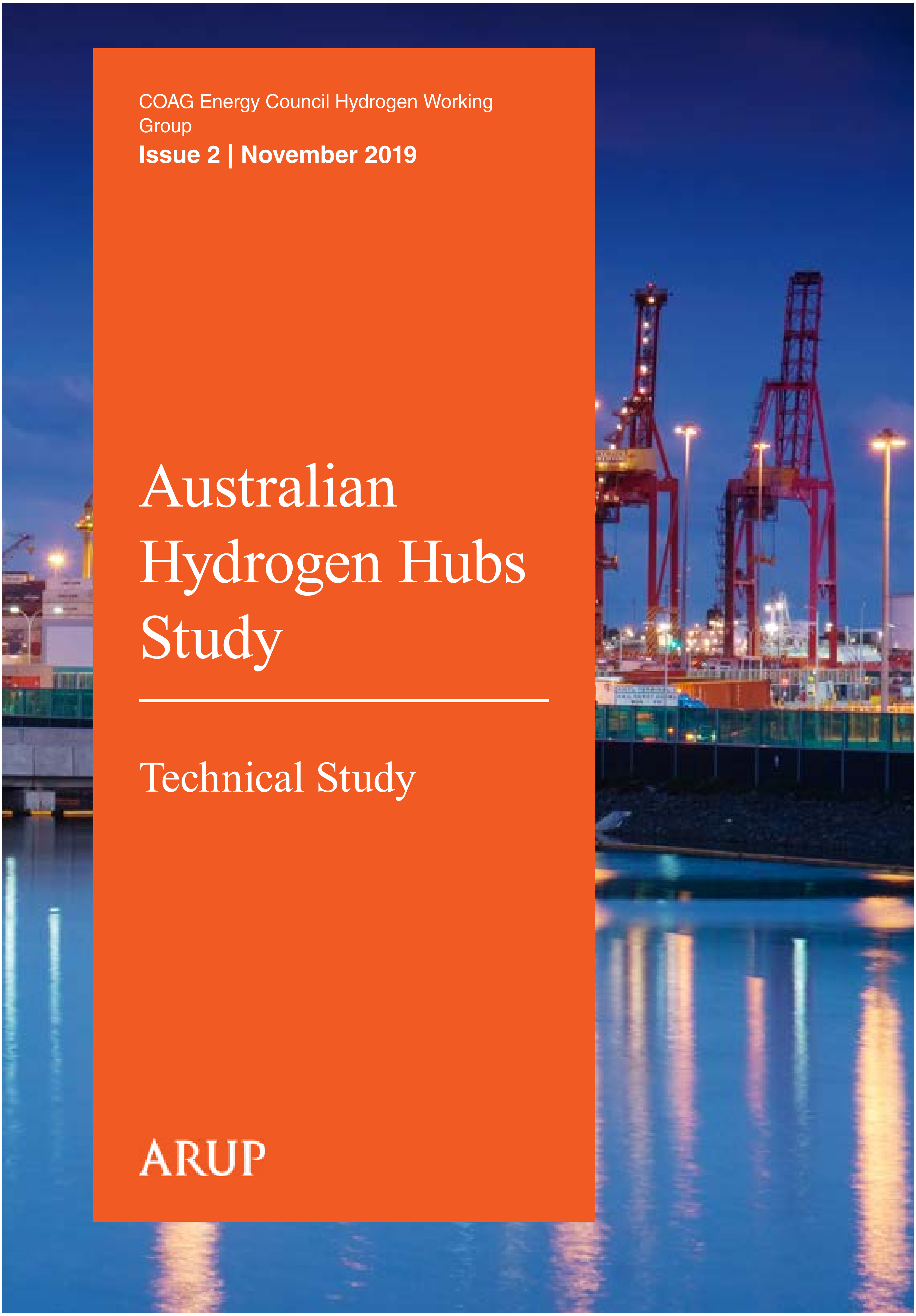

COAG Energy Council Hydrogen Working Group

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Australian Hydrogen Hubs Study

Technical Study

ARUP

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Glossary of Terms

TERM	DESCRIPTION
ACT	Australian Capital Territory
ASEAN	Association of Southeast Asian Nations
BEV	Battery Electric Vehicles
BESS	Battery Energy Storage System
CFD	Computational Fluid Dynamics
COAG	Council of Australian Governments
CCS	Carbon Capture and Storage
CSG	Coal Seam Gas
CSP	Concentrated Solar Power
DWT	Dead weight Tonnage
ERIA	Economic Research Institute for ASEAN and East Asia
ESS	Energy Storage System
FCEV	Fuel Cell Electric Vehicles
G20	Group of Twenty
GA	Geoscience Australia
GHG	Greenhouse gas
GIS	Geographic information system
GJ	Gigajoule
GW	Gigawatt
H2	Hydrogen
HDPE	High-density polyethylene
HGVs	Heavy Goods Vehicle
ID	Identification
IEA	International Energy Association

TERM	DESCRIPTION
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LOA	Length Overall
LNG	Liquid Natural Gas
LOHC	Liquid Organic Hydrogen Carriers
MCH	Methylcyclohexane
MWh	Megawatt-hour
PHES	Pumped Hydroelectric Energy Storage
PRRT	Petroleum Resource Rent Tax
RAPS	Remote Area Power Supply
R&D	Research and Development
SDGs	Sustainable Development Goals
SMR	Steam methane reforming
TJ	Terajoule
WEC	World Energy Council
WWTP	Waste Water Treatment Plant

Executive Summary

According to the International Energy Agency and the World Energy Council, Australia has the potential be the world's largest hydrogen producer.

The potential role of hydrogen in the transition to a more sustainable energy future has attracted strong interest globally over recent years. According to the International Energy Agency and the World Energy Council, Australia has the potential be the world's largest hydrogen producer. The Economic Research Institute for ASEAN and East Asia (ERIA) forecasts that Australia is poised to become the East Asia region's largest hydrogen exporting source, exporting 42% of regional supply by 2040[1].

The Council of Australian Governments (COAG) Energy Council committed to developing and implementing a national strategy for hydrogen in December 2018, in close consultation with industry and the community. The vision is for Australia to be a major player in a global hydrogen industry by 2030. The key opportunity of incentivising early investment in a hydrogen economy is captured in the 2018 Hydrogen White Paper vision statement:

Our vision is a future in which hydrogen provides economic benefits to Australia through export revenue and new industries and jobs, supports the transition to low emissions energy across electricity, heating, transport and industry, improves energy system resilience and increases consumer choice.[2]

Hydrogen can be generated from renewable energy resources, and it is as a clean, flexible, storable and safe energy vector. When used as a fuel it does not generate carbon emissions. Hydrogen can also be generated from using natural gas, coal and biomass. Where carbon is a by-product of this process these emissions can be captured and stored.

In this study, unless otherwise indicated, 'hydrogen' refers to 'clean hydrogen' which is defined as being produced by utilising renewable energy (green hydrogen) or fossil fuels with carbon capture and storage (blue hydrogen). This definition reflects the principle of technology neutrality set by COAG Energy and Resources Ministers when they commissioned a comprehensive and ambitious strategy for the development of an Australian hydrogen industry. It follows that a clean hydrogen supply chain is also needed to realise a clean hydrogen economy.

The International Energy Agency (IEA) has identified the opportunity to create 'hydrogen hubs' could bring down the cost of low-carbon hydrogen pathways[3]. The term 'hub' refers to a region that has the potential to aggregate demand for hydrogen. These hubs could be coastal industrial clusters or co-located near ports. The creation of hubs is expected to be an effective springboard to growing a hydrogen economy. It is in this context that Arup have been commissioned by COAG to develop criteria for determining the feasibility of hydrogen export hubs, precincts, cities and regions and to assess the supply chain infrastructure needed to support these hubs in Australia.

The International Energy Agency (IEA) has identified the opportunity to create 'hydrogen hubs' could bring down the cost of low-carbon hydrogen pathways.

Study Overview

Arup have conducted interviews with targeted industry and government stakeholders to gather data and perspectives to support the development of this study. Arup have also utilised private and publicly available data sources, building on recent work undertaken by Geoscience Australia and Deloitte, and the comprehensive stakeholder engagement process to inform our research. This study considers the supply chain and infrastructure requirements to support the development of export and domestic hubs. The study aims to provide a succinct "Hydrogen Hubs" report for presentation to the hydrogen working group.

