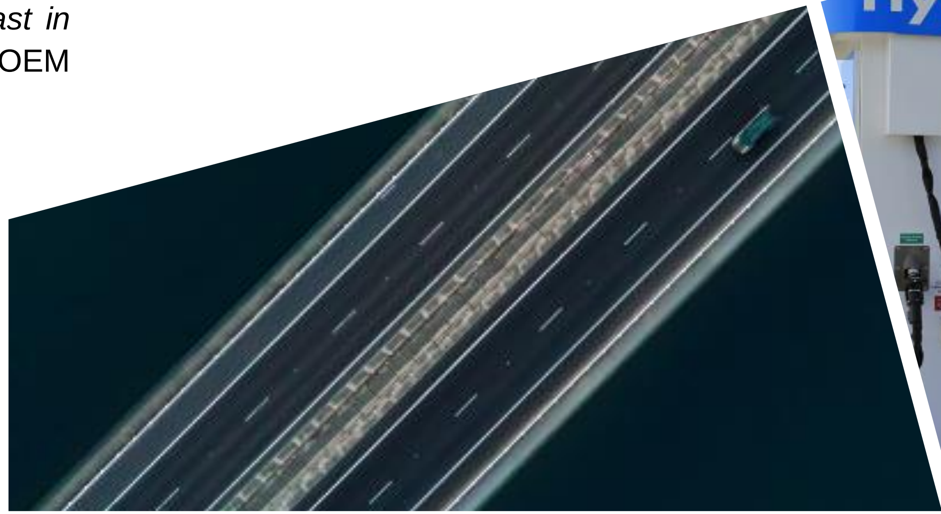
BEVs have spent more time in the market, and as such have achieved a more compelling value proposition. In part, this is due to rapidly falling battery prices. In 2015, an EV battery was approximately 60% of a medium-size BEV's retail price. Today, that number is closer to 30%.

The cost of FCEVs is less reliant on battery prices. This is because, although hydrogen cars need batteries to store electricity, they require significantly smaller battery capacity than BEVs. For example, a Tesla Model 3 has a minimum battery size of 50kWh, compared to 1.6kWh in a Toyota Mirai. The main cost of a FCEV is instead related to the fuel cell stack and storage tank, as illustrated in Figure 5. While there is an expectation of future cost competitiveness, looking towards 2030, the capital outlay for the purposes of trials and demonstrations is likely to remain expensive, when compared to alternative technologies today.

The International Energy Agency (IEA) report on The Future of Hydrogen considers the whole life costs of various transport technologies in a carbon-constrained future [11]. This includes FCEVs, BEVs and ICE vehicles using synthetic fuels. Synthetic fuels are considered to be low-emission alternatives to diesel to allow ICE vehicles to be used in a carbon-constrained future.

FCEVs are currently one of the most expensive technologies when compared to diesel and other alternatives. In the longer term, estimates (See Figure 5 and Figure 6) suggest that the technology will become comparable or even cheaper than these alternatives from a whole of life cost perspective, if infrastructure is highly utilised. This is most true for long-haul applications, where hydrogen offers lower fuel cell costs than battery costs in BEVs, and lower operation and maintenance costs than diesel trucks.

"…over the 25-year life of a diesel fuelled bus, the capital costs are insignificant compared to their operational costs. For hydrogen and electric vehicles, this [cost profile] is the other way around. Additionally, no one knows exactly how long a fuel cell will last in operation, since no one has run a FC bus for 25 years…" – Bus OEM



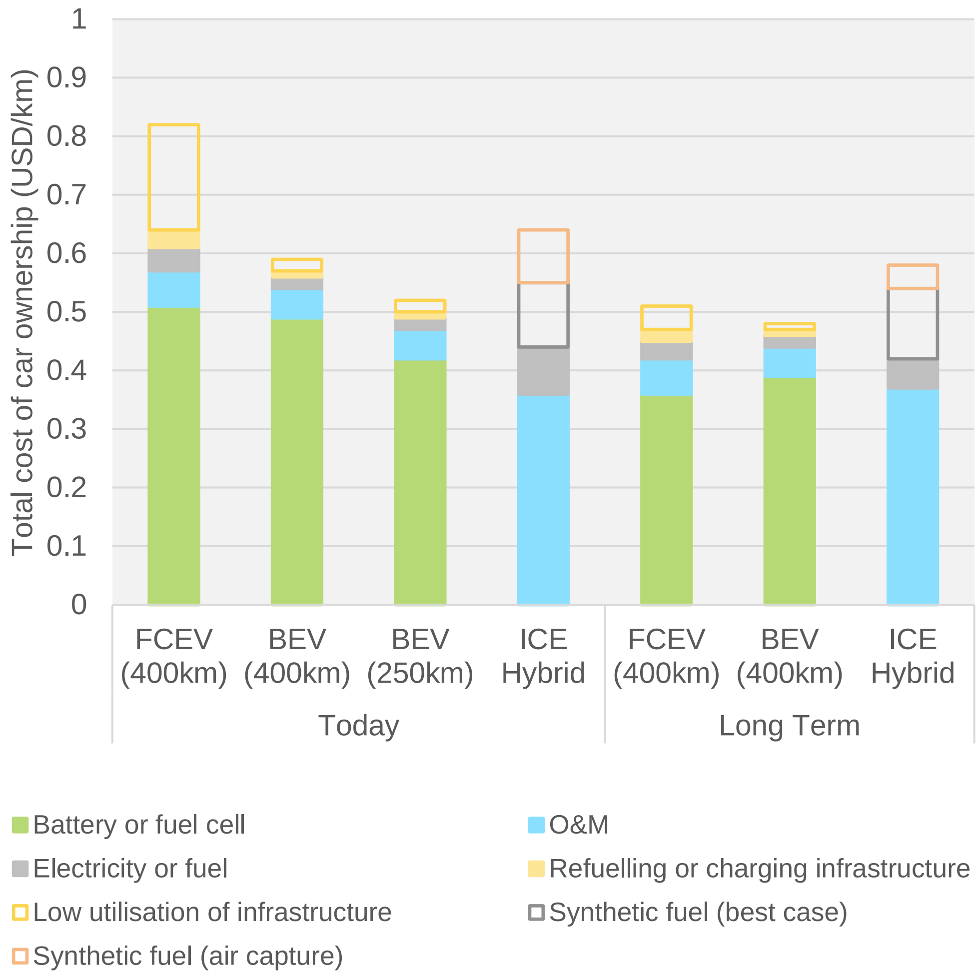


Figure 5: Total Cost of Ownership of different car types. Reproduced from The Future of Hydrogen, IEA [11]

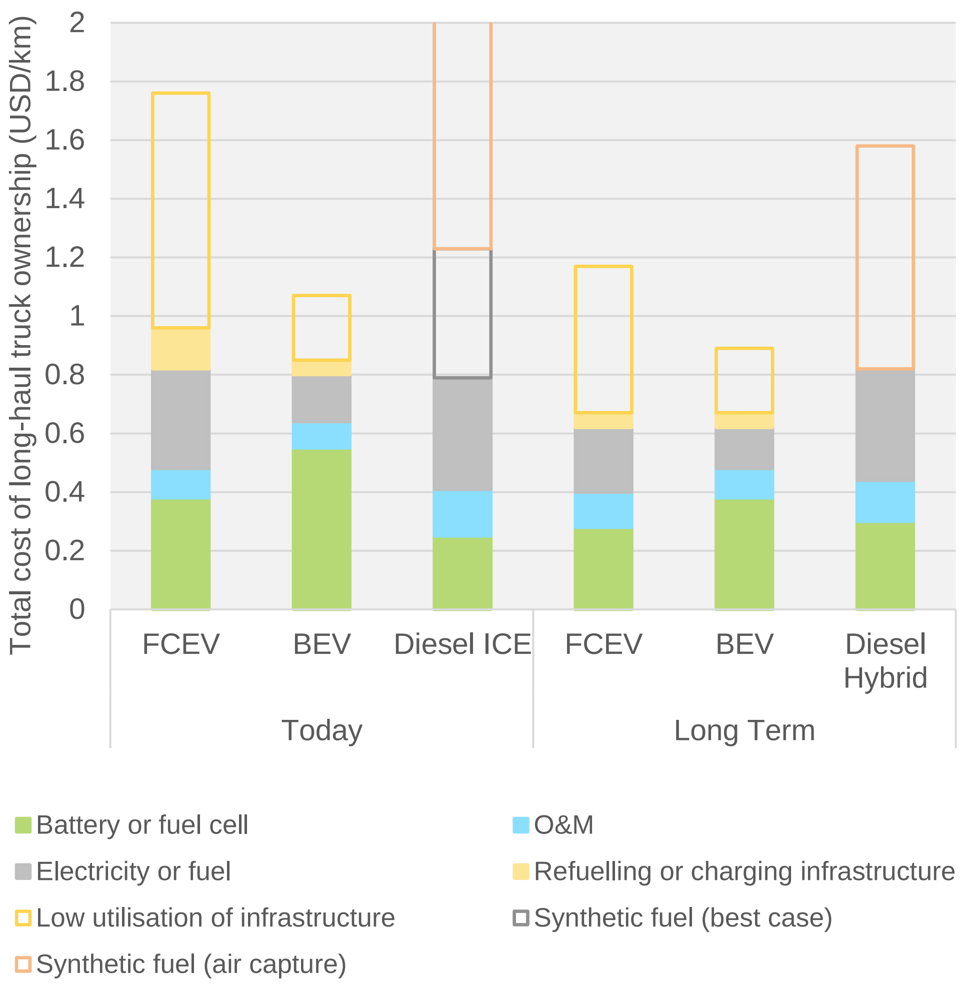


Figure 6: Total Cost of Ownership of different long-haul truck types. Reproduced from The Future of Hydrogen, IEA [11]

CHAPTER 2

ASSESSMENT METHODOLOGY

The aim of this study was to identify the most promising trials, pilots and demonstrations that could be undertaken in Australia to advance the hydrogen for transport opportunity and, more broadly, the hydrogen economy.

The methodology of this study focussed on leveraging international best practice and considered opportunities through the lens of success criteria that are particular to the Australian market.

During the study, Aurecon also engaged with a broad range of transport industry stakeholders to gather their insights and perspectives on hydrogen. The stakeholder group encompassed Original Equipment Manufacturers (OEMs), fuel retailers, hydrogen distributors and commercial end users.

2.Methodology

This chapter outlines the parameters, assumptions and approach that has been used to identify the most promising trials, pilots and demonstrations that could be undertaken in Australia.

The Hydrogen for Transport opportunity in Australia is relatively nascent. For this reason, the study has collated international trials and demonstration activity for best practice reference. This research has been married up with a multi-criteria assessment framework, and broad Australia-based stakeholder engagement in order to validate assumptions and undertake preliminary market sounding.

The market for hydrogen transport technology

The opportunity for implementing hydrogen as a transport technology spans across multiple modes. Each application has different characteristics, and these affect the opportunities for implementing trials, demonstrations and pilots. Figure 7 below outlines the four-step methodology for the study.

1. An international market scan based on desktop research of international opportunities relating to Hydrogen for Transport
2. Based on the likelihood of success in the Australian market, the study identified four transport modes for further analysis and development of pilots and trials
3. For each of the four transport modes, additional research was undertaken to develop scalable hypothetical project options for pilot or trial. This resulted in a total of 13 possible projects of differing scales across the four transport modes, with various opportunities and constraints associated with them.
4. Each of the 13 hypothetical projects was assessed against a set of key success criteria to identify which of the projects presents as a preferred pilot or trial for deployment in Australia.

Figure 7: Steps to assess opportunities for Australian implementation

1. International market scan

The first step to understanding the hydrogen market opportunities was an international market scan of current developments. Aurecon defined a number of key parameters relating to the market scan in order to ensure the investigation provides the most relevance to Australian implemented trials and demonstrations. Table 3 highlights the key parameters from the market scan.

There are a range of international market examples across a number of transport modes. For Australia, this presents multiple possible pathways to implement hydrogen technology into the transport ecosystem.

Table 3: Parameters of the international market scan

General project parameters	• Only trials within the last five years have been included in the market scan. • Future projects with a high degree of certainty are included but proposed trials with little substantiation are not. • The study generally focuses on transport applications with hydrogen as the direct fuel source (e.g., not hydrogen as an input to synthetic fuels, known as power-to-liquid applications).
Cost estimation and market sizing	• Average pilot costs and overall global spending on pilots are estimates only and do not include R&D investment. • In instances where pilot costs have not been published, Aurecon has estimated the investment based on average costs for that particular use case.
Relevance to Australia	• To align with the Working Group Issues Paper, this report focuses on transport sectors that are expected to include an Australia-ready hydrogen-fueled variant by 2030. Based on this rationale, project trials relating to commercial aviation and some shipping forms have generally been excluded from the study.

2. Identifying four preferred use cases

To enable sufficient focus in the study, based on international maturity and likely success in Australia, four use cases were selected for further analysis.

Rationalising the global market scan to four discrete transport modes was conducted through a number of steps, including consideration for:

- The global maturity of the particular application of hydrogen technology
- The supply of vehicles and infrastructure to Australia within the short to medium term
- Market factors relating to cost, procurement and implementation
- The Australian market's appetite to adopt the trial and scale the opportunity beyond the life of the trial

3. Developing use cases for each mode

The detailed investigation of prospective opportunities considers each of the four preferred use cases at a number of scales, namely:

- A small trial with a capital cost of less than A$5 million
- A medium trial with a capital cost between A$5 million and A$20 million
- An integrated pilot with a capital cost between A$20 million and A$100 million, which requires broader integrated effort to realise project benefits

A range of scales were selected in order to understand and illustrate the implications of project scale for overcoming barriers and unlocking value across different types of pilots, demonstrations and trials. The size of pilots also gives an indicative view of the capital outlay required for a given size of fleet and supporting (refuelling) infrastructure.