Study Outcome

The hydrogen supply chain infrastructure required to produce hydrogen for export and domestic hubs was identified along with feedback from the stakeholder engagement process. These infrastructure requirements can be used to determine the factors for assessing export and domestic hub opportunities. Hydrogen production pathways, transportation mechanisms and uses were also further evaluated to identify how hubs can be used to balance supply and demand of hydrogen.

A preliminary list of current or anticipated locations has been developed through desktop research, Arup project knowledge and the stakeholder consultation process. Over 30 potential hydrogen export locations have been identified in Australia through desktop research and the stakeholder survey and consultation process. In addition to establishing export hubs, the creation of domestic demand hubs will be essential to the development of an Australian hydrogen economy. It is for this reason that a list of criteria has been developed for stakeholders to consider in the siting and design of hydrogen hubs. The key considerations explored are based on demand, supply chain infrastructure, and investment and policy areas.

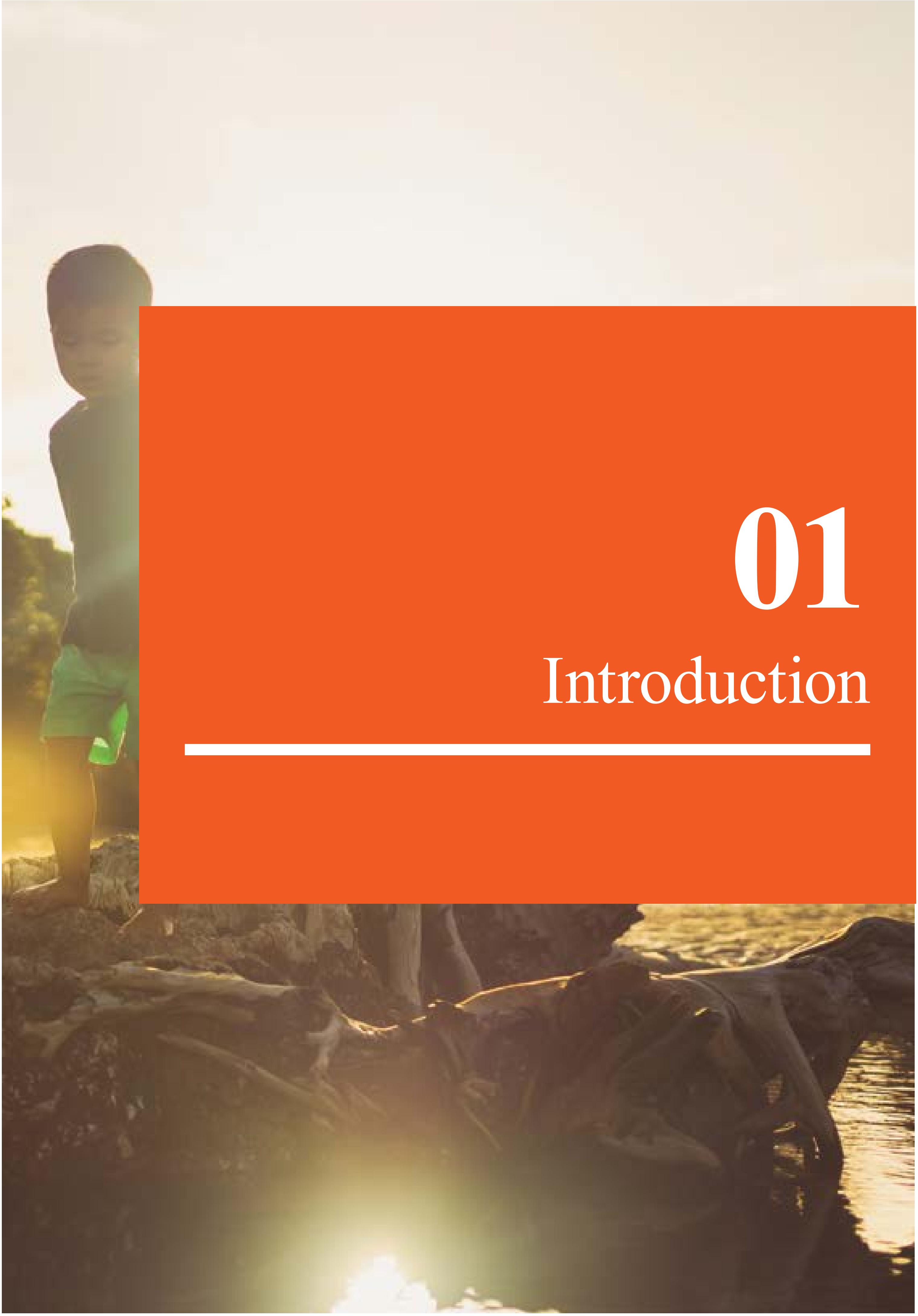
Based on these considerations, a list of criteria were developed to assess the viability of export and domestic hydrogen hubs. Criteria relevant to assessing the suitability of export and domestic hubs include:

- Health and safety provisions;
- Environmental considerations;
- Economic and social considerations;
- Water availability;

- Land availability with appropriate zoning and buffer distances & ownership (new terminals, storage, solar PV, industries etc.);
- Availability of gas pipeline infrastructure;
- Availability of electricity grid connectivity, backup energy supply or co-location of renewables;
- Road & rail infrastructure (site access);
- Community and environmental concerns and weather. Social licence consideration;
- Berths (berthing depth, ship storage, loading facilities, existing LNG and/or petroleum infrastructure etc.);
- Port potential (current capacity & occupancy, expandability & scalability);
- Availability of, or potential for, skilled workers (construction & operation);
- Availability of, or potential for, water (recycled & desalinated);
- Opportunity for co-location with industrial ammonia production and future industrial opportunities;
- Interest (projects, priority ports, state development areas, politics etc.);
- Shipping distance to target market (Japan & South Korea);
- Availability of demand-based infrastructure (i.e. refuelling stations).

A framework that includes the assessment criteria has been developed to aid decision making, rather than recommending specific locations that would be most appropriate for a hub. This is because there are so many dynamic factors that go into selecting a location of a hydrogen hub, that it is not appropriate to be overly prescriptive or prevent stakeholders from selecting the best location themselves, or from the market making decisions based on its own research and knowledge. The developed framework rather provides information and support to enable these decision-making processes.

[1] Australian Government: COAG Energy Council. National Hydrogen Strategy: Issues paper series – Developing a hydrogen export economy. Available at: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/supporting_documents/NationalHydrogenStrategyIssue3DevelopingHydrogenExportIndustry.pdf
[2] Hydrogen Strategy Group. 2018. Hydrogen for Australia's future. Available at: https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf
[3] IEA. 2019. Commentary: The clean hydrogen future has already begun. Available at: https://www.iea.org/newsroom/news/2019/april/the-clean-hydrogen-future-has-already-begun.html



01

Introduction

1.1 Sustainable development

Australia has joined a number of countries around the world looking to harness the hydrogen opportunity.

There is global momentum toward the pursuit of a more sustainable and resilient energy future. The Kyoto Protocol, developed under the United Nations Framework Convention on Climate Change, came into effect in 2005 and commits its parties by setting internationally binding greenhouse gas emissions target reductions[4]. These targets are measured as equivalent in carbon dioxide, commonly referred to as carbon emissions. In Australia, and many countries around the world, the energy sector (comprising stationary energy, transport and fugitive emissions) continues to be the largest contributor to greenhouse gas emissions.

In September 2015, the General Assembly adopted the 2030 Agenda for Sustainable Development that included 17 Sustainable Development Goals (SDGs)[5]. Building on the principle of "leaving no one behind", the Agenda emphasises a holistic approach to achieving sustainable development for all. SDG 7 "Affordable and Clean Energy" and SDG 11 "Sustainable Cities and Communities" promote the sustainable energy security and resilience.

The potential role of hydrogen in the transition to a more sustainable energy future has garnered strong interest globally over recent years. Hydrogen can be generated from renewable resources, and is as a clean, flexible, storable and safe molecular energy vector. When used as a fuel it does not generate carbon emissions. Hydrogen can be extracted from sources including water, natural gas, coal and biomass. Where carbon dioxide is a by-product of this process these emissions will need to be captured and stored.

Hydrogen was also the focus of two keynote meetings at the 2019 G20 Summit in Japan including “The Future of Hydrogen” and “Demand and Supply Potential of Hydrogen Energy in East Asia”.

Australia has joined a number of countries around the world looking to harness the hydrogen opportunity. The potential export market for Australia to East Asia[6], in particular Japan, South Korea, Singapore, Taiwan, China and others emerging as potential markets, has stimulated focus on early market advantage for potential hydrogen generating countries such as Australia.

1.2 Australia's competitive advantage

The IEA Future of Hydrogen[7] report identifies four near-term opportunities to boost the hydrogen economy on its pathway to sustainability. When overlaid against current resources, economy and infrastructure, it appears that Australia has a competitive advantage. The report refers to the growth opportunities through investment in a hydrogen economy as referenced in Table 1.

Table 1. Growth opportunities through investment in a hydrogen economy

#	IEA NEAR-TERM OPPORTUNITIES	AUSTRALIA'S COMPETITIVE ADVANTAGE
1	Make industrial ports the nerve centres for scaling up the use of clean hydrogen.	Australia has major ports along its coastlines exporting resource commodities, many with existing LNG and petroleum infrastructure. These ports are well suited to support both large upscaling of hydrogen production for export and domestic use.
2	Build on existing infrastructure, such as the extensive network of natural gas pipelines.	Australia has 38,000km of gas transmission and 88,000km of distribution pipeline servicing 4.3m households and 130,000 business. These are primarily on the east coast and are also found in a number of regions in WA and the NT. Replacing or blending natural gas with hydrogen in this network at even a 5% of volume would significantly boost demand and likely drive down hydrogen costs.
3	Expand hydrogen in the transport sector through fleets, freight and corridors.	Over three quarters of Australia's non-bulk freight is transported on roads with Australia's rail and maritime networks also playing a key role in meeting the national freight task. All of which can be potentially transitioned to hydrogen fuel and Hydrogen Vehicle Fuel Cell (HVFC) technology.
4	Launch the hydrogen trade's first international shipping route.	Australia is the second largest exporter of LNG globally after Qatar (LNG is approximately 18% of Australia's total exports) and has extensive trade routes established globally. Exports to South East Asia, China and Japan account for 19%, 33% & 45% of Australia's total LNG export earnings, respectively. The lessons learnt from this industry can be easily capitalised to progress the Australian hydrogen industry.

With the continuing decline in costs of solar and wind generation and an abundance of renewable resources, Australia is firmly placed to take advantage of both renewable hydrogen generation and curtailment advances. Australia is already a trusted trading partner and energy provider in the region. Combined with its relative geographical proximity, an abundance of renewable energy assets and experience developing resources and energy projects, Australia is well-placed to be a major hydrogen supplier to these nations[8]. The Australian Government has recognised the benefits to leveraging Australia's competitive advantage early on. The roll out of a National Hydrogen Strategy[9] will provide a two-fold benefit through coordinating existing domestic efforts as well as signal internationally that Australia has serious intent in relation to leading the global hydrogen export economy.

1.3 Coupling of export and domestic markets

At the same time, maturing hydrogen technologies, growing investor confidence (both domestically and internationally) and gaining stakeholder support to develop a hydrogen economy are key pillars that will support the development of an export market

A key area of export focus involves building upon the existing strong bilateral trade relations with the Asian market. Japan, South Korea and China are currently the three single largest LNG importers globally. As these key markets shift their energy consumption to alternative energy vectors such as hydrogen, lucrative export opportunities will emerge for Australia. Japan is currently our biggest energy export market, importing $41bn of Australian minerals and energy[10].

These foreign economies have also signalled a need for the development of hydrogen economies to export their hydrogen goods and to maintain balance of trade. In the case of these three Asian nations, this will largely entail the Australian import of hydrogen-fuelled transport fleets (cars, HGVs, buses, etc.) which will in turn support the development of an Australian domestic hydrogen market. The implications of this hydrogen-based trade relationship are already being championed with bilateral agreements such as the Australia-Japan Memorandum of Cooperation on Energy and Minerals Cooperation signed on 16th June 2019, which includes specific focus on cooperation in establishing a future hydrogen supply-chain and industry including in new policies and regulations, research and new trade and investment opportunities[11]. In addition, Australia signed a letter of intent in September 2019 to collaborate with South Korea in development of a Hydrogen Action Plan by the end of the calendar year[12].

At the same time, maturing hydrogen technologies, growing investor confidence (both domestically and internationally) and gaining stakeholder support to develop a hydrogen economy are key pillars that will support the development of an export market. Australia is currently undertaking a range of hydrogen projects to kick-start the domestic economy ranging from blending hydrogen into existing domestic gas networks (Adelaide) and trialling export supply chains (Melbourne) to pilot refuelling stations (Canberra and Perth) and seawater electrolysers (Newcastle).

Given the value drivers for each market and establishing the necessary synergies will be crucial to the successful roll out of the hydrogen economy. Perhaps more fundamentally, a strong domestic hydrogen market could be instrumental in supporting the 'scale up' of hydrogen production facilities that will facilitate cost-competitive export and give investors the confidence to implement long-term programmes for hydrogen development.

1.3.1 Hydrogen hubs

The establishment of "hydrogen hubs" provides an effective springboard to achieving the vision outlined above and is the focus of this study report.

The term "hub" refers to a region that has the potential to aggregate demand for a product (hydrogen in this instance). The principle behind this is based on creating an intelligent system such that the end-product provides greater benefits than the sum of its individual parts. The outcome of this is an increase in demand, supply, maturing technologies and lowered costs.

The primary advantages of establishing hydrogen hubs are summaries in Table 2 below.

Table 2. Primary advantages of establishing hydrogen hubs.

#	ADVANTAGE	DESCRIPTION
1	Sector coupling	Sector coupling refers to intelligent linking of systems and markets to create new services and provide additional value. Versatility to be used in different sectors enables benefits to be shared and prices to be lower.
2	Decarbonising existing supply chains	Locating hydrogen hubs in already populated industrial areas provides the option to displace fossil fuels with clean hydrogen in a cost-effective way. This will benefit the existing industry but will also induce further investment in these locations.
3	Co-location	Locating hydrogen generation in proximity to existing LNG, petrochemical and other resource-based industries (ammonia and methanol being key examples) will save costs by utilising the already existing infrastructure and skills – transmission & distribution lines, storage, transport routes and established industry knowledge. * It will also enable economies of scale and scope.
4	Centres of Industrial and Academic Eminence	The creation of any hub stems the development of technology and encourages investment. Consequently, the creation of hydrogen hubs will attract hydrogen based industrial and academic institutions to the regions (based on the advantages above to be gained) creating "Centres of Eminence".

* Note: Please note that reference is made in this report to 'ammonia' the reference is to 'anhydrous ammonia' unless otherwise stated (i.e. liquid ammonia). Urea and other forms are less concentrated and therefore not likely to be a long-distance economic transport mechanism.

The establishment of hydrogen hubs is also anticipated to improve alignment of interest between industry, authorities and academia. They will ensure that regulation and policy are developed in time to enable safe and equitable investment environments that consider environmental impact, public opinion and safety in the process.

1.4 Study Overview

Arup have been commissioned by COAG to identify locations under consideration by stakeholders for hydrogen export hubs, develop criteria for determining the feasibility of hydrogen precincts, cities and regions and assess the supply chain infrastructure needed to support these hubs in Australia. The previous work undertaken by Geoscience Australia and Deloitte through their Prospective Hydrogen Production Regions of Australia[13] and Australian and Global Hydrogen Demand Scenario Analysis[14] reports respectively have been vital to the development of this document.

Arup conducted interviews with stakeholders from both Government and industry bodies. The primary aim was to gather data and perspectives from key potential players in the hydrogen landscape as well as to investigate key issues such as: perceived barriers and enablers, existing pilot projects, investor and jurisdictional appetites to pursue hydrogen and so forth. The data gathered from this engagement methodology has been distilled to shape the study's findings.