In total, 13 hypothetical projects of differing scales across the four transport modes were developed, with various opportunities and constraints associated with each.

4. Assessing each hypothetical project

Developing a detailed assessment of prospective use cases involved understanding the key benefits, scope of opportunity and likely constraints of all 13 opportunities.

Key success criteria were developed to support the assessment of each of the projects. The criteria were developed with consideration for:

- The likely users of each hypothetical trial
- The operational characteristics (such as refuelling behaviour)
- Preferred locations and geographical catchments for undertaking the pilot
- Preferred partners to procure, invest and operate the pilot (where relevant)
- The components required to undertake the pilot (primarily relating to the number of vehicles required and the associated refuelling infrastructure)
- Indicative time to implement the trial
- Indicative capital costs to undertake the project

The following section describes the criteria in more detail.

What defines a successful pilot?

A pilot or trial of an emerging technology can have a number of factors which determine whether it is a success within the market. Technology pilots are undertaken for a number of reasons. For example, a new technology may be piloted to prove the operational performance and test the user experience. Alternatively, the pilot may aim to create end user awareness and encourage broad adoption of a new technology.

This study acknowledges that there are often multiple outcomes that a technology demonstration is trying to achieve. Table 4 outlines five key themes that are considered central to the success of the Hydrogen for Transport opportunity in Australia. These range from strategic considerations relating to the broader interest of the hydrogen economy through to more practical considerations such as the performance of the new technology relative to incumbent technology.

Table 4: Key success criteria for Hydrogen for Transport

Strategic growth	The ability for the project to advance the strategic interests of Australia's hydrogen economy. This considers elements such as: • How well the opportunity can support the COAG Energy Council's vision to build a clean, innovative and competitive Australian hydrogen industry that is a major global player by 2030 • The value the opportunity contributes to the broader hydrogen value chain • How well the opportunity progresses the hydrogen agenda across commercial, regulatory, technological and social dimensions
Addressable market	The ability for the project to grow the use case beyond the life of the trial, including: • The likelihood of the use case being undertaken more broadly within the relevant transport sector in Australia • Ability to increase the volume of vehicles from a supply and infrastructure perspective
Relative performance	The competitiveness of the hydrogen use case compared to both the incumbent technology and alternative technologies. This will consider: • The cost competitiveness of the technology relative to alternatives • The availability and supply of the technology relative to alternatives • The technical and operational characteristics relative to alternatives
Procure and implement	The ability to procure and implement the relevant trial technology, where: • Australian specific operations will be considered in terms of procurement methods, standards and modifications • Appetite of industry partners and user groups to facilitate implementation • Capability (and perception) of proposed industry partners • Appetite of the local value chain to facilitate implementation
User adoption	The ability for the project to influence the perception and behaviour of the use case audience, including: • The direct target market of the proposed use case • The broader Australian public perception of the Hydrogen for Transport opportunity

Multi-criteria analysis

The above key success criteria were used to qualitatively score each of the 13 hypothetical projects, building in the priorities of the National Hydrogen Strategy Taskforce Strategy by assigning a weighting for each criterion. This analytical framework acknowledges that there are multiple (and often conflicting) criteria which need to be considered when evaluating the relative strengths of each hypothetical trial. This approach is further outlined in Figure 8, and Chapter 4 contains the complete multi-criteria scoring results.

Figure 8: Pairwise weighting and multi-criteria scoring

A pairwise ranking assessment (conducted by the taskforce) – this determines the relative priority of each success factor

Criteria	Weighting
Strategic growth	30%
Addressable market	10%
Relative performance	40%
Procure & implement	15%
User adoption	5%

Each use-case scored across multiple criteria - A qualitative rating, but each assessment is supported by an evidence base of research and stakeholder input

1	Poorly satisfies the criteria
2	Moderately satisfies some, but not all, aspects of the criteria
3	Moderately satisfies the criteria
4	Highly satisfies some, but not all, aspects of the criteria
5	Highly satisfies the criteria

Consideration of integrated outcomes

The primary focus of this study is the viability of individual pilots and trials. Beyond small scale trials, investment in the Hydrogen for Transport opportunity will inevitably lead to more holistic 'integrated' outcomes. For example, this may be expressed through vertical integration of the technology within a particular industry sector.

This study acknowledges that part of assessing discrete initiatives is to consider how they can contribute to more complex integrated solutions which have a higher degree of impact and a broader set of benefits. Figure 9 highlights some of these integrated outcomes which are considered in detail in Chapter 5.

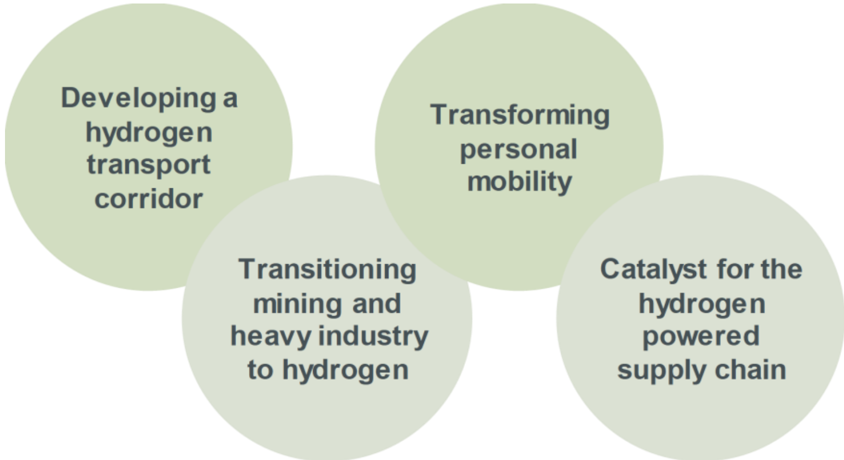


Figure 9: Examples of integrated Hydrogen for Transport outcomes

CHAPTER 3

INTERNATIONAL DEVELOPMENTS

Research from across the globe has been used to assess the maturity of available technology in ten defined modes of transport.

The opportunity to develop trials of each transport mode within Australia has been evaluated to draw out the four most prospective modes.

3.International developments

Hydrogen mobility technologies, in particular hydrogen fuel cells, have been implemented in a broad range of transport applications around the world. While some of these technologies have reached full commercialisation, such as FCEVs, others are still in relative infancy. These projects on the global stage have been used to evaluate the maturity and prospect of implementing similar projects in Australia. Applications of ten transport modes are considered across the sectors of private, public, and commercial transport.

There are several countries which have announced hydrogen roadmaps or strategies to accelerate the uptake of hydrogen as a fuel within their economy. This has corresponded with an increased rate of development of hydrogen technologies and supply chains, and enabled a fast pace of global learning.

While every effort has been made to capture and represent the true state of projects being undertaken around the world, the commercial nature of the sector limits the publicly available information.

The success of a trial depends on many factors, including the context in which it is to be implemented. This study defined a number of key parameters relating to the market scan, in order to assess the prospect for a trial in Australia:

- Global maturity of technology
- Supply of vehicles and infrastructure to Australia
- Market factors relating to cost and implementation
- The Australian market's appetite to adopt the technology

One factor in this study is the undertaking to date of relevant trials within Australia. This indicates a high level of readiness in terms of procurement and implementation. Private vehicle refuelling, fleet vehicles, buses, material handling, and goods vehicles, are all the subject of trials, either undertaken or planned in Australia.

Table 5: Sectors and modes considered by international desktop research

SECTOR	MODES	MARKET CHARACTERISTICS	EXISTING FUEL SOURCES
Private	Private vehicles Fleet vehicles	• Sophisticated supply chain, primarily controlled by private, overseas interests • Australia averages 910,000 passenger (non-commercial) vehicle sales per annum and has 12.4 million registered motor vehicles	Petroleum based, low BEV penetration but OEMs' range growing
Public	Passenger Rail Bus Ferry Aviation	• Public transport has modest market share ranging from 6% (Hobart) to 26% (Sydney) of commutes • Rail is the most popular mode in Sydney, Melbourne and Brisbane • Smaller cities (Adelaide, Canberra, Hobart) rely on buses to facilitate public transport • Inter-state travel is dominated by short-haul aviation	Electric power, diesel and petroleum BEVs scaling quickly and a number of trial bus opportunities
Commercial & Industrial	Material Handling Freight Rail Goods Vehicles Shipping	• There is a variety of machinery vehicle types including haul trucks, loaders, bulldozers, excavators • A small number of major players operate the majority of the country's freight rail network • Australia averages approximately 240,000 commercial vehicle sales per annum and has approximately 3.7m light & heavy vehicles in use – the majority are heavy rigid and articulated trucks	Diesel and petroleum based Lower presence and scale of BEVs, niche BEV retrofit opportunities

Private Transport

In 2018, over 81 million cars were sold globally [12], representing a large market potential for alternative-fuel private transport vehicles. However, only ~1.5% of cars sold globally in 2018 were Electric Vehicles (EVs). This indicates that while there is market potential, alternative-fuel vehicles are still in early adoption and the key reason for this is regularly cited as the premium attached to such vehicles, as exemplified by a recent report on the running costs of private vehicles in Australia [13].

With the price of EV technology set to decrease, particularly in batteries, fuel cells and hydrogen production [14], successful uptake of alternative-fuel vehicles will become more reliant on factors other than cost, as cost will no longer be a differentiator.

Private Vehicles

Prominent Trial - California Fuel Cell Partnership, U.S.A

The California Fuel Cell Partnership (CaFCP) is an industry and government group of organisations which work to increase the uptake and progression of FCEVs.

Since its founding in 1999, CaFCP has installed 37 operational HRS, with a further 26 in development or undergoing works. In addition, it works on regulation, training and public awareness.

Member organisations of CaFCP that work in the refuelling sector include Air Liquide, Linde and nel. Other members include vehicle OEMs, government organisations and logistics companies.

The estimated spending on the 63 HRS is A$128-189 million, based on market cost ranges for an individual HRS in other countries.

There are seven models of commercially available FCEVs in various locations. Most large trials to date are centrally funded projects intent on demonstrating the technology, with a focus on the infrastructure required to operate an FCEV. As a result, there are over 330 Hydrogen Refuelling Stations (HRS) installed in over 20 countries. These HRS serve more than 11,000 FCEVs which are registered globally. HRS installation includes a mixture of on-site electrolysis and storage-only stations.

Major refuelling initiatives are underway in Europe (Hydrogen Mobility Europe), South Korea (HyNet) and the USA (California Fuel Cell Partnership), among other geographies. The estimated total global expenditure on HRS and FCEVs is over A$2 billion (excluding R&D

initiatives), and spending is expected to increase, with at least seven countries implementing FCEV targets in the 2020-2030 timeframe.

Based on the extent of vehicle roll out, it is clear that FCEVs and HRS are technically mature, with commercially available models in many major markets. Technical maturity is only one consideration for determining a good trial prospect however, and privately-owned FCEVs face the following challenges:

- Existing BEV market share in this sector
- Requirement for distributed HRS to service a private vehicle market

There are currently two models of FCEV available for lease in Australia, which sets a precedent for the procurement of such vehicles. However, FCEVs are around three times the cost of the average car in Australia and refuelling infrastructure is scarce. While uptake of FCEVs can be encouraged through incentives and provision of refuelling infrastructure, there is limited guarantee of the outcomes as the ability of the Government to influence the procurement route is limited.

Table 6: Private vehicles - mode opportunity

Private Vehicles	
Technology Maturity	Good
Ease of Procurement	Moderate
Operational Suitability	Limited
User Adoption	Limited
Overall Opportunity	**Moderate**

Passenger fleet vehicles

Prominent Trial – Hype, France

Hype is a hydrogen-only taxi fleet operating in Paris, France. When launched in 2015, it was the first hydrogen taxi fleet in the world, with just five FCEVs. Today, Hype has over 100 FCEVs in operation, with plans to reach 600 by the end of 2020.

In addition to the FCEVs, four Air Liquide HRS have also been installed in Paris in order to operate the fleet. With a refuelling time of 3-5 minutes, and a range of around 500km, the taxis have a similar operating pattern to existing ICE taxis.

Hype has a number of industry partners, including Air Liquide, Toyota and the European Union.

The estimated spending committed to date for the 600-car fleet is A$80-100 million, based on component costs in Europe.

Besides private vehicles, another option to demonstrate viability of fuel cell cars is the inclusion of FCEVs in fleets such as taxi services, car-sharing schemes and corporate fleets.

International project examples, at the larger scale, often include dedicated refuelling infrastructure. However, as the number of HRS increase, it is becoming easier for companies to procure FCEVs and operate them around existing local infrastructure. Several small-scale projects without dedicated refuelling infrastructure have been undertaken and are a good indication that the projects investing in the infrastructure alone are influencing the uptake of FCEVs in their area.

In addition to cars, fuel cell assisted bicycles are also commercially available in Europe. This approach of electrifying private transport has already been taken with BEV technologies and so a strong analogy for the possibilities and areas for exploration already exists.

Both FCEVs and FC assisted bicycles are commercially available as hydrogen fleet vehicles today. The technology for both types of vehicles is mature. However, only a single supplier of FC assisted bikes exists currently in Europe, whereas FCEVs are already commercially available for lease in Australia.

The benefit of fleet vehicles is that they can be implemented in situations where utilisation of the refuelling infrastructure can be maximised through the operational patterns of the vehicles.

The first fleet vehicle trials with FCEVs have received positive user feedback which is promising for future interaction with other users.