The hydrogen supply chain infrastructure required to produce hydrogen for export and domestic hubs was identified along with feedback from the stakeholder engagement process. These infrastructure requirements can be used to determine the factors for assessing export and domestic hub opportunities. Hydrogen production pathways, transportation mechanisms and uses were also further evaluated to identify how hubs can be used to balance supply and demand of hydrogen.

A preliminary list of locations has been developed through desktop research, Arup project knowledge and the stakeholder consultation process. Those interviewed in-person and via the online survey were prompted for drivers and preferences for the location for the export of hydrogen.

In addition to establishing export hubs, the creation of domestic demand hubs will be essential to the development of an Australian hydrogen economy. It is for this reason that a list of criteria has been developed for stakeholders to consider in the siting and design of hydrogen hubs. The key considerations explored are based on demand, supply chain infrastructure, and investment and policy areas.

[4] https://unfccc.int/kyoto_protocol
[5] https://sustainabledevelopment.un.org/?menu=1300
[6] Australian Government: COAG Energy Council. National Hydrogen Strategy: Issues paper series – Developing a hydrogen export economy. Available at: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/supporting_documents/NationalHydrogenStrategyIssue3DevelopingHydrogenExportIndustry.pdf
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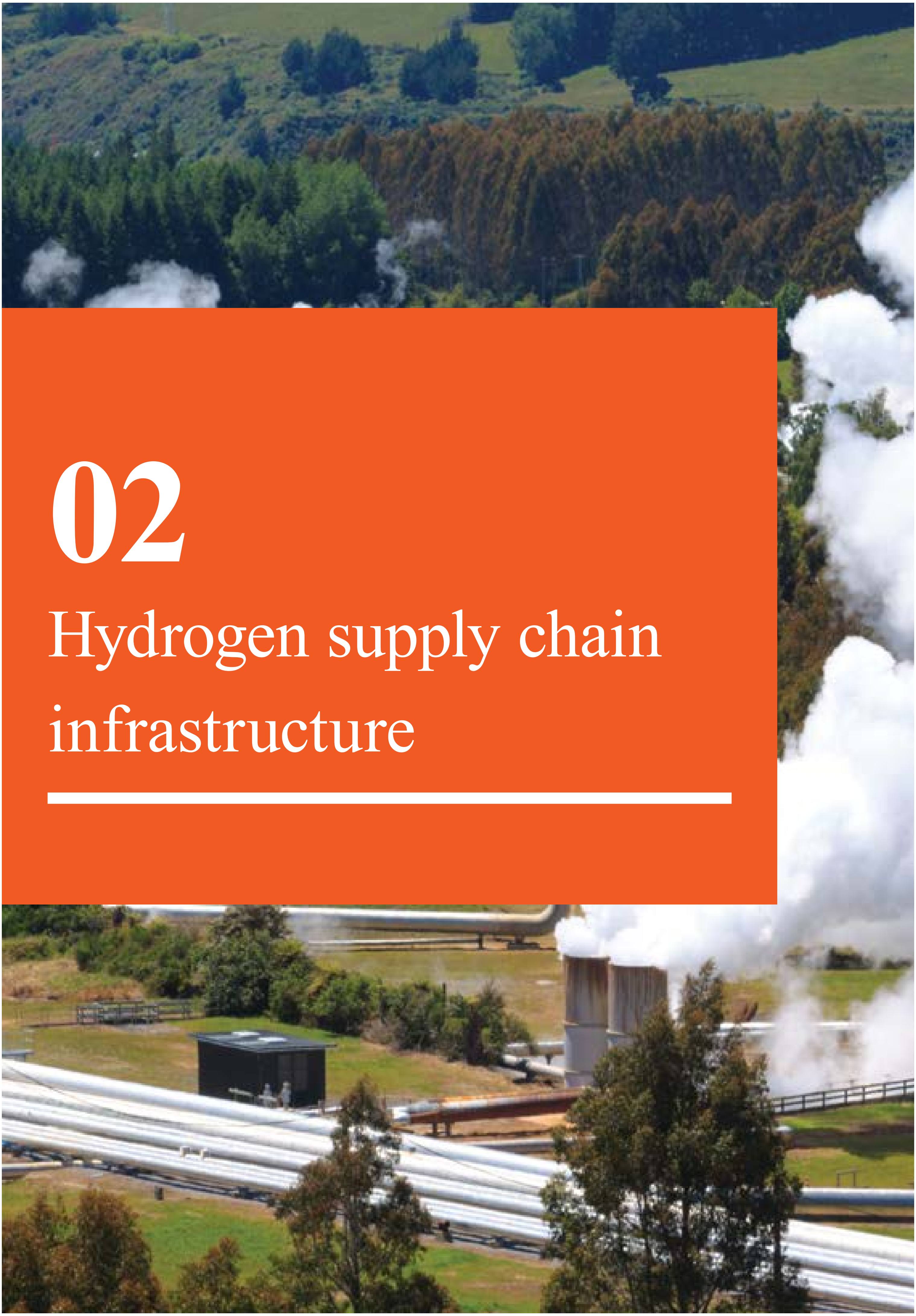
[8] Australian Government: COAG Energy Council. National Hydrogen Strategy: Issues paper series – Developing a hydrogen export economy. Available at: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/supporting_documents/NationalHydrogenStrategyIssue3DevelopingHydrogenExportIndustry.pdf
[9] https://www.industry.gov.au/about-us/what-we-do/coag-energy-council-hydrogen-working-group
[10] https://minister.environment.gov.au/taylor/news/2019/new-australia-japan-partnership-strong-energy-and-resources-future
[11] METI. 2019. *Memorandum of Cooperation on Energy and Minerals Cooperation between Ministry of Economy, Trade and Industry of Japan and Department of the Environment and Energy of Australia.* Available at: https://www.meti.go.jp/press/2019/06/20190618008/20190618008_08.pdf
[12] https://www.minister.industry.gov.au/ministers/canavan/media-releases/new-report-puts-hydrogen-production-map
[13] Geoscience Australia. 2019. *Prospective hydrogen production regions of Australia.*
[14] Deloitte (for COAG Energy Council - National Hydrogen Strategy Taskforce). 2019. *Australian and Global Hydrogen Demand Growth Scenario Analysis.*



02
Hydrogen supply chain infrastructure

This chapter focuses on the hydrogen supply chain infrastructure required to produce hydrogen for export and domestic hubs. The hydrogen supply chain consists of production, transport, storage and end market, all of which are covered in this chapter.

This chapter outlines the development of a list of criteria to guide the decision-making process for assessing supply chain infrastructure. The following chapters then extend upon these criteria to consider the factors for assessing export and domestic hub opportunities in Australia. Insights are drawn from the stakeholder engagement process (reference to Appendix A), desktop review of existing documentation and industry exposure to hydrogen projects, operating, under development, or in the future.

2.1 Hydrogen supply chain

The hydrogen supply chain consists of production, transport, storage and end use. The production of hydrogen (fossil fuels or renewables) and end use (domestic use or international export) will affect the infrastructure along the supply chain. This section considers the storage, transport and safety considerations of the supply chain. Hydrogen production is discussed at high level in Section 2.2. End uses are introduced but discussed in further detail in Chapter 4.

2.2 Hydrogen production

There are currently a number of ways of extracting hydrogen each with their own benefits, challenges, limitations, and carbon footprints. They are:

1. **Green hydrogen**
   Hydrogen produced from electrolysis the electricity comes from renewable sources;

2. **Blue hydrogen**
   Hydrogen produced from natural gas with carbon capture and storage (CCS);

3. **Grey hydrogen / Brown hydrogen**
   Hydrogen produced as a by-product of industrial processes or from carbon-based fossil-fuel energy sources without CCS.

These categories are not universally agreed and there is a lack of clarity on specific cases. For example; if hydrogen is produced via electrolysis using grid power with a largely but not completely renewable grid supply mix, would this be considered green hydrogen? Is the use of carbon offsetting for projects acceptable for green or blue hydrogen credentials? Is there a categorisation needed for the green credentials of the supply chain (delivery to the end user)?

Each production process requires different infrastructure elements, considerations and provides different efficiency outcomes. To determine assessment criteria to evaluate potential hydrogen hubs, high-level critical infrastructure elements of each process must first be identified.