"People drive the car and appreciate it's just like driving any other car"
– Global FCEV manufacturer

Table 7: Fleet vehicles - mode opportunity

Fleet Vehicles	
Technology Maturity	Good
Ease of Procurement	Moderate
Operational Suitability	Good
User Adoption	Moderate
Overall Opportunity	**Good**

Public Transport

In 2015, over 50 trillion passenger-kilometres were travelled globally, of which around 25% were completed on urban public transport and inter-urban rail [15]. With potential to reduce urban congestion, improve local air quality and increase accessibility between regional areas and economic centres, public transport is a key sector in obtaining many strategic objectives.

Furthermore, public transport is visible to a large proportion of society and as such offers an excellent opportunity for building public awareness around the possibilities and benefits of hydrogen as a fuel.

A recent study by the University of Queensland showed that the Australian public have a limited knowledge of the properties of hydrogen as a fuel [16], but generally have a neutral view of its use. Through strategic implementation of hydrogen technologies in the public transport sector, awareness, understanding and positivity around hydrogen as a fuel can be increased.

Passenger Rail

Prominent Trial – Alstom, Germany

Alstom has developed the world's first FC train, the Coradia iLint. In 2018, two iLint trains started commercial operation in Lower Saxony, Germany, as the first stage of a 14-train contract with the local transport authority.

The trains currently run on a 100km section of track but have a range of around 1,000km on a single tank of hydrogen, which is a similar range to diesel trains. While the trains are currently more expensive than their diesel counterparts, at around A$15 million per train, Alstom claim they are cheaper to run.

Another local German transport authority has since placed an order for 27 iLint trains to run in the Taunus region, due to start operation in 2022.

The reported spending committed to date for the 27-train fleet and 25 years of maintenance and hydrogen supply is A$750-800 million.

Where FC driven trains have a competitive advantage is in areas where electrification of track is prohibitively expensive, but transport is being decarbonised as part of a strategic objective of the local operator. Since FC trains do not require electrified track, and have similar operational characteristics to diesel trains, they are a strong competitor.

With around 75% of passenger movements by rail already relying on electricity through electrified track [17], the potential for replacing fossil-fuel-driven locomotives is largely in regional areas with lower utilisation of the rail system.

Globally, limited FC trains are in service, currently only in Germany, but there are a handful of projects underway which are aiming to bring more FC trains into operation through trials, primarily in the UK, Germany and Japan. The technology may be proven to an operational level, but the supply of such locomotives is limited. However, the primary manufacturer of FC trains, Alstom, is a major supplier of rolling stock to Australia already, which suggests that there are likely to be limited integration issues.

FC trains do not offer a benefit of implementation on sections of track which are already electrified, as they would not use the existing power supply infrastructure. However, there are significant portions of track in Australia which are serviced by diesel-powered trains. In these cases, FC trains offer a similar range and operational ability, while reducing the associated emissions.

Table 8: Passenger rail - mode opportunity

Passenger Rail	
Technology Maturity	Good
Ease of Procurement	Limited
Operational Suitability	Moderate
User Adoption	Moderate
Overall Opportunity	**Moderate**

Passenger Bus

Prominent Trial – JIVE, Europe

The JIVE and JIVE 2 programmes in Europe are set to achieve 300 FC buses in 22 cities around Europe by the early 2020s. To date, around 140 of these buses are already in operation.

The buses are of a variety of models but have a typical range of ~300km on a single tank of hydrogen. The refuelling infrastructure for the buses around Europe is being provided as part of a separate project, MEHRLIN, which is rolling out HRS across Europe, in seven locations where the infrastructure for the buses does not already exist.

The total cost of the JIVE and JIVE 2 projects is ~A$350 million.

While most of the buses in operation globally are LHD, those used as part of the JIVE project in the UK are RHD, indicating that procurement of such vehicles is available.

There will be around 2.5 million buses on the road, globally, by 2025, with about 50% of these being purchased between 2018 and 2025 [18]. This indicates that there is market share available for alternative-fuel buses in the short term and probably through the long term as well as we see the downward pressure on transport emissions increasing.

FC buses have been adopted in many countries around the world over the last ~20 years, with varying levels of success. While operating the buses has not been prohibitive, it appears most often that the cost early adopters faced was not viable in the long term. However, as the technology developed, and interest in alternative fuels has increased, FC buses have become more attractive.

Major projects for implementing FC buses are underway in China, Europe and the USA with smaller trials operating in several countries. This includes a previous trial in Perth, Western Australia, which provides a precedent for procurement and implementation in Australia. Trials in other countries have shown limited issues with user adoption, with users even preferring the experience of FC buses in some cases.

"I particularly enjoy driving a fuel cell bus because of the smooth ride without the noises and vibrations you have in a diesel bus. You feel more relaxed after your shift and in addition you know that you have done something good for the environment." Bus driver at RVK, Cologne [19].

There are currently more than five models of FC bus commercially available in various locations. Buses typically operate along known routes, with a back-to-base approach. This enables them to highly utilise refuelling infrastructure.

There is, however, a procurement issue in Australia: the Australian Design Rules. Buses manufactured for overseas markets are often not compliant with Australian regulation. This can be overcome by using Australia-produced FC buses, of which at least one is in development.

In addition, bus provision in many states is typically run through state governments entering contracts with operators. These often run on a 5-year cycle, with differing start dates, meaning that there are usually contracts up for tender on a regular basis.

The contracting structure is complex, with some states such as Queensland having 18 different contracts just for the regional urban bus services. While this provides a lot of opportunities for FC buses to enter into operation, it will also require a lot of co-ordination to achieve wide uptake of FC buses.

Furthermore, the established procurement contracts with the operators do not typically take into account an allowance for new technologies and trialling new systems. It will be necessary for state governments, therefore, to alter their procurement strategy in order to promote the uptake of alternative technology buses.

Table 9: Passenger bus - mode opportunity

Passenger Bus	
Technology Maturity	Good
Ease of Procurement	Moderate
Operational Suitability	Good
User Adoption	Good
Overall Opportunity	**Good**

Ferry

Prominent Trial – Water-go-round, U.S.A

The Water-go-round is an 84-person capacity passenger ferry due to start operation in San Francisco by the end of 2019. It will be the largest capacity FC ferry to date and is expected to run for three months as a preliminary trial.

The range of the ferry allows the boat to operate its usual route across San Francisco Bay for two days without refuelling. When necessary, the boat will refuel from a hydrogen storage truck, much like its diesel counterparts.

The intent of the trial is to develop a ferry which can be expanded to commercial production. The reported cost per boat is ~A$9 million and the developer claims that the fuel and maintenance costs will be lower than existing diesel ferries.

Trials of hydrogen fuel cell ferries are few and far between around the globe, with only one or two currently in operation. There are approximately five highly developed trials due to start operating in the next 1-2 years, however, which will no doubt boost the knowledge sharing around this mode.

Hydrogen-based ferry technologies are considered to have a moderate level of global maturity due to their low level of operational trials and the absence of any commercially available product.

The potential impact of implementing hydrogen ferries on the wider strategic objectives of developing a hydrogen economy is deemed to be small, relative to other modes. As such, it is not thought to be a prudent investment for Australia to fund domestic development of hydrogen ferries at this stage.

Based on the success of other trials around the world, it is conceivable that procurement of suitable hydrogen ferries would be possible in the next 5-10 years.

The fixed route and existing fuelling schedule of ferries in Australia would lend itself well to the implementation of hydrogen ferries, should they become commercially available at a competitive cost.

Table 10: Ferry - mode opportunity

Ferry	
Technology Maturity	Moderate
Ease of Procurement	Limited
Operational Suitability	Moderate
User Adoption	Moderate
Overall Opportunity	**Moderate**

Prominent Trial – ZeroAvia, U.S.A

ZeroAvia have developed a working prototype of a 6-person FC aircraft, using their ZA600 drivetrain. The intention is to develop a 10 to 20-person capacity FC aircraft with airframe partners, which can be used for short-haul flights.

The prototype has a range of ~ 925 km, making it suitable for regional flights. It is expected that a version of the FC drivetrain will be certified in 2022, and so are likely to be available commercially shortly thereafter.

Air transport accounts for around 2% of all global man-made carbon emissions [20]. As a result, it is an industry which recognises the need to mitigate its carbon dioxide emissions. It is possible that hydrogen can play a role in the emissions mitigation targets that the International Air Transport Association (IATA) sets out however, trials of hydrogen technologies in aviation are currently limited to small-scale aircraft, up to six passengers, and fuel cells for ancillary power in larger aircraft.

Hydrogen-driven aviation technology is globally low in maturity, with only small-capacity aircraft tested to date. None of these trials have yet resulted in a commercially available product and are a long way off from the high-capacity commercial aircraft which operate around the world today.

The defined routes and bases of aircraft do, however, lend themselves, operationally, to a hydrogen fuel infrastructure. In addition, the long distances and heavy vehicles involved play to hydrogen's natural advantages as a fuel system. Therefore, it is conceivable that hydrogen fuel systems would be preferred to battery-electric systems when the transition to alternative fuels begins to evolve in the aviation industry.

With limited aircraft manufacture in Australia, and few examples to follow, it is not recommended that investment is made into the domestic development of hydrogen-powered aircraft. As such, it is not anticipated that a trial in Australia is feasible within the next 10 years.

Table 11: Aviation - mode opportunity

Aviation	
Technology Maturity	Limited
Ease of Procurement	Limited
Operational Suitability	Moderate
User Adoption	Limited
Overall Opportunity	**Limited**

Commercial & Industrial

The transportation of goods accounts for around 40% of final energy consumption in the transport sector, globally [21]. Due to this, the commercial and industrial sector of transport is responsible for around 10% of global man-made carbon emissions.

As a result, there is potential for material impact to Australia's emissions profile through enabling and implementing alternative fuels, such as hydrogen, in this sector.

With manufacturers, retailers and many global brands making environmental commitments, the opportunities to work with industrial and commercial partners in the space of alternative fuels is increasing. This opens the door to Governments around the world creating partnerships and incentivising the transport-related decisions of large organisations.

Material Handling

Prominent Trial – Carrefour, France

The supermarket Carrefour has implemented ~140 FC forklift trucks, produced by Plug Power. The forklifts operate in one of Carrefour's major warehouses in France.

The forklifts can be refuelled in two minutes, compared to a battery swap time of 15 minutes for their traditional counterparts. In addition, the refuelling station can be housed on-site and takes up only 2-3m^2, while also removing the need for a battery charging room.

The forklifts are commercially available for ~A$90,000 and several major contracts for supply have been signed in the USA by Amazon and Walmart, among other companies already using the Plug Power forklifts.

Hydrogen-powered material handling equipment covers a plethora of potential vehicles. The most technologically advanced, globally, is the FC forklift. These have been implemented in many large companies and some small trials in Australia. As such, these present the best procurement and implementation opportunity in the material handling category.

With site-based operations, material handling vehicles can achieve high utilisation of refuelling infrastructure and, in some cases, have been proven to increase productivity compared to electric counterparts.

The key to uptake in the material handling category is seen as being the incentivisation and selection of industrial partners who can undertake the trial of specialised equipment as part of a wider corporate strategy.

Other avenues of exploration which would be of particular interest in Australia are material handling vehicles within the mining sector. These could be on-site haulage trucks, private freight rail links or other specialist mining equipment. With such a large mining industry, Australia has the potential to become a first mover in the space, through partnering with industry-leading organisations.

Table 12: Material handling - mode opportunity

Material Handling	
Technology Maturity	Good
Ease of Procurement	Good
Operational Suitability	Good
User Adoption	Moderate
Overall Opportunity	**Good**

Freight Rail

There are currently no widely publicised trials of FC freight trains occurring or planned globally. There have been, however, a number of prototype FC locomotives used for material handling at a mine in South Africa. These small-scale projects demonstrate potential for hydrogen in freight trains, which could be developed in future.

While no freight rail trials have been identified, the natural advantage of hydrogen over batteries in the long-haul, heavy transport sector suggests this is likely to present opportunities in the future as carbon emissions reductions are targeted, as battery-electric locomotives are unlikely to be competitive in this space.

Table 13: Freight rail - mode opportunity

Freight Rail	
Technology Maturity	Limited
Ease of Procurement	Limited
Operational Suitability	Good
User Adoption	Good
Overall Opportunity	**Moderate**

Goods Vehicles

Prominent Trial – Hyundai Hydrogen Mobility, Switzerland

Hyundai and H2 Energy, under the joint venture Hyundai Hydrogen Mobility, have committed to the production of 1,600 FC trucks, with the first 50 trucks being delivered to Switzerland in 2020.

The vehicles are 18-ton trucks with a range of 400km and have been developed specifically for European conditions. The trucks are expected to all be in operation by 2025.

Hydrogen for the first 50 trucks will be produced by Hydrospider, a joint venture between Alpiq and H2 Energy. The hydrogen will be produced with electricity from one of Alpiq's hydroelectric stations.

While FC cars have been commercially available, primarily for leasing, since 2002 in limited locations, there are currently no commercially available FC trucks or vans. There is one model, from manufacturer Dongfeng, which has been announced for future commercial production. In addition, there are a number of special purpose vehicles which have been produced for use in various locations, including 500 Dongfeng FC trucks used in Shanghai for city deliveries.

While there are no commercially available models of medium and heavy goods vehicles, there are a number of trials that have been implemented around the world. This proves the operational capabilities of hydrogen goods vehicles and indicates a high level of technology maturity.

Back-to-base operation of goods vehicle fleets will be the most viable as it will enable a high utilisation of refuelling infrastructure and not rely on public refuelling availability.

Table 14: Goods vehicles - mode opportunity

Goods Vehicles	
Technology Maturity	Good
Ease of Procurement	Moderate
Operational Suitability	Good
User Adoption	Moderate
Overall Opportunity	**Good**

Shipping

Prominent Trial – MAN Energy Solutions, Germany

In 2018, MAN Energy Solutions committed ~A$7.5 million to develop an ammonia-fuelled engine for ships. The project is expected to conclude in 2020-21 and if deemed to be a commercial success, the first engine could be operational by 2022.

The engine will use ammonia as a hydrogen carrier and will be based on the company's existing liquified petroleum gas (LPG) dual-fuel engines. The company expects that around 3000 of its existing operational engines can be converted to use ammonia.

In 2017, 10.7 billion tons of goods were transported by sea [22]. This demonstrates a large global market for shipping services. However, only limited trials of hydrogen powered vessels have been undertaken. The technology of choice for large alternative fuel vessels appears to be internal combustion of hydrogen or ammonia, however, this is yet to be proven viable on a large scale.

Shipping and aviation are not considered to be good prospects for trials in Australia due, primarily, to the low technological maturity of hydrogen in these modes. With few examples of trials available globally which could be considered to be having significant impact on the modes, it is difficult to see where Australia could offer a particular advantage in this space.

Table 15: Shipping - mode opportunity

Shipping	
Technology Maturity	Limited
Ease of Procurement	Limited
Operational Suitability	Moderate
User Adoption	Moderate
Overall Opportunity	**Limited**

International developments summary

Based on the international market research undertaken, the following four modes are considered most suitable for demonstrating pilots in Australia

Opportunity Key: ■ Moderate opportunity ▲ Moderate to good opportunity ● Good opportunity

Table 16: Assessment of prospective modes for hydrogen trials in Australia

Mode	Rationale for trial of mode	Supply	Commercialisation	Adoption
Fleet vehicle	• Range of use cases to consider (e.g., cars, vans, bikes) • Low barriers to influence procurement model (government first approach) • Low marginal cost to add additional vehicles to fleet (low percentage cost of trial) • Low barriers to fuelling infrastructure due to hub-and-spoke usage model	● Multiple manufacturers	● Range of scales of use cases	● Direct influence in procurement
Passenger Bus	• Well established technology and overseas manufacturing base • Ability for government to directly influence procurement contracts (when linked to State owned transport agencies e.g., State Transport Authority in NSW) • Captive fleet and opportunities for consolidated depot infrastructure • Technical constraints concerning Australian Design Rules to be considered (e.g., vehicle width)	■ Previous issues with overseas models	● Range of scales of use cases	● Ability to influence procurement

Mode	Rationale for trial of mode	Supply	Commercialisation	Adoption
Material Handling	• Broad applications within an Australian context, leveraging existing skills and areas of competitive advantage (e.g., mining, industrials, manufacturing) • Partnerships with specific corporate users linked to their corporate technology strategy (e.g., FMG, BHP and Rio Tinto) • Some technologies more developed than others, opportunity to be a first-mover on mining and industrial applications	Few suppliers of limited machine types	Commercialisation of some products	Industry partnership required
Goods Vehicles	• Similar advantages as private fleet opportunities • Opportunity to focus on a select number of private freight providers and create partnerships in order to influence supply chain and procurement • Link to longer-term opportunities (i.e., end-to-end hydrogen logistics supply chain including rail)	Multiple manufacturers	Small scale trials only with typically smaller vehicles	Ability to influence procurement

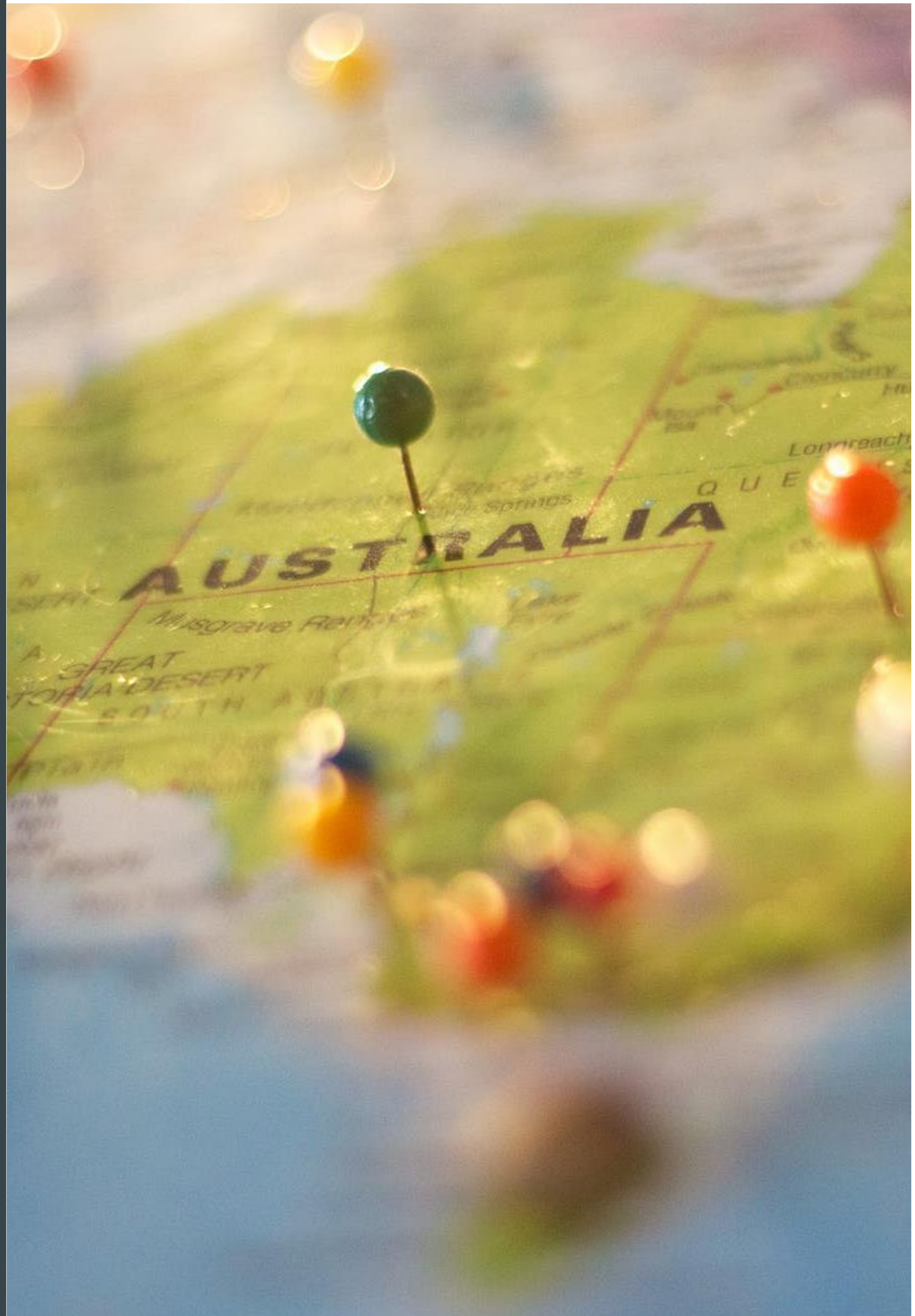
CHAPTER 4

OPPORTUNITIES IN AUSTRALIA

A total of 13 prospective trial options have been investigated in detail. For each, the assessment considers the value proposition of the trial and strengths relative to the key success criteria.

Assessing the prospective trials was considered from two perspectives. Firstly, this study utilises a multi-criteria framework to ‘score’ the outcomes of each trial; secondly, a range of stakeholder engagements were conducted to elicit industry perspectives.

The assessment shows that the best opportunities are in establishing a Low Emission Zone FCEV fleet, utilising FC bus fleets in metropolitan and Park and Ride scenarios, and in implementing hydrogen-fuelled material handling equipment.



4.Opportunities in Australia

Having evaluated fleet vehicles, passenger buses, material handling and goods vehicles to be the best opportunities for trials in Australia, specific hypothetical projects were developed. The following detailed assessment considers the 13 prospective use cases summarised in Table 17.

The use cases are defined by their mode and the scale of capital investment required to implement them. In this way, consideration is given to stand-alone projects and wider integrated systems. The technology components of the use cases are based on preliminary findings from trials overseas. In order to know the accurate cost to implement such a project in Australia, suppliers and operators should be approached for specific pricing.

As detailed in Chapter 2, the following criteria for success of a trial have been defined for the assessment:

- Strategic growth
- Addressable market
- Relative performance
- Procurement and implementation
- User adoption

The highest-ranking use cases represent those most likely to result in successful trials which can be implemented in Australia.

Scoring Key

1	Poorly satisfies the criteria
2	Moderately satisfies some, but not all, aspects of the criteria
3	Moderately satisfies the criteria
4	Highly satisfies some, but not all, aspects of the criteria
5	Highly satisfies the criteria

Table 17: Summary of assessed hypothetical projects

Mode	Use Case	Scale	Technology	Application	Time to implement	Score
Passenger Fleet Vehicles	Bike Fleet	*Small Trial*	Trial of **275-unit** fuel cell bicycle fleet in a pay-as-you-go use case	Suitable for use within an institution, highly visible, low set-up costs	6-12 months	2.0
	Gov't Fleet	*Small Trial*	Trial of a **~15 FCEV** fleet with centralised refuelling model	Most suitable for organisation without a fleet agency	1-2 years	2.9
	Corridor Fleet	*Medium Trial*	Trial of a larger **~90 FCEV** fleet with multiple refuelling stations	Focus on developing a trial 'corridor' (e.g., frequented ride-sharing route)	2-4 years	2.8
	Hydrogen Demonstration Zone	*Integrated Pilot*	Implementation of a 3km Low Emission Zone or 'Hydrogen Demonstration Zone' with **375 FCEVs** and eight HRS	Focussed on helping the low emission transition of local companies and residents	4-6 years	3.5
Passenger Bus	Individual	*Small Trial*	**Single bus** (and associated infrastructure) procurement	Suitable as demonstration vehicle on short, repetitive journeys (e.g., Airport shuttle)	1-2 years	1.6

Mode	Use Case	Scale	Technology	Application	Time to implement	Score
	Metropolitan	*Medium Trial*	Trial of a larger **~9 vehicle** bus fleet with central refuelling	Suitable to service known route with base depot and daily travel ~300km	2-3 years	3.8
	Park and Ride	*Integrated Pilot*	Trial of a larger **35 vehicle** bus fleet supported by 3 refuelling stations	Applicable for a Park and Ride (P&R) scheme across 3 commuter suburbs	4-6 years	3.5
Material Handling	Material Handling	*Small Trial*	Trial of small fleet **(~35 units)** of forklifts or similar handling equipment	Suitable for a warehousing application with long periods of continuous use	1-2 years	3.4
	Mine Haulage	*Medium Trial*	**Retrofit of a diesel haul truck to a FCEV** powertrain with single refuelling point	Suitable for a demonstration project in partnership with mine	2-4 years	3.2
	Private Rail Link	*Integrated Pilot*	Demonstration of **three FC locomotives** on new section of private rail network	Can be a demonstration project in partnership with a private rail operator	4-6 years	2.9
Goods Vehicles	Gov't Logistics	*Small Trial*	Trial of **~4 vans** with centralised refuelling point	Suitable for hub and spoke logistics, such as council building maintenance	2-4 years	2.3
	Last-mile	*Medium Trial*	Trial of **~25 van fleet** with single refuelling station for urban delivery	Suitable for government or private logistics (e.g., AusPost, NBNCo, Woolworths)	2-4 years	2.9
	Road Freight	*Integrated Pilot*	Trial of **~90 vehicle** truck fleet with nine distributed refuelling stations	Suitable for government or private industry logistic partnership	4-6 years	3.2

PILOT 1 - a small bicycle fleet

A bicycle fleet is attractive in a small number of applications and generally does not score well from the perspective of a hydrogen opportunity. While the technology is available, FCEV bicycles are expensive relative to electric and pedal-powered alternatives.

It is recommended that this opportunity is not pursued, unless specific partnerships (e.g., University campuses) can be formed to support the investment rationale.

Table 18: Bicycle fleet opportunity assessment

	Comments	Score
Strategic Growth	• A publicly visible demonstration of fuel cell technology • Low fuel demand - not likely to catalyse supply chain development	1
Addressable market	• Fleet sizes generally contained to less than 500 units, scaling would require transferring the technology across multiple applications or implementing fleets in other locations	1
Relative performance	• Very costly compared to electric (~2-3x), and non-powered bicycle alternatives (~5x) • Market share increasingly captured by electric scooter alternatives (e.g., Lime, Voi, Hive)	2
Procure and Implement	• Procurement at the council or institutional (e.g., university) level would be relatively practicable • Partnership with industry bodies (e.g., RACV partnerships with City of Melbourne) can assist with funding and operational mechanisms	4
User Adoption	• Low risk pathway to introduce Australian public to hydrogen technology • Market adoption of bicycles scheme in some cities has historically been low (e.g., the exit of OBike from Melbourne)	3
	Total Score (weighted)	**2.0**

Key learnings from stakeholders

- Investment of this nature would deliver benefits mostly relating to marketing Hydrogen for Transport and increasing public awareness

  "…users are interested to see how refuelling takes place and to see how it works…" – Global car manufacturer

- A number of bicycle and scooter share schemes have been unsuccessful within the public realm. Targeting an institutional application (e.g., Universities) may be more likely to overcome barriers

  "…distinctive yellow bicycles quickly caused headaches as people dumped them on footpaths and streets…"– ABC News [23]

PILOT 2 - a small government fleet

A small public-sector fleet of around 15 vehicles would have a broad set of applications. Strategically, such a fleet would allow for public demonstration and the establishment of refuelling infrastructure in metro areas (e.g., near a town hall, or maintenance depot).