The following sub-sections and figures seek to identify the primary infrastructure elements of hydrogen production required in the formation of both hydrogen export and domestic hubs.

Green hydrogen

Critical infrastructure requirements for green hydrogen are:

- Water source;
- Connectivity to renewable energy source;
- Firmed energy source (i.e. it delivers steady electricity feed);
- Electrolysis or thermo-chemical splitting system;
- Storage cell.

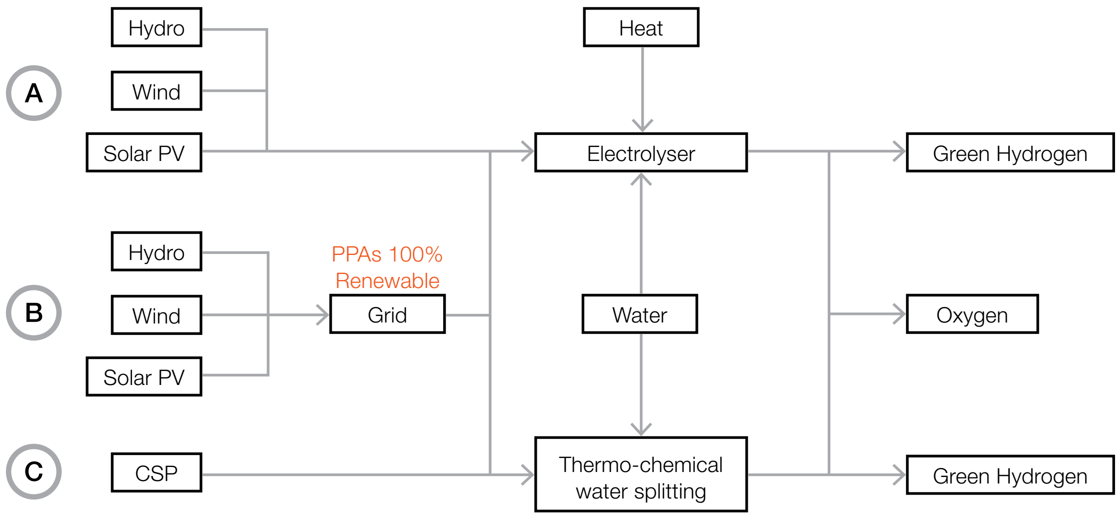


Figure 1. Green hydrogen production elements
Source: R.Kothari, et.al, Comparison of environmental and economic aspects of various hydrogen production methods, Renewable & Sustainable Energy Reviews, July 2006

Although sourcing hydrogen through this method is environmentally the cleanest solution and produces no emissions, there are limitations. Electrolysis is an evolving technology that is becoming increasingly more cost effective and efficient. However, current electrolysers have a low round trip efficiency, resulting in energy outputs that are significantly lower than amount of energy input. Green hydrogen is dependent on the price of renewable electricity utilised in the electrolysis process. The availability of green hydrogen is intrinsically linked to the intermittent availability of renewable energy sources which will also impact the level of utilisation of equipment used in the electrolysis process.

A Pathway A in Figure 1 represents renewable energy source directly connected and used to provide a constant electrolyser energy feed.

B Pathway B shows the same renewable energy resource that is grid connected and may be considered green when PPAs are used to encourage renewable energy sources to connect to the grid; however, these may not be deemed appropriate under green hydrogen certification schemes.

C Pathway C uses high temperatures from concentrating solar power (CSP) to produce hydrogen and is assumed to self-generate electricity or draw green electricity from the grid.

Blue hydrogen

Critical infrastructure requirements for blue hydrogen are:

- Hydrocarbon fuel source;
- Steam methane reforming (SMR) system or other;
- Carbon capture and storage (CCS) or carbon sequestration system.

The pathways to produce hydrogen from various forms of hydrocarbon have numerous steps and are complex, with numerous feedback loops and additional reactions to increase hydrogen yield and reduce emissions.

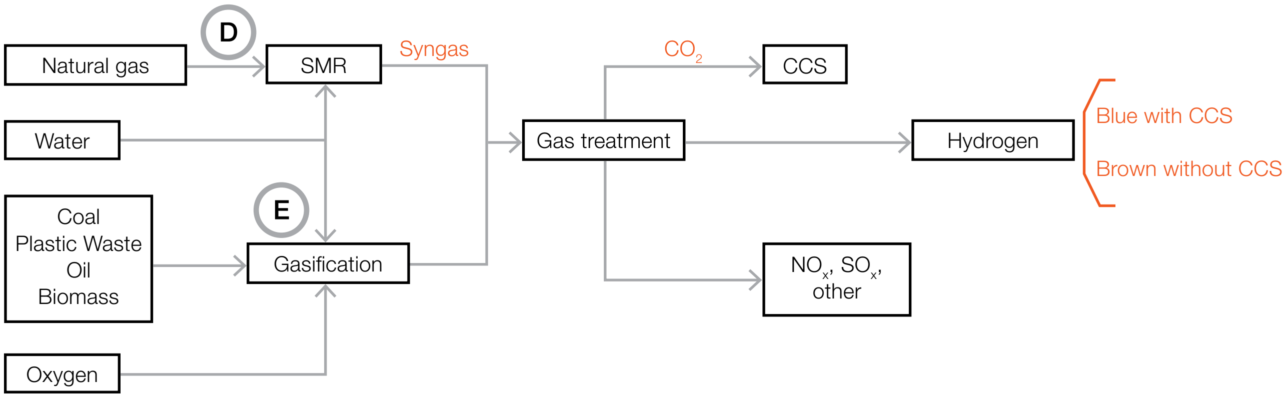


Figure 2. Blue hydrogen production elements
Source: C. Koroneos, et.al, Life cycle assessment of hydrogen fuel production processes, Inter, Journal of Hydrogen Energy, January 2004

D Pathway D in Figure 2 represents a simplified view of the production of hydrogen from natural gas (or methane) through an SMR process, leading to production of hydrogen alongside carbon dioxide and other lesser emissions.

E Pathway E represents a simplified view of gasification process, also leading to production of hydrogen alongside carbon dioxide and other lesser emissions.

In both cases the production stream is only considered “blue” when CCS is used to sequester the carbon dioxide into long-term underground storage (usually underground depleted natural gas reservoirs or porous sealed gas reservoirs.

2.2.1 Storage

Currently, there are three main ways of storing hydrogen for transportation each with their own associated advantages and disadvantages.

With the current state of technology, hydrogen can be compressed, liquefied or attached to a chemical carrier. Table 3 from the National Hydrogen Roadmap developed by the CSIRO summarizes the current technology used for storage and their limitations.

Table 3. National Hydrogen Roadmap - Pathways to an economically sustainable hydrogen industry in Australia.[15]

TECHNOLOGY	DESCRIPTION	ADVANTAGES / DISADVANTAGES
Compression - Low pressure tanks	No additional compression needed from hydrogen production. Only used for stationary storage where lower quantities of hydrogen are needed relative to available space.	Advantages: Established technology Disadvantages: Poor volumetric energy density
Compression - Pressurised tanks	A mechanical device increases the pressure of the hydrogen in its cylinder. Hydrogen can be compressed and stored in steel cylinders at pressures of up to 200 bar. While composite tanks can store hydrogen at up to 800 bar, pressures typically range from 350 to 700 bar. Compression is used for both stationary storage and transport of hydrogen.	Advantages: Established technology Disadvantages: Low volumetric energy density, energy intensive process
Compression - Underground storage	Hydrogen gas is injected and compressed in underground salt caverns which are excavated and shaped by injecting water into existing rock salt formations. Withdrawal and compressor units extract the gas when required.	Advantages: High volume at lower pressure and cost, allows seasonal storage Disadvantages: Geographically specific
Compression - Line packing	A technique used in the natural gas industry, whereby altering the pipeline pressure, gas can be stored in pipelines for days and then used during peak demand periods.	Advantages: Existing infrastructure, straightforward hydrogen storage technique at scale