This pilot is considered appropriate for a small impact demonstration, notwithstanding the likely competitiveness of BEVs at this scale.

Table 19: Small government fleet opportunity assessment

	Comments	Score
Strategic Growth	• A small fleet opportunity may have low public visibility, but will contribute to strategic priorities • The opportunity can allow for the establishment and sharing of refuelling infrastructure with other fleet use cases (e.g., bus fleets within the same catchment)	4
Addressable market	• Multiple avenues to pursue the fleet opportunity (i.e., local government, public and private sector) • Initial focus on trials within public sector fleets	4
Relative performance	• Some availability of commercially manufactured vehicles (e.g., Toyota, Hyundai et al.), but this is limited in Australia • Range and usage pattern similar to incumbent ICE cars • Capital cost of FCEV is ~3-4x cost of average ICE car	1
Procure and Implement	• Preferred direct procurement or control (performance specifications) to the organisation's fleet company • Procurement challenge will remain with refuelling infrastructure – can leverage R&D trials (e.g., match funding with a multi-national)	5
User Adoption	• Broadly good adoption expected – no major negative responses unless refuelling behaviour is prohibitive • The costs on a per-km basis would be high (~2x currently), public perception of this needs to be managed	3
	Total Score (weighted)	**2.9**

Key learnings from stakeholders

- Cost consciousness is likely to limit the appetite for individual companies to switch to FCEVs. The fleet purchase will need to be incentivised, and be cognisant of asset depreciation.

  "…everyone wants to do something [in terms of low-emissions transport] but most companies don't want to pay more for their energy usage…" – Fuel Retailer

- The relative performance of FCEVs in this segment is not strong when compared to BEVs.

  "…the battery electric market is moving so quickly, and their prices continue to fall. FCEV may find a segment that they're good for but in terms of a viable alternative for small vehicles it seems unlikely…" – Fuel Retailer

PILOT 3 – Medium ‘corridor’ fleet

A fleet of this size would be appropriate in a number of public sector and commercial applications. Businesses, however, would need to have ‘back-to-base’ operations to make hydrogen competitive to alternatives.

While a 90-unit fleet is an attractive proposition, the procurement difficulties and high costs are likely to make this opportunity unattractive to a large portion of commercial businesses.

Table 20: Corridor fleet opportunity assessment

	Comments	Score
Strategic Growth	• Substantial size of fleet would create specific demand for refuelling infrastructure and new OEM vehicle imports • Significant opportunity as there are over 2 million fleet cars in Australia	3
Addressable market	• Multiple opportunities to integrate within existing fleets of Government and/or private businesses • Limited to businesses which use vehicles with predictable, frequent routes (e.g., delivery services, maintenance and operations)	3
Relative performance	• High capital costs relative to incumbent combustion vehicles (~3-4x) • Range and usage pattern similar to incumbent combustion engines	2
Procure and Implement	• Commercially available vehicles and de-centralised refuelling infrastructure • Procurement challenge will remain with refuelling infrastructure – can leverage R&D trials (e.g., match funding with a multi-national)	4
User Adoption	• Useability similar to incumbent vehicles • Users need to be comfortable with a back-to-base refuelling arrangement	4
	Total Score (weighted)	**2.8**

Key learnings from stakeholders

- Car-share concepts have relatively low uptake in Australia. The fleet model, however, is seen as the most promising application for incorporating FCEVs into the private mobility market.

  “…Australians like to own cars, so breaking consumer behaviour is difficult from the perspective of uptake in fleet vehicles. It may be something we see in future generations, there is a trend of declining driver licences…” – Fuel Retailer

- Initial fleet users will need to be comfortable with back-to-base refuelling arrangements and limited vehicle choice. OEMs will be reluctant to offer substantial range until demand is established.

  “…the process we’re going through now is advocacy and knowledge sharing… our parent company is closely monitoring what is the interest for the hydrogen economy. In order to progress [to importing vehicles] we’d need to see either established infrastructure or confirmed plans for investment…” – Global car manufacturer

PILOT 4 – Hydrogen Demonstration Zone

A large fleet (more than 500 vehicles) could be well utilised in conjunction with a broader low emission urban demonstration. Practically speaking, this would require both policy action (e.g., low emission zoning) and multi-modal adoption.

Demonstration of a large-scale private vehicle fleet would be best supported through parallel implementation of policy mechanisms and creation of a 'hydrogen demonstration zone'

Table 21: Hydrogen Demonstration Zone opportunity assessment

	Comments	Score
Strategic Growth	• High strategic potential to integrate a larger FCEV fleet with broader precinct and/or hydrogen hub outcomes • Coordinated effort with other low-emission technologies and policy mechanisms to support the transition	5
Addressable market	• FCEV becomes more attractive with appropriate low-emissions policy– users are incentivised to adopt vehicles which mitigate emission charges. There is no existing market for this. • A centralised hydrogen precinct approach is amenable to a concentrated demand of refuelling infrastructure	1
Relative performance	• Within a fleet scenario (taxi and/or car share) performance will be similar to incumbent combustion vehicles • Capital outlay would be 3x higher than traditional fleets (not including offsets associated with the low emissions mechanisms)	3
Procure and Implement	• Procurement of a large number of units (<500) will increase the timeframe for implementation as currently around 4,000 Mirais produced annually across the globe • Multiple refuelling stations (12+) will be required to satisfy fleet	3
User Adoption	• If users are incentivised within a 'hydrogen demonstration zone', they are more amenable to investing in low emission vehicles • Users would require surety in the availability of refuelling infrastructure, otherwise preferences would be given to other low emission technology (e.g., BEV or LPG)	5
	Total Score (weighted)	**3.5**

Key learnings from stakeholders

- Creating surety of refuelling demand (through 'hydrogen demonstration zone' policy mechanisms for example) is seen as an important measure to increase the uptake of a new technology.

  "…I think it looks worse when you build something and the demand isn't there…we have a high-speed charger in Euroa that only gets used once or twice a month. Generally, from a small initiative point of view we would try and line up some of the demand [before investing]…" – Fuel Retailer

- A collaborative effort between government, fuel suppliers and OEMs is seen as the best approach to increasing vehicle availability.

  "…We need to move past the 'chicken and egg' discussion…in terms of increasing the availability of vehicles, infrastructure providers need to work with the OEMs. Simple to say, but a difficult approach to implement …" - Global car manufacturer

PILOT 5 - a single hydrogen bus

Investing in a single hydrogen bus is considered to offer poor value for money. An investment of this scale would require a strong commitment from the asset owner to demonstrate the technology due to the high upfront capital costs.

Investment in a single bus would be limited to a few applications (e.g., an Airport or Shopping Centre) and only relevant to organisations looking to improve their sustainability credentials.

Table 22: Single hydrogen bus opportunity assessment

	Comments	Score
Strategic Growth	• Buses are highly visible and have a broad user base. A trial of this scale, however, it not likely to allow for a high degree of publicity	2
Addressable market	• Application limited to a 'special transit' application (e.g., Airport shuttle, tourist bus)	2
Relative performance	• An investment of this size it not conducive to good utilisation of refuelling infrastructure – cost vs. benefit rationale will be challenging • The upfront costs of the FCEV Bus are prohibitive (3-5x more expensive than incumbent vehicles) • Buses have a long asset life (20 years). Operators will be concerned with operational and depreciation implications	1
Procure and Implement	• FC buses made overseas do not meet ADRs • Australian FC bus manufacture possible within 12 months with upfront investment	2
User Adoption	• The passenger experience will be improved (vibrations, noise, exhausts) when compared to diesel technology • Bus operators not inclined to make the switch, particularly the effort required to use and run a single FCEV	2
	Total Score (weighted)	**1.6**

Key learnings from stakeholders

- The back-to-base operation of buses and their typical daily distances makes them well suited to use while public hydrogen infrastructure is limited.

  "…It is logical to begin with hub-based infrastructure and a natural extension to then build it out…Airports for example have lots of space and you can serve the airport bus routes and shuttle [quite easily]…" – Fuel Retailer

- Although hydrogen technology is a higher upfront capital cost at present, the total cost of ownership compared with diesel buses is forecast to be lower.

  "…an electric bus saves around $52,00 in operational costs per year [compared to diesel], therefore after 9 years it balances out the additional upfront cost.…" – Bus Developer

PILOT 6 – a metropolitan bus route

A medium scale investment (approximately nine vehicles) provides enough critical mass to service a specific metropolitan bus route. A fleet of this size would increase the utilisation (and therefore cost effectiveness) of refuelling infrastructure.

A moderately sized bus fleet has a number of benefits – it allows sizeable demonstration of the technology, and the opportunity for operational testing in a real-world application.

Table 23: Metropolitan bus route opportunity assessment

	Comments	Score
Strategic Growth	• A dedicated hydrogen bus route is likely to have a good degree of visibility and public engagement • Bus operators will have the opportunity to prove the technology in a realistic operational environment	4
Addressable market	• Multiple metro and regional bus operators would be appropriate to run a FCEV route • Other operations in the private sector are also appropriate	5
Relative performance	• Good utilisation of depot refuelling infrastructure, although peak demand requirements will need to be managed • Fleet operators will be concerned with the long asset life (~20 years) and the implications this has on operational costs and asset depreciation	3
Procure and Implement	• FC buses from OEMs abroad do not meet ADRs but Australian compliant FC bus is in development • Alternatively, a hydrogen-mixed fuel system could be incorporated into LPG gas buses (e.g., Euro 6 bus) - relevance of this to the Australian market is limited	4
User Adoption	• Public users will easily adopt a FCEV Bus. It is likely that the passenger experience will be improved (vibrations, noise, exhausts) when compared to incumbent diesel technology	5
	Total Score (weighted)	**3.8**

Key learnings from stakeholders

- If performance of hydrogen buses can be demonstrated (across the whole asset lifecycle) as comparable to existing diesel fleets, this will encourage fleet operators to explore hydrogen as a low emissions alternative to combustion engine vehicles.

  "…Fleet operators will be concerned about practical considerations. How many drivers do I need? Will this mean I need a new OEM relationship? Is the refuelling the same amount of time? How will the asset depreciate in value over time…" – Hydrogen Technology Distributor

- The long asset life of buses (20 years) makes it difficult to quickly convert a sizeable portion of the fleet to hydrogen

  "…the downside is that it takes a long time to convert a Bus fleet from one fuel to another. I'd suggest that an OEM product is best. If there were a way to convert existing fleet to 100% hydrogen it comes at a huge risk. …" - Hydrogen Technology Distributor

PILOT 7 – a park and ride bus route

An integrated system of buses and supporting infrastructure would be able to provide a clean and efficient transport alternative. It would perform best as an upgrade for an existing bus route to a Park and Ride setup, or as a solution in greenfield mass transit.

A fleet of this size (approximately 50 buses) could be used in a greenfield development or upgrade of existing bus route. A 'Park and Ride' solution could be integrated with hydrogen in other modes.

Table 24: Park and ride bus trial opportunity assessment

	Comments	Score
Strategic Growth	• A large FCEV bus fleet opens the opportunity to create new, dedicated low-emission commuting corridors • Strategically speaking, this could tie into broader aims relating to low-emission zoning and mass-transit solutions	4
Addressable market	• Investment opportunities exist in large metropolitan centres • A zone supported by policy mechanisms (e.g., hydrogen demonstration zone) is more amenable to a concentrated demand of refuelling infrastructure	4
Relative performance	• Potential to compete with existing Park & Ride operations or greenfield Bus investments • Capital outlay would be ~3-4x higher than traditional fleets (not including offsets associated with the policy mechanisms)	3
Procure and Implement	• Long time frame to implement dedicated bus routes - can be sequenced with smaller fleet developments and trials	3
User Adoption	• Public users will easily adopt a FCEV Bus. It is likely that the passenger experience will be improved (vibrations, noise, exhausts) when compared to incumbent diesel technology	5
	Total Score (weighted)	**3.5**

Key learnings from stakeholders

- A key strength of the hydrogen refuelling infrastructure is the ability for the equipment to serve multiple use cases. This presents opportunities for multi-modal investment.

"…one of the benefits of the hydrogen refuelling infrastructure is that the technology is basically the same [across modes]. As long as the equipment is setup up to deliver to different types of vehicles, it just becomes a matter of storage. The key thing is to understand the refuelling profile, and [match] the performance characteristics…" - Hydrogen Technology Distributor

- While the market applications for FC buses are extensive, the procurement route is challenging. In order to introduce a FC bus fleet government would need to navigate state bus procurement contracts.

"…The biggest issue we see [with buses] is the current regulation concerning state procurement methods…" - Energy Agency

PILOT 8 – material handling equipment

Material handling equipment is a large and diverse market, and there is significant opportunity to penetrate markets with industry participants who are looking to reduce their vehicle emissions. Hydrogen is particularly attractive because of the opportunity to link with other industrial applications of hydrogen.

A number of Australian businesses are well placed to undertake hydrogen trials in their logistics activities. Overseas success can be leveraged to demonstrate the benefits to end users.

Table 25: Material handling opportunity assessment

	Comments	Score
Strategic Growth	• Opportunity to partner with commercial interests e.g., FMCG or supermarket who have high volume of stock movement • Poor public visibility, main benefit imparted to commercial interests	2
Addressable market	• Wide range of users with material handling needs across a range of sectors • Opportunity to share refuelling infrastructure with other transport modes at a single site	3
Relative performance	• Some availability of commercially manufactured forklift units, which result in higher productivity • FCEV understood to perform better in both range and refuelling requirements when compared to traditional BEV material handling	4
Procure and Implement	• Preference to partner with commercial company who has sufficient Capital to invest in sustainability initiatives – link to corporate carbon reduction goals • Technology is well demonstrated overseas (e.g., Forklifts)	5
User Adoption	• If value can be demonstrated to commercial companies, broadly good adoption expected, as seen globally • Value must be demonstrated in terms of end-to-end lifecycle cost as well as benefits such as reduction in downtime / number of units required to move same volume of material	2
	Total Score (weighted)	**3.4**

Key learnings from stakeholders

- Hydrogen vehicles have a greater range than electric vehicles, thus reducing the refuelling / charging needs for material handling fleets

  "…electric forklifts need a large number of internal charging stations. Downtime could be minimised by transitioning from electric to hydrogen…"– Hydrogen technology distributor

  "Refuelling infrastructure for forklifts takes up relatively small floor space… 3m x 1.5m" – Global car manufacturer

- Hydrogen forklifts are a relatively easy mode to build into an end-to-end logistics supply chain for bulk material handling, especially in cases where the hydrogen is being produced on site

  "…If you are going to have hydrogen mobile transport it makes sense to have the forklifts doing the same at either end…" – Global metals producer

  "…with forklifts the refuelling infrastructure is less cost intensive [than other hydrogen applications]…from a footprint perspective it is also a compact electrolyser…" – Global car manufacturer

PILOT 9 – mine haulage equipment

With such a large mining industry, Australia could be a first mover in this space and help to reduce the emissions of the global mining industry. Procurement and implementation of technology (e.g., a FC haulage truck) will be challenging and require local expertise.

Hydrogen in the mining industry is strategically attractive, but local capabilities in fuel cell vehicle design and manufacture will need to be developed in order to produce operationally capable vehicles.

Table 26: Mine haulage equipment opportunity assessment

	Comments	Score
Strategic Growth	• Opportunity for Australian manufacturers to benefit from "first mover" advantage in this transport mode • If vehicle being used on private land initially, may not be subject to same level of regulation as public road use	4
Addressable market	• Initial use in mining sector could grow into wider uptake for heavy vehicles once commercial viability is demonstrated • Typical load and haul fleet on mine sites between 30-100 vehicles	5
Relative performance	• No data available on heavy haulage trucks however, based on light vehicle trials, performance is expected to be comparable to diesel, and better in terms of range/capacity compared to BEV • On-highway trucks are seen as preferred mode to trial and implement emerging technology	3
Procure and Implement	• Supply chain is the greatest challenge for this transport mode currently. Currently only two companies have expressed plans to develop FC mining haulage	1
User Adoption	• Mining and heavy industry is used to managing risks with handling and processing hazardous materials - hydrogen is no different • Users are highly concerned with payload ability, operating efficiency and truck cycle time – hydrogen technology would need to demonstrate good performance in these areas	2
	Total Score (weighted)	**3.2**

Key learnings from stakeholders

- The technology for heavy-haulage vehicles is still to be proven (compared with light vehicles and vans) which makes it even more important to support early pilots and trials

  "…light vehicles using hydrogen batteries is proven… the technology for heavy trucks is more difficult due to the amount of torque needed…" – Global metals producer

- Mining vehicles are specialised but the development would be for a market which is universal across countries. Australia would likely be able to support manufacture through self-consumption initially

- The typical Iron, Coal and Bauxite mine sites in Australia have between $200-$300m of installed load and haul capital. The main total cost of ownership is from trucking fleet as opposed to dig fleet, presenting a sizeable market for hydrogen

PILOT 10 – a private rail link

A hydrogen-powered rail link could facilitate a large mine to transport output to a distribution hub. FC locomotives could be developed domestically or with existing expertise internationally. A fixed, high-utilisation route (e.g., bulk-freight component to a supply chain) would provide an alternative to diesel and generate demand for hydrogen.

Australia has many private rail operators who could run a pilot. The unproven performance and long development times are likely, however, to hold back commercial investment.

Table 27: Private rail link opportunity assessment

	Comments	Score
Strategic Growth	• Opportunity to integrate rail link into an existing bulk material handling supply chain to "value stack" and share the costs of production and refuelling infrastructure across multiple modes	3
Addressable market	• Private freight rail could be used to demonstrate technology in-country before expanding into longer-haul freight distances • 56% of all rail freight in 2011-12 was bulk iron ore transport from mines to ports in Western Australia [24]	4
Relative performance	• Electrification of remote lines is not economically viable and hydrogen provides a similar range to diesel. The technology can be used as a low-emission alternative to existing diesel locomotives	3
Procure and Implement	• Most viable option would appear to be for a commercial company requiring bulk material handling to integrate a private freight rail link as part of its end-to-end logistics supply chain • High capital costs, but can be reduced if integrated into a brownfield site where rail infrastructure already exists	2
User Adoption	• Mining and heavy industry is used to managing risks with handling and processing hazardous materials so hydrogen is perceived as no different • Low public interaction anticipated in mine remote locations	2
	Total Score (weighted)	**2.9**

Key learnings from stakeholders

- There is an opportunity to leverage existing in-country manufacturing, and produce hydrogen trains in Australia

  "…the train could come before the truck as they are low volume, high value, and don't have the LHD/RHD issue and there is still manufacturing in Australia…" – Global metals producer

- Companies in Australia have existing private rail infrastructure that they are willing to use to trial hydrogen technology

  "…if there was a hydrogen train, we would put it on our rail link…" – Global metals producer

- Partnerships and co-investment from commercial entities and the Government will support first-mover trials and refuelling infrastructure
- *"…A number of companies joined forces to deliver the pilot of the first hydrogen truck at the Port of Los Angeles…"* – Global car manufacturer

PILOT 11 – government logistics

A small trial of four back-to-base vans which can be introduced to an existing fleet along with an HRS which could be made publicly available. Low utilisation of refuelling infrastructure could be overcome through partnering with another trial or through staged increase of the fleet.

A small fleet, while operationally feasible, does not offer many strategic benefits or commercially attractive outcomes for businesses.

Table 28: Public sector logistics opportunity assessment

	Comments	Score
Strategic Growth	• Commercial fleets offer the opportunity to prove FCEV technology, but this scale is too small to be impactful • Light commercial vehicles can form part of a hydrogen-powered supply chain	2
Addressable market	• There are a broad set of applications suitable for a small FCEV logistics fleet and can be used as the first stage of a fleet-wide replacement of ICEs	3
Relative performance	• A FCEV fleet performs well in a hub-and-spoke model • Small businesses would be concerned about managing peak demand with one HRS (e.g., morning and night refuelling)	2
Procure and Implement	• Vehicles could be procured directly from OEMs (traditional or non-traditional) • Alternative ownership structures (e.g., service level agreement based) would offer a lower risk entry for small-to-medium enterprises	3
User Adoption	• Most medium enterprises are very cost sensitive when it comes to fuel and energy costs, so likely to form part of a larger existing fleet • Adopters would need to be incentivised to undertake the investment and operational risk	2
	Total Score (weighted)	**2.3**

Key learnings from stakeholders

- Achieving attractive vehicle costs may focus on importing through emergent, non-traditional OEMs

  "…we should be looking at non-traditional OEMs, there are a number of companies in China and Japan starting to build these vehicles. These OEMs would be at a lower price bracket and deliver a more competitive FCEV…" – Fuel Retailer

- A FCEV fleet has considerable upfront investment costs (and therefore investment risks). This could be mitigated through an alternative ownership structures that is more akin to models seen in the sharing economy.

  "…A really interesting example is with Nikola [Motor Company] hydrogen products. They offer a service agreement arrangement [for delivery] rather than sale or lease of the vehicle. This availability style contract fixes costs for the [logistics] business and reduces risk …" – Fuel Retailer

PILOT 12 – last mile logistics

A larger commercial fleet could perform well in urban logistics (e.g., 25 FC vans within an existing fleet). A scale of such size could enable early logistics within a LEZ and provide infrastructure to promote the uptake of FC vehicles by others.

A mid-sized fleet of commercial vehicles could perform well in a number of applications. While upfront costs are high, the whole of life value proposition may be compelling.

Table 29: Last mile logistics opportunity assessment

	Comments	Score
Strategic Growth	• Demonstration of a logistics fleet of this size would increase industry confidence in commercial viability of the concept • Commercial logistic operations could test hydrogen technology in demanding conditions	3
Addressable market	• For metro-operations, the fleet would be highly visible and could play to an organisation's broader sustainability goals	5
Relative performance	• Capital outlay is high compared to traditional vehicles, and operational costs have the potential to escalate beyond traditional trucks and vehicles • Performance of the technology can be improved through an integrated logistics hub (incorporate onsite hydrogen generation of ~0.5-1MW) and renewable energy generation	2
Procure and Implement	• Procurement could be undertaken directly through OEMs, but commercial users would need incentives to compensate for higher costs and increased operational risk	3
User Adoption	• Most commercial businesses are cost-sensitive and likely to be reluctant to adopt the technology • This is balanced, however, by the strong opportunity for credible social licence afforded by the hydrogen opportunity	4
	Total Score (weighted)	**2.9**

Key learnings from stakeholders

- At fleets of this size, logical partnerships are with commercial customers who have a willingness to participate in emissions reduction and partner on roll-outs

  "…I would be focussing on commercial customers with a declared sustainability position… for example, we have a close relationship with [a supermarket] and they could consider having their delivery trucks converted to hydrogen…" – Fuel Retailer

  "…Hydrogen is a natural evolution [for us], over and above [what we're doing] with electric vehicles…" – Grocery Retailer

- The practicalities of running a commercial fleet will also need to be considered. Operational considerations will be of a high priority.

  "…You will never get a fleet manager who is willing to put their core business at risk…[they] want to know that they can carry at a known price and known efficiency…" – Hydrogen Technology Distributor

PILOT 13 – Road freight corridor

A fleet of 90 semi-trucks can provide bulk-freight along an intra-state or inter-state route. This could become a hydrogen mobility corridor as part of a hydrogen-powered supply chain.

A large fleet is attractive as the catalyst for a 'hydrogen corridor' – a known intra-state or inter-state route, where utilisation of refuelling infrastructure is high.

Table 30: Road freight opportunity assessment

	Comments	Score
Strategic Growth	• An integrated hydrogen corridor or hydrogen highway will leverage Australia's high kilometre reliance on road freight • Highway infrastructure can be shared between commercial, private and government interests	5
Addressable market	• Utilisation would focus on partnership with major national freight and logistics (e.g., Pacific National, Australia Post, Linfox, Brambles Ltd)	4
Relative performance	• Economies of scale are more achievable in a larger fleet arrangement owing to the volume of hydrogen fuel required (~20x more than a private vehicle)	2
Procure and Implement	• Government would be relied upon to procure and implement depot / public refuelling infrastructure (coordinated with existing refuelling entities) • Logistics partners would need to be guided and incentivised to purchase FCEV fleet	2
User Adoption	• Centralised investment in a corridor of infrastructure can encourage the uptake by multiple commercial users (freight, logistics, mass transit)	3
	Total Score (weighted)	**3.2**

Key learnings from stakeholders

- Investment of this scale will need a high degree of industry coordination in order to sure-up demand and justify the infrastructure utilisation

  "…From an industry perspective, it's all about the scale. The technology is relatively proven – from an Australian perspective it is all about who will buy the technology…it's all about the usage of the vehicles and the [demand] that will underwrite the investment…" - Hydrogen Technology Distributor

- Access to vehicles is the greatest barrier to commencing any pilots and trials for this use case. Users are willing and ready to support the first trial programs in Australia

  "…we have spoken with a range of heavy truck manufacturers but their focus is on established markets in the USA and Europe… need to do something to entice manufacturers to take part in trials or production in Australia" – Global metals producer

CHAPTER 5

INTEGRATED OUTCOMES

The real benefits of trials, demonstrations and pilots do not occur in isolation – they contribute to a broader system of change.

This study highlights the systems thinking and integrated outcomes that are pertinent to the hydrogen for transport opportunity. In progressing any pilot or trial, we encourage investigation of long-term benefits to the broader transport system and growth of the domestic hydrogen economy.

5.Integrated outcomes

Chapter 2 introduced the concept of integrated outcomes – acknowledging that the benefit of pilots, demonstrations and trials rarely comes from their isolated operation but how they can contribute to a broader system change and vertical integration throughout a particular sector of the economy. This thinking is pertinent for the Hydrogen for Transport opportunity. As Figure 10 highlights, the opportunities surrounding hydrogen supply chain, refuelling and vehicles are all linked. The best chance of success comes from applying an approach which can further advance the whole hydrogen economy, rather than just a specific end use or application.

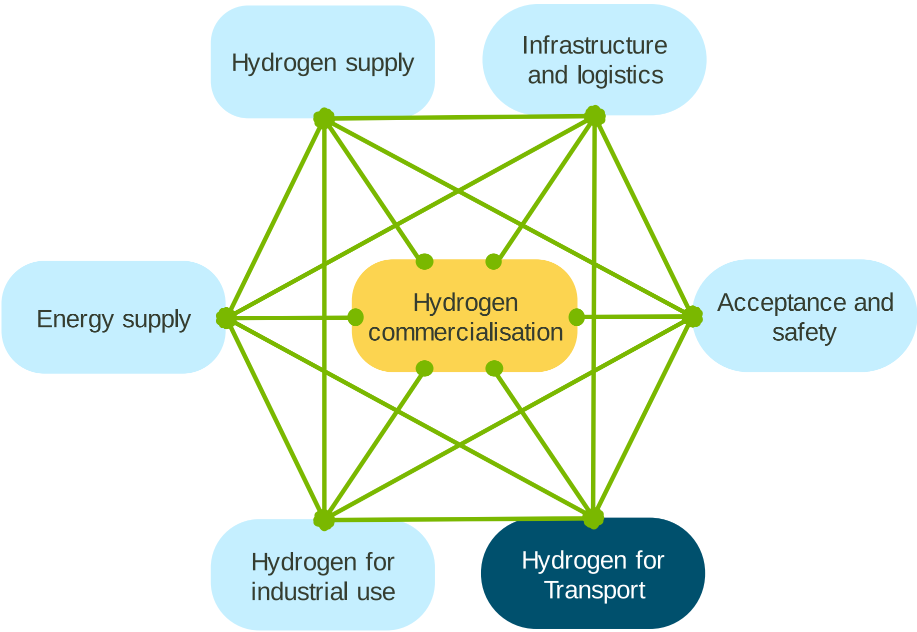


Figure 10 Integrated considerations of Hydrogen for Transport

This study raises four initial concepts of how pilots and trials can be framed for integrated outcomes. This is not an exhaustive assessment, rather an indicator of how government and industry can approach the implementation of trials and their broader scaling to commercial opportunities.