TECHNOLOGY	DESCRIPTION	ADVANTAGES / DISADVANTAGES
Liquefaction - Cryogenic tanks	Through a multi-stage process of compression and cooling, hydrogen is liquefied and stored at -253oC in cryogenic tanks. Liquefaction is used for both stationary storage and transport of hydrogen.	Advantages: Higher volumetric storage capacity, fewer evaporation losses Disadvantages: Requires advanced and more expensive storage material
Liquefaction - Cryo-compressed	Hydrogen is stored at cryogenic temperatures combined with pressures approaching 300 bar.	Advantages: Higher volumetric storage capacity, fewer evaporation losses Disadvantages: Requires advanced and more expensive storage material
Material based - Ammonia (NH_3)	Hydrogen is converted to ammonia via the Haber Bosch process. This can be added to water and transported at room temperature and pressure. The resulting ammonia may need to be converted back to hydrogen at the point of use.	Advantages: Infrastructure is established, high hydrogen density (17.5% by weight) Disadvantages: Almost at theoretical efficiency limit, plants need to run continuously, energy penalty for conversion back to hydrogen, toxic material

When selecting a form of storage, there is a trade-off between the quantity of hydrogen required, tank size and energy to facilitate the process[16]. Other factors that are relevant when choosing a storage method include length of storage, distance of transportation, purity requirements and speed of release. Stakeholder consultation indicated there was a relatively low knowledge of storage technologies when compared to hydrogen production or transportation, and that while storage as ammonia was the most preferred method, alternative technologies were not far behind. The selection of appropriate storage will be site specific and dependent upon availability of any naturally occurring underground and other surrounding infrastructure, including access to and distance to transport to demand centres.

2.2.2 Transport

One of the biggest cost implications for hydrogen is transport between supplier and consumer. Storage and transport pathways need to be considered in conjunction once supply and demand parties have been identified.

Additionally, the end use of the hydrogen also needs to be considered when selecting the appropriate storage and transport method. Hydrogen can be transported via gas pipelines or transported through logistics routes via trucks, ships or railway lines. Table 4 outlines the hydrogen transport methods with their associated storage types and indicative distances.

Table 4. National Hydrogen Roadmap - Pathways to an economically sustainable hydrogen industry in Australia.[17]

VEHICLE	STORAGE TYPE	INDICATIVE DISTANCES	DESCRIPTION / USE
Truck (Virtual pipelines)	Compression, liquefaction, ammonia	<l000km	Transport of liquefied and compressed hydrogen as well as ammonia is available commercially. Ammonia is less likely as a hydrogen carrier here given the scale requirements and need to convert back to hydrogen for use. Higher pressures/ liquefaction are typically used for trucking distances greater than 300km.
Rail	Compression, liquefaction, ammonia	800-1100km	As per trucks but for greater distances travelled.
Pipeline	Compression	1000-4000km	More likely to be used for simultaneous distribution to multiple points or for intercity transmission.
Ship	Ammonia, liquefaction	>4000km	Unlikely to use compression storage for shipping given cost of operation, distance and lower hydrogen density. A likely vehicle for export.

Transport and storage of large volumes of hydrogen via the existing gas infrastructure is possible. There are two mechanisms for hydrogen distribution in pipelines, methane enrichment (also referred to as blending or spiking) and pure hydrogen piping. Methane enrichment involves adding hydrogen into the existing natural gas supply up to a specified concentration level. Pure hydrogen piping requires either conversion of existing infrastructure to accommodate 100% hydrogen gas or new pipelines.

The existing gas distribution network is considered suitable for up to 10% blending, pending review by appropriate parties, however conversion to 100% hydrogen will possibly require mains, meter and appliance replacement (as well as studies as to how it will affect commercial and industrial off-takers). Further discussion on hydrogen blending and conversion are provided in Section 4.2.3.

The existing gas transmission network may or may not be suitable for transport and storage of hydrogen. However, research is underway to determine if and how blending could occur depending on suitable material composition and at the higher operating pressure. Commercial constraints are also considered a barrier (i.e. long-term capacity contracts). Opportunities may exist to use the pipeline corridor to build new pipelines specifically designed for hydrogen. This is further discussed in Section 4.2.3.

2.2.3 Hydrogen potential

The versatility of the hydrogen allows it to be applicable in several energy sub-sectors ranging from stationary energy to transport fuels.

This section introduces some of the potential uses for hydrogen and these are explored in greater detail in Chapter 3 and 4:

- Stationary electricity;
- Hydrogen fuelled transport and mobility applications;
- Domestic heat application;
- Industrial feedstock;
- Industrial heat application;
- Export potential from Australia.

2.3 Infrastructure assessment criteria

The hydrogen supply chain requires a complex combination of new and/or existing infrastructure. The infrastructure for production, storage and transport can vary depending on the location, fuel source and its end use. This section of the report describes the elements required for a hydrogen hub through criteria related to production considerations, end use and other considerations. The specific criteria related to export and domestic hubs are described in Chapters 3 and 4 respectively.

Infrastructure components and site considerations can vary depending on the fuel source. As ‘green’ hydrogen is sourced directly from electrolysis, fed directly from a renewable energy source, specific conditions are required for this type of hydrogen hub. For the purpose of this assessment all other hydrogen sources (blue, grey, brown) will be categorized into ‘other’. These production pathways for hydrogen will also require specific site criteria.

2.3.1 Green Hydrogen Production

Green hydrogen pathways have their own set of criteria that need to be considered when assessing site selection. These are listed below.

Renewable energy source

The process of ‘green’ hydrogen is possible through electrolysis of water powered by a renewable energy source. For this type of facility, there needs to be a renewable source of energy connected to the site. It is considered that wind, solar and hydropower energy resources could be used due to their relative cost advantage. Conventional hydropower plants with upper storage reservoirs or Pumped Hydro Energy Storage (PHES) plants could be used for firming of solar and wind energy generated energy to improve the utilisation of variable renewable resources for green hydrogen.

Weather data

Renewable energy sources such as solar PV and wind generate energy where weather conditions can make output unpredictable. Energy storage such as PHES and battery energy storage systems (BESS) can be used to manage this intermittency. Certain locations around Australia are also more susceptible to cyclones which lead to prolonged cloud cover, dust, high wind speeds, rain and flooding. While current projects utilise site specific data from monitoring to manage intermittency, risks due to extreme weather should be considered in site selection. To manage this one respondent suggested a bi-coastal export industry to ensure no gaps in hydrogen delivery.

Water access

Green hydrogen produced via electrolysis primarily requires electricity and water. The electrolysis stacks require ultra-pure deionised water in order to not damage sensitive components. The quantity of demineralised water required is approximately 9 litres per kg of hydrogen produced[18]. Electrolysis plants typically use potable water for the process as a cheap, clean and easily accessible source of water, with an appropriate water treatment system included to purify the water to an acceptable demineralised quality. This typically results in a demand of approximately 15-20 litres of potable water per kg of hydrogen depending on the design of the water treatment system.

Commercial operation of large-scale hydrogen production via electrolysis may need 'firm' power. Generation by solar PV and wind is inherently variable and if grid electricity is expensive, large scale energy storage would be necessary to permit high capacity operation. This storage could be provided by BESS or PHES. Stakeholder consultation indicated electrolyser capacity factor between 60-80% could be achieved through appropriate siting and combination of wind and solar, however higher factors could be achieved (if proved economic) through a combination of storage options for both electricity and hydrogen. Smaller scale electrolyser opportunities may not require any backup and / or energy storage to be commercially viable, particularly where the cost of electrolysers falls over time.

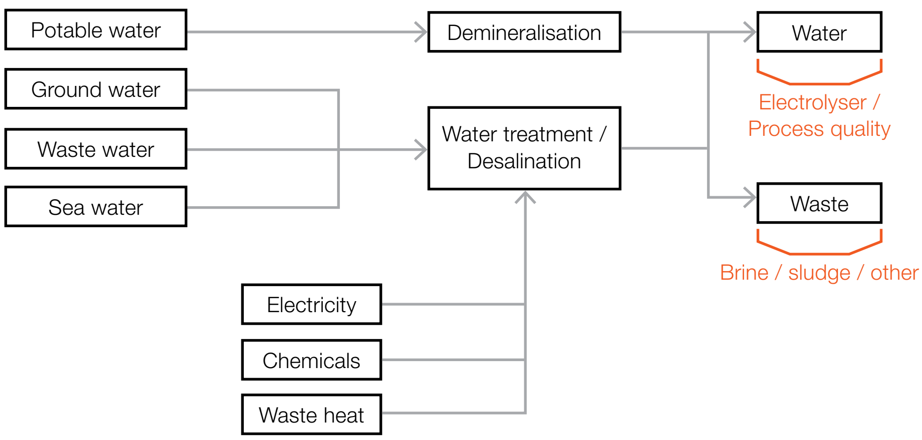


Figure 3. Potential water sources and inputs required to produce green hydrogen

Energy storage

Commercial operation of large-scale hydrogen production via electrolysis may need 'firm' power. Generation by solar PV and wind is inherently variable and if grid electricity is expensive, large scale energy storage would be necessary to permit high capacity operation. This storage could be provided by BESS or PHES. Stakeholder consultation indicated electrolyser capacity factor between 60-80% could be achieved through appropriate siting and combination of wind and solar, however higher factors could be achieved (if proved economic) through a combination of storage options for both electricity and hydrogen. Smaller scale electrolyser opportunities may not require any backup and / or energy storage to be commercially viable, particularly where the cost of electrolysers falls over time.

2.3.2 Other (blue, grey and brown) hydrogen production

Other (blue, grey and brown) production pathways have their own set of criteria that need to be considered when assessing site selection. These are described below.

Gas pricing

Natural gas as an input to blue hydrogen production, is an important consideration when choosing a site. Across Australia, natural gas prices vary between the east and west coast. With higher prices of natural gas in certain areas, the costs of hydrogen production via SMR also increase which may render that site too costly for hub development.

Coal gasification and combustion

In the case of brown hydrogen production pathways, coal needs to be readily accessible as an input. Accessibility and availability of coal with short transport distances from mine to gasifier plant, and at reasonable cost, will impact this production pathway and need to be considered if pursued.

Electricity pricing

Hydrogen production through non-renewable methods requires high amounts of heat and energy for industrial processes such as SMR and gasification. The price of electricity in this instance is a determinant factor in the location of the sites. High costs in electricity coupled with high energy demand will result in an increased cost of hydrogen production.

Carbon sequestration

In the case for blue hydrogen carbon sequestration is required for the process requiring vast amounts of land as carbon sinks. Alternatively, specific geological conditions are required for large amounts of carbon sequestration underground. Common methods for this include large underground cavities covered by a water body to trap carbon.

2.3.3 Other site selection criteria

These premises for site selection focus on the non-technical criteria. Informed by the stakeholder engagement process, desktop research and current hydrogen projects, they are core elements of a successful site selection that needs to be considered for all future hubs.

Environmental and heritage considerations

During site selection, it is important to consider any environmentally sensitive areas. These areas may be sensitive due to a number of factors including impacts on flora and fauna or heritage listed areas. Depending on the specific site, they may be sensitive to external factors such as noise, air and light pollution. The risks associated with these types of considerations need to be addressed during site selection.

Health and safety

As a potential energy fuel source, hydrogen has the inherent ability to be highly combustible and carries similar risks to natural gas. Several safety risks have been identified by the Energy Pipelines Cooperative Research Centre that will impact infrastructure considerations[19].

Compared to natural gas, hydrogen:

- Is lighter and will disperse quickly reducing the risk of gas explosion;
- Can increase flammability ranges when blended with natural gas, increasing the likelihood of ignition;
- Can lead to a concentrated fire risk and explosions due to its quick dispersion rates;
- Can produce low-visibility flames when ignited;
- Can impact certain metals such as high-strength steels, titanium alloys and aluminium alloys rendering them brittle;
- Is non-toxic.

Any industrial process will require stringent health and safety considerations for development. However, as an emerging concept, regulations, safety requirements and standards that are either developed solely for hydrogen or focus on hydrocarbons have not yet been adapted to mitigate the risks of hydrogen usage. With proper guidelines, information and engineering system design, hydrogen risks can be properly managed. Regulatory standards for hydrogen production are in their early development phase in Australia.

Whilst standards are being developed, standards from International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) can be used.

Economic and social considerations

Economic benefits associated with the hub was the second highest factor relating to the development of hubs during stakeholder consultation. Situated near towns or cities, the hub will facilitate a growth in jobs and therefore economic activity within the area. Additionally, local stakeholder alignment, engagement and acceptance will need to be acquired for the development of the hub. Industry buy-in through partnerships and/or system coupling would also be required for hub siting.

2.4 End markets for hydrogen

The end market of hydrogen can impact the necessary infrastructure elements for site selection. For domestic uses, hydrogen is most commonly used in its gaseous state which requires specific transport and storage considerations. For long-haul international exports, hydrogen is preferably liquefied or converted to ammonia or another carrier. Each form of hydrogen export transport has different infrastructure requirements for economic development.

2.4.1 Export use

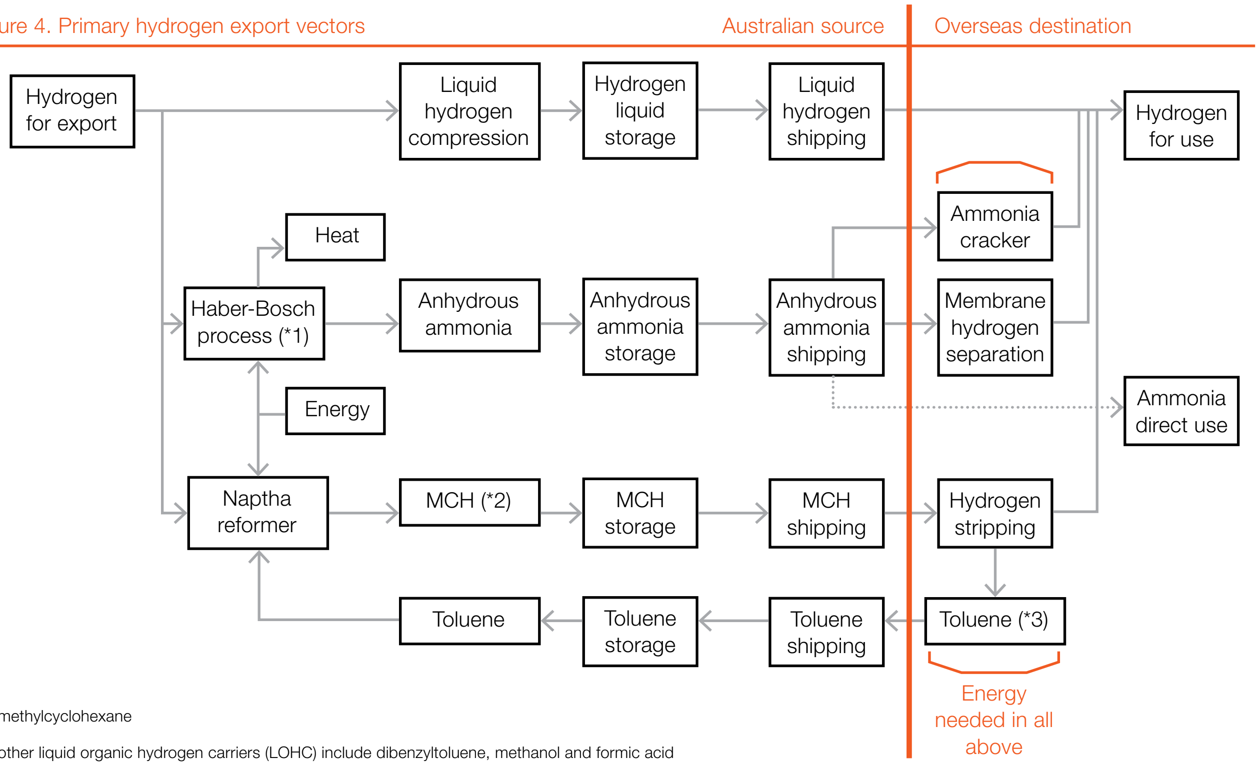
There are three primary approaches to bulk hydrogen export through shipping channels which are considered economically viable and are shown in Figure 4:

- Liquid hydrogen (i.e. in cryogenic form);
- Ammonia (i.e. in anhydrous form);
- Liquid organic hydrogen carrier (i.e. requiring return of LOHC for recharge).

The latter approach to using organic liquids at atmospheric temperature and pressure which reduces some of the hazards of cryogenic liquid carriage (i.e. at minus 253° Celsius), but comes with potential harmful or toxic organic chemical characteristics which need to be safely managed.