As part of this study we introduce the concept of integrated outcomes, outlined in Figure 11. The four concepts take each of the four transport modes (i.e., fleet cars, buses, material handling and goods vehicles) and envisages an optimal, integrated end state for each.

Concept 1 is a hydrogen highway. This provides shared refuelling infrastructure along a highly-utilised route which is used by passenger vehicles (both public and private), commercial vehicles and goods vehicles. This would result in decarbonisation of long-distance transport along the route, which would be best situated between major economic centres.

Concept 2 is an industry focussed system to transition mining and heavy industry to hydrogen. This concept plays to hydrogen's strength in heavy, long-distance transport, while also incorporating corporate fleets and material handling in order to increase infrastructure utilisation. This concept has a local hydrogen eco-system due to the fact that often mining sites or large heavy-industry plants are in remote areas.

Concept 3 is an urban integration of hydrogen technology. This means that multiple modes, including buses, fleet and private mobility, could leverage infrastructure provided within a specific urban catchment. Policy mechanisms could also be introduced within the catchment in order to incentivise the uptake of hydrogen and other low-emission technology.

Concept 4 is a hydrogen-powered supply chain. This looks primarily at the logistics throughout a supply chain, from material handling for manufacture, through to local courier delivery. Since these activities are operated on a back-to-base model, it promotes high utilisation of refuelling infrastructure.

These concepts use the principle of value-stacking to improve the cost-benefit of the individual trials by implementing them as part of a larger system. The key considerations for each of these concepts are raised in Figure 11 with possible component pilots outlined in Figure 12. This highlights the diversity of uses available for each of the pilots and how they can each be applied to multiple integrated systems.

Thinking in systems

Regardless of the size of the hydrogen trial, it is important to frame the investment in the context of how the trial could link to longer-term outcomes for the transport industry and broader hydrogen economy.

By way of example, Figure 13 considers how all 13 of the hypothetical projects could be orchestrated to contribute to one of the integrated outcome concepts.

What is important to note here is that often multiple modes are needed to contribute towards these outcomes. This multi-mode approach is pertinent for hydrogen; the nature of the supply chain and refuelling infrastructure means that a high utilisation of infrastructure is required for the opportunity to make commercial and operational sense.

A particular use case (or application of hydrogen technology) may contribute to more than one type of outcome. For example, developing hydrogen powered on-road haulage trucks could be used in both the mining and surface transport (logistics) industries. In turn, this technology could support both the outcome of a fully hydrogen-renewable-powered mine site or the outcome of a hydrogen powered logistics supply hub.

1 Hydrogen highway	2 Integrated industry	3 Urban integration	4 Integrated logistics
Developing a hydrogen transport corridor	**Transitioning mining and heavy industry to hydrogen**	**Transforming personal mobility**	**Catalyst for the hydrogen powered supply chain**
Integrated Outcome Characteristics			
• Coordinate investment in medium scale fleets across logistics, mass transit and freight • Accelerate utilisation of hydrogen infrastructure along specific travel corridors	• Cluster hydrogen transition within a specific mining region • Utilise hydrogen infrastructure across multiple use cases, both machinery and freight • Centralise hydrogen production support operations	• Create urban centres as the centrepiece for the hydrogen transition • Fleets of buses and rideshares share common-user refuelling • FC bikes and scooters are subsidised and available to use refuelling infrastructure	• Clustering of hydrogen fuelled logistics activities • Leveraging multiple applications of a single commercial / industrial user • Focus on warehousing, storage, logistics, and onsite fuel production
Key Considerations			
• How can utilisation be improved through multiple use-case sharing? • What is the optimal size of the hydrogen corridor (e.g., Melbourne to Sydney)?	• What is the extent of applications that can be converted to hydrogen? • Can a mining town support its own hydrogen production facility?	• What is the level of investment required to support a micro-hydrogen economy? • How can user adoption be ensured (through policy mechanism or otherwise)?	• How can government incentives best align with commercial interests? • How can incumbent users be incentivised to switch behaviour?

Figure 11: Examples of integration outcomes for Hydrogen for Transport

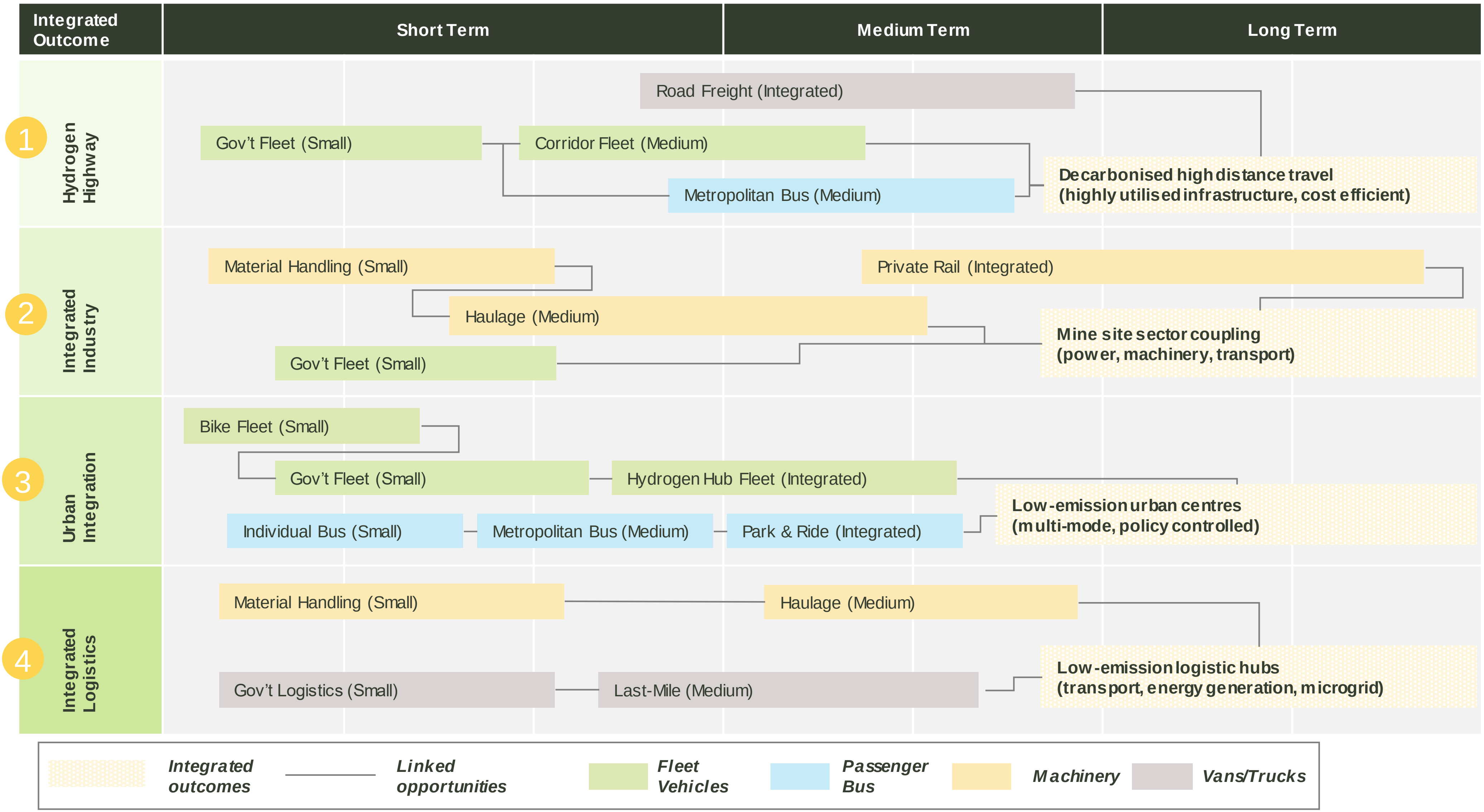


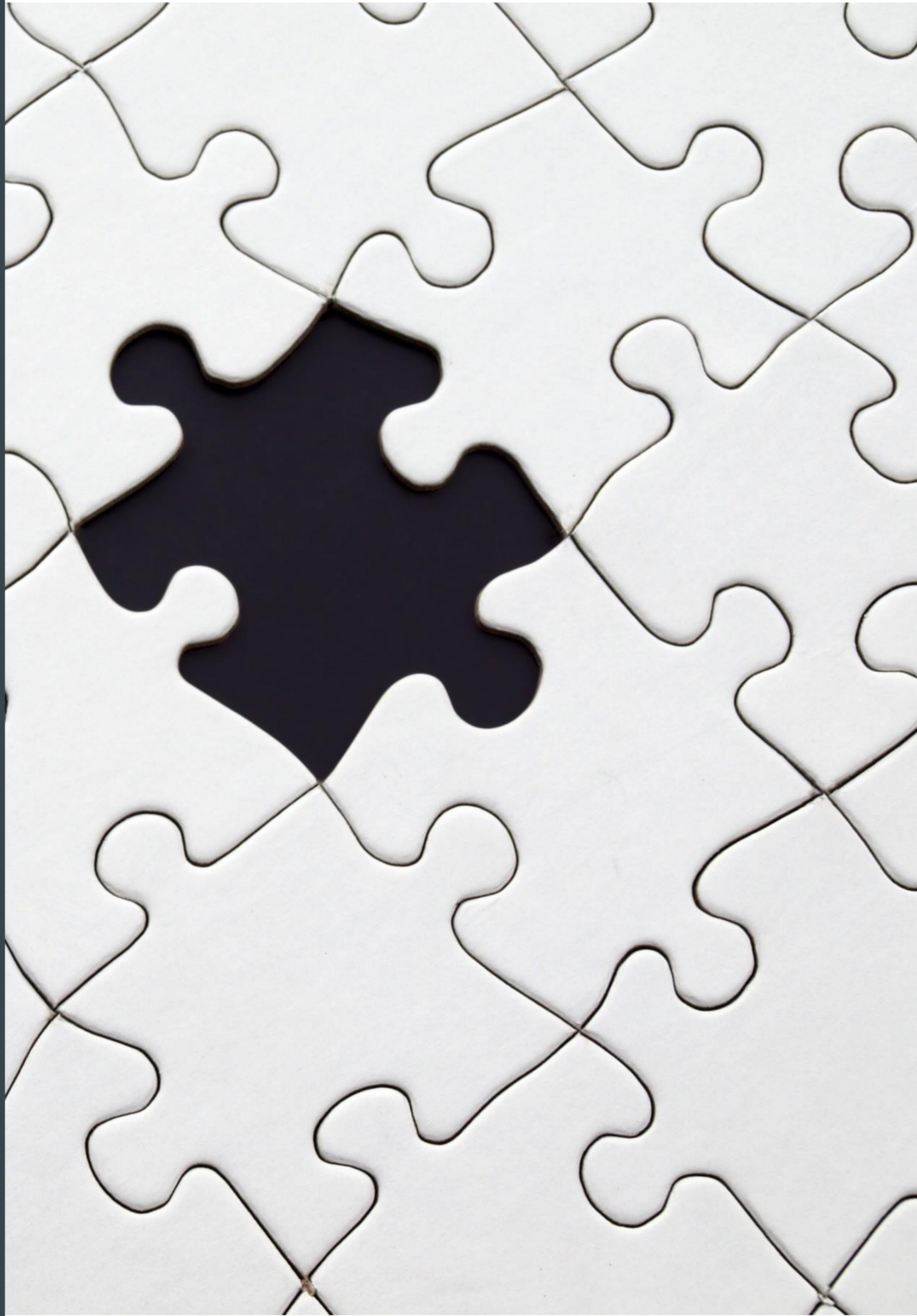
Figure 12: Co-ordination of individual pilot projects for integrated outcomes

CHAPTER 6

IMPLEMENTATION AND COMMERCIAL MODELS

The success of any emerging technology pilot or trial is underpinned by its implementation strategy, and ultimately the commercial model that encourages uptake by the market.

This chapter highlights some key lessons that stakeholders have identified from the implementation of other transport trials, as well as opportunities to employ innovative procurement methods to incentivise engagement by industry.



6.Implementation and commercial models

Learning from Australian stakeholders

This study engaged with a broad set of stakeholders within Australia for market sounding. A number of these stakeholders have previously participated in transport trials, demonstrations and pilots. Learnings have been distilled from our stakeholders, and these learnings are seen as critical considerations when implementing any of the recommended Hydrogen for Transport opportunities.

Table 31: Key lessons from stakeholders

Creating a market for Hydrogen for Transport	
• The general consensus among stakeholders is that the development of hub-based infrastructure will be the easiest pathway to getting momentum with the technology • Introducing hydrogen transport options, particularly in commercial situations, needs to be cognisant of the end user's 'core business' and the risks that need to be mitigated • It is seen as important to have a clear public discussion about the rationale of the project, and highlight why the trial was chosen over a business-as-usual operation or alternative technology	*"…back-to-base is a good starting point for rolling out infrastructure…we don't want to go too wide too early…"* – Vehicle OEM *"…Fundamentally [the concerns of the market] are about not putting the core business at risk, whether that core business is transporting people or goods …"* – Hydrogen Technology Distributor *"…In addition to transport, [we] need to look at the supply chain and cost of hydrogen production…there is a need to look at hydrogen in a systematic way …"* – State Government Department

Supporting industry and private interests

- Trials which can effectively coordinate multiple stakeholders have been reported to have a high chance of success. In the context of the Hydrogen for Transport opportunity this would involve actively coordinating OEMs, fuel suppliers and commercial partnerships in order to deliver a functioning pilot and refuelling infrastructure
- Private industry is looking to government to subsidise not only the capital costs but the operational risks associated with adopting a relatively untried technology

"[We need to see] public-private partnership with the government in order to defray some of the [high] capital costs…"

– Fuel Retailer

"…In terms of [vehicle supply] you need some leverage to entice their strategic direction from overseas markets to Australia…something has to be done at the group level, as the individual company is not enough to influence them…"

– Mining and Resources Company

"…We need to see a coalition of providers working together. Integrating the supply chain including transport. [This includes] the wind farm development, electrolyser behind the meter, and logistics travel to the refuelling station …"

–Energy Research Centre

Influencing procurement and contracting

- There are a number of procurement models which can be leveraged to better align outcomes among government, operators, contractors and end users.
- Trials, demonstrations and pilots need to have a high level of influence over the procurement model. This influence is used to align purchasing, operations and maintenance to the required performance outcomes.

"…There is the opportunity to implement innovation in available style contracting which incentivises innovation in both refuelling and transport …"

– Hydrogen Technology Distributor

Creating a compelling value proposition

- The market needs to be won over with the financial and operational benefits of hydrogen technology. Stakeholders would like to see hydrogen 'play to its strengths' in terms of industrial and commercial applications
- Stakeholders want to see trials, demonstrations and pilots replicate real life performance. Commercial entities are highly concerned with considerations such as refuelling times, training requirements, maintenance costs, and OEM availability.

"…When I talk to commercial customers everyone is so price conscious…the challenge with FC vehicles is to get them at an acceptable price bracket …if we look at BEV pricing, it has taken nine years to get competitive…"

– Fuel Retailer

"…There is a reluctance from [fleet operators] due to the unknowns of cost parity. Since there are no trials in Australia, all lifetime cost comparisons are anecdotal …"

– Hydrogen Technology Distributor

"…Back-to-back refuelling can still prove to be [operationally challenging] …"

– Hydrogen Technology Distributor

Procurement models to maximise outcomes

Australia's transport industry is largely privatised. In terms of mass transit, government agencies still have overall stewardship of the transport network, but the operation and maintenance of rail and bus fleets is typically subcontracted to a third-party provider.

Public transport contracting arrangements vary by State. Some are based on zonal arrangements, others are segmented according to service type (e.g., public transport, coach and school buses). For example, states such as NSW operate its bus network through 15 contracts – although this number represents a significant consolidation of contract areas since the early 2000s. These contracts are usually awarded through a competitive tender, but operators have also been known to negotiate direct award.

Implementing trials and pilots through public transport contracts will therefore rely on suitable renewal terms within the next 2-5 years, and this is limited. The trial will also rely on the ability for government to influence the tender arrangement or negotiated award.

Limitations of traditional tenders and performance-based contracts

A competitive tender or some form of negotiated performance-based contract are the 'traditional' approaches to engage third-party transport providers. Contracts of this nature aim to achieve a quality service for users, a fair price to government and a viable business for the private operator. While traditional contracting models could logically be used to implement a Hydrogen for Transport trial, the arrangement is likely to present a number of challenges.

In particular, private operators will be reluctant to take on the financial and operational risk presented by running part of the fleet on an emerging technology. With buses, for example, the arrangement is made difficult by not only the high upfront capital cost, but the high level of uncertainty regarding the operational and maintenance requirements. Traditional tender arrangements are not in a position to support this kind of risk and complexity.

"…one of the biggest regulatory hurdles is the state procurement of buses. The whole process is rigid and can't be changed easily. Current contracts simply call out diesel buses to run on xyz route and this level [of specification] constrains the operator for a long time…"

– Energy Agency

"…a key question is how you persuade private bus operators to spend more…"

- Hydrogen Agency

Consortiums and government partnerships

A more common approach to deal with the complexity and risk associated with trialling an emerging technology is to contract and implement through a consortium that can collaborate and closely support Government, and the transport operator.

A number of these models have been implemented in Europe, and often the consortia will be tasked with multiple ‘projects’ – pooling expertise and developing capability as each trial is implemented.

Consortia model in Europe

3Emotion is a Europe-based consortium that consists of 16 partners, each with a well-defined contribution to the task of FCEV bus implementation. The group sees itself as an enabler to bridge the gap between fuel cell bus demonstrations and larger scale deployment.

This consortium consists of public transport operators, bus manufacturers and fuel cell manufacturers. Importantly the consortium also involves local authorities and partnerships in European countries. This ‘cluster’ of expertise in hydrogen bus trails has propagated to five sites in Europe, operated by seven public transport operators.

Consortia model in London

Transport for London (TfL) has led the way in the adoption of a fuel cell bus fleet via a joint undertaking. The initial fleet has been operated as part of the Clean Hydrogen in European Cities project (CHIC). The city is expanding its fleet with two additional Van Hool fuel cell buses. These two buses are part of the 3Emotion project described above.

The contract itself is between Belgian bus builder Van Hool and TfL, but the contract is supported by the 3Emotion fuel cell bus consortium.

The ability for commercial interests to manage risk

The private market (e.g., OEMs and fuel retailers) are also aware of the complexity and risk associated with adopting emerging technologies within the transport sector. To this end, a small number of progressive automobile and transport companies have explored commercial models which overcome the traditional barriers associated with implementing an emerging technology.

Nikola motor offering an integrated leasing model

Nikola Motors has an innovative approach to bringing its hydrogen trucks (the Nikola class 8 truck) to the market – the company is looking to bundle truck, fuel and maintenance expenses into a single long-term lease.

Nikola plans to build its own network of truckstop-sized hydrogen fuel stations across the USA and Canada. The plan to combine the major costs of truck ownership and operation into a single monthly lease requires a million-mile lease at a cost of 95 cents per mile.

The company plans to open its first commercial station under this model in California in 2021.

CHAPTER 7

RECOMMENDATIONS

Through the research and assessments undertaken, key themes have emerged around how to identify and implement successful Hydrogen for Transport trials.

The following recommendations reflect the international and domestic experiences with hydrogen for transport and other implementations of new transport technology.

7.Recommendations

In Chapter 1 the key barriers and risks that need to be considered when implementing hydrogen transport trials, demonstrations and pilots were discussed. Recommendations have been arranged against each of these considerations, with Table 32 providing detail for each recommendation.

Table 32 Recommendations against each key barrier and risk

Supply (vehicles and infrastructure)	**We recommend that a number of avenues are explored regarding the supply of vehicles and infrastructure** There is a very limited set of hydrogen vehicles among traditional OEMs. For this reason, we recommend that trials consider as many avenues as possible regarding the procurement of hydrogen technology. Either 'non-traditional' OEMs or opportunities for in-country manufacturing should be considered for initial non-passenger trial opportunities.
Relative Performance	**We recommend bus, trucks and material handling are the most suitable pilots** Of all the use cases considered, bus and truck fleets emerged as the preferred pilots within the scale of A$20-A$100 million. These fleet arrangements score well because of the relative strengths of hydrogen technology in these applications, the large addressable market, and strategic objectives that can be achieved. From a performance perspective, the highest scoring opportunities offer high utilisation of refuelling infrastructure (e.g., back-to-base refueling models). This includes government fleets, bus corridors and logistics hubs. A case can also be made for pursuing material handling and haulage in the mining sector, but the procurement barriers will need to be considered closely. **We recommend that whole of life costing is undertaken** The capital cost of hydrogen technology is currently prohibitively high. The financial viability of the technology makes more sense when viewed from a whole-of-life perspective. Currently, however, the evidence base for this is limited. Buses, for example, have a thirty-year life and it is difficult to demonstrate the cost-effectiveness. We recommend that any pilot or trial decision considers estimates of operational and maintenance costing – these should be included in the commercial arrangement and the creation of a value proposition.

Market Preferences	**We recommend that hydrogen use cases focus on a narrow set of industries and applications** Combustion engines and BEVs are likely to win the hearts and minds of consumers in the majority of transport applications. Furthermore, when compared to both these technologies, hydrogen has the most barriers relating to the cost-effective roll out of refuelling infrastructure. For these reasons, hydrogen is likely to remain a relatively niche technology. Success will come from undertaking a narrow range of applications and doing them well. Focusing on fleet passenger transport, logistics activities and industrial sectors, such as mining, is seen as the preferred approach. **We recommend that trials are implemented in business-as-usual environments** The technology is relatively nascent – commercial entities, in particular, will be highly concerned with the operational performance of a hydrogen fleet and the whole of life costing (regardless of whether government assistance is provided for capital costs). Furthermore, trials will need to be publicly visible and well-integrated into a 'business as usual' setting in order to encourage broad adoption. **We recommend that trials need to be of a scale greater than A$5 million** In general, trials less than A$5 million do not have a large enough addressable market, or strategic impact to be considered effective. Investment within the A$20-A$100 million range allows for substantial-enough size of fleet. For example, a bus investment is not considered effective until it can support an end-to-end route.
Regulation and Policy	**We recommend that government looks beyond capital grants to support opportunities** A vertically integrated industry trial is preferable to enable the capital investment for refuelling infrastructure to be distributed across multiple modes. This could occur within activities such as mining, logistics, urban transport or intra-city freight. From an industry perspective, however, the business case for the procurement of hydrogen FCEVs will need to be incentivised by government policy
Commercial Factors	**We recommend that pilots are partnered with industry stakeholders** This study found that successful trials are often achieved through a partnership of multiple stakeholders. A commercial model that is underpinned by a partnering arrangement (e.g., a manufacturer, end user, and refuelling infrastructure provider), with appropriate risk apportionment between the different entities, will encourage best outcomes for initial trials.

Next Steps

Based on the findings of this study, our analysis shows that buses, trucks, and material handling are the most suitable transport modes for an initial pilot or trial.

The proposed next steps to support the implementation of a hydrogen transport trial should include:

1. Detailed cost-benefit analysis to validate the findings from this study, and the relative value of each pilot or trial
2. Formalise a roadmap for implementation that supports the whole of economy (including domestic use, export etc) view of a hydrogen future, to inform investment priorities
3. Explore methods for procurement, including innovative commercial arrangements to incentivise private investment and maximise collaboration

With a fully developed hydrogen economy roadmap, key stakeholders (including government entities, end users, manufacturers, and investors) will have a clearer understanding of the end-to-end value proposition, enabling decision-makers to identify the projects which will facilitate strategic growth for a hydrogen economy in Australia.

Appendix

Summary assessment of mode opportunities

Mode	Technology maturity	Ease of Procurement	Operational suitability	User adoption	Overall
Private Vehicles	Good: commercially available	Moderate: for lease in Australia	Limited: Low infrastructure utilisation	Limited: High initial cost	**Moderate**
Fleet Vehicles	Good: commercially available	Moderate: for lease in Australia	Good: High infrastructure utilisation	Moderate: Initial cost vs publicity	**Good**
Passenger Rail	Good: commercial operation	Limited: single provider	Moderate: advantageous in rural areas	Moderate: Similar experience	**Moderate**
Passenger Bus	Good: commercially available	Moderate: multiple suppliers	Good: High infrastructure utilisation	Good: Improved experience	**Good**
Ferry	Moderate: in development	Limited: not available	Moderate: Similar to existing service	Moderate: Similar experience	**Moderate**
Aviation	Limited: initial development	Limited: not available	Moderate: Similar to existing service	Limited: Poor public perception	**Limited**
Material Handling	Good: commercially available	Good: multiple suppliers	Good: Performance gains possible	Moderate: Similar experience	**Good**
Freight Rail	Limited: initial development	Limited: not available	Good: Natural technical advantage	Good: Improved experience	**Moderate**
Goods Vehicles	Good: commercial operation	Moderate: special release only	Good: High infrastructure utilisation	Moderate: Similar experience	**Good**
Shipping	Limited: initial development	Limited: Not available	Moderate: Similar to existing service	Moderate: Similar experience	**Limited**

Multi-criteria assessment scoring for each proposed trial

Scoring Options

Score	Description
1	Poorly satisfies this criteria
2	Moderately satisfies some, but not all, aspects of this criteria
3	Moderately satisfied this criteria
4	Highly satisfies some, but not all, aspects of this criteria
5	Highly satisfies this criteria

Assessment Criteria	Bike Fleet	Gov't Fleet	Corridor Fleet	Hydrogen Hub Fleet	Bus - Individual	Bus - Metropolitan	Bus - Park and Ride	Material Handling	Mine Haulage	Private Rail Link	Trucks - Govt Logistics	Trucks - Last Mile	Trucks - Road Freight	Weighting
Strategic Growth	1	4	3	5	2	4	4	2	4	3	2	3	5	30%
Addressable Market	1	4	3	1	2	5	4	3	5	4	3	5	4	10%
Relative Peformance	2	1	2	3	1	3	3	4	3	3	2	2	2	40%
Procure and Implement	4	5	4	3	2	4	3	5	1	2	3	3	2	15%
User Adoption	3	3	4	5	2	5	5	2	2	2	2	4	3	5%
	2.0	**2.9**	**2.8**	**3.5**	**1.6**	**3.8**	**3.5**	**3.4**	**3.2**	**2.9**	**2.3**	**2.9**	**3.2**	

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Bringing ideas to life