At present the research literature suggests the use of high-pressure hydrogen-gas tube shipping is not considered economically viable for hydrogen export, but may form an economic domestic road/rail transport mechanism.

Figure 4. Primary hydrogen export vectors



(*2) methylcyclohexane

(*3) other liquid organic hydrogen carriers (LOHC) include dibenzyltoluene, methanol and formic acid

The following introduces a list of infrastructure requirement to facilitate the economic delivery of international export opportunities, based on the export vectors in Figure 4:

Liquid hydrogen export

- Hydrogen produced remotely and delivered by compressed road/rail tanker or dedicated pipeline;
- Liquification at port requiring good electricity network capacity and connection, land at port for liquification plant with adequate perimeter barrier/exclusion zone, and hydrogen tanker / pipeline receival area;
- Cryogenic storage at port;
- Cryogenic pipe transfer to ship;
- Ship berth pocket and channel of at least 14.2m;
- Moderate shipping days to export market.

Ammonia hydrogen export

- For coal feedstock hydrogen production needs to be close to coal source;
- For renewable energy feedstock hydrogen production needs to be in or proximate to a renewable energy zone[20] and have water access;
- Water pipelines facilitate the delivery of potable water, or proximity to sewerage or sea water facilitates water processing, for green hydrogen production;
- Natural gas pipelines facilitate the delivery of methane for brown hydrogen production;
- Proximity to depleted natural gas underground reservoirs, or suitable sealed porous underground reservoirs facilitates CCS and delivery of blue hydrogen;
- Land is required at best location for hydrogen and ammonia production;
- Good electricity network capacity and connection at best location for hydrogen and ammonia production;
- Road/rail networks, or pipeline to the port for domestic leg of the ammonia transport;
- Liquid ammonia tanker / pipeline receival area;
- Liquid ammonia storage at port;
- Liquid ammonia pipe transfer to ship;
- Ship berth pocket and channel of at least 14.2m;
- Moderate shipping days to export market.

LOHC hydrogen export[21]

- Hydrogen produced remotely and delivered by compressed road/rail tanker or dedicated pipeline;
- Reformer process to convert toluene to Methylcyclohexane[22] (MCH) at port requiring good electricity network capacity and connection, land at port for reformer plant with adequate perimeter barrier/exclusion zone, and hydrogen tanker / pipeline receival area;
- Toluene and MCH storages at port;
- Pipe to transfer MCH to ship and pipe to transfer toluene to storage;
- Ship berth pocket and channel of at least 14.2m;
- Moderate shipping days to export market.

2.4.2 Domestic use

The following introduces a list of domestic use cases, which might also suggest domestic hub locations which are advantaged through agglomeration of production and usage, and are considered in more detail in Chapter 4.

- Existing gas distribution networks can accommodate small percentage of hydrogen blending;
- Gaseous hydrogen storage applications requiring tanks, compressors, electricity source, dispensing (for transport);
- Conversion to/from ammonia for industrial processes, producing fertilisers and explosives is a major user of hydrogen;
- Hydrogen for transport applications require refuelling stations and are a focus for many States and Territories;
- Hydrogen can be used for industrial processes as a natural gas substitution since it can be directly burned to produce energy or heat.

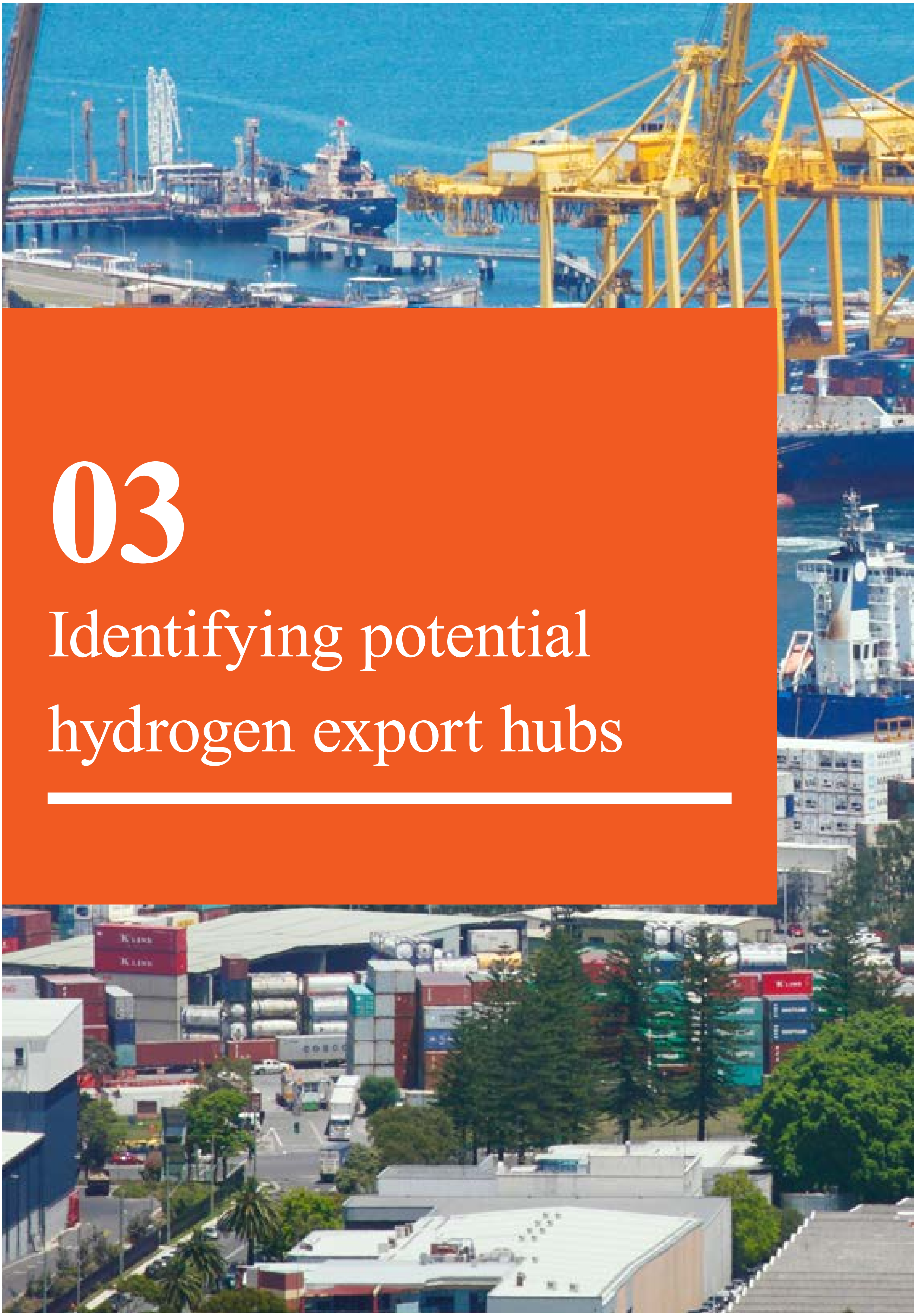
2.5 Summary

Determining a site for a hydrogen hub is a complex process that requires many considerations. From weather data, existing infrastructure and utilisation cases there is a long list of criteria that should be used to select the site.

When selecting a site, key considerations include how the hydrogen is produced and how it will be used. The hydrogen production method requires specific conditions relating to energy production, feedstock type and location, and grid connectivity. Similarly, the offtake market of hydrogen will also require specific conditions such as port accessibility for export or road/ rail or storage pipeline infrastructure for domestic use.

A selected site will exhibit trade-offs that must be accounted for during the planning and development phases of the project. These project risks and limitations should be identified and mitigated early in the concept stage of hub development. The economics of the value chain, domestic uses, and export approaches should define which hubs are most attractive for further investment and development.

[15] CSIRO. 2018. *Hydrogen for Australia's future.* Available at: https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf
[16] CSIRO. 2018. *National Hydrogen Roadmap - Pathways to an economically sustainable hydrogen industry in Australia.* Available at: https://www.csiro.au/~/media/Do-Business/Files/Futures/18-00314_EN_NationalHydrogenRoadmap_WEB_180823.pdf?la=en&hash=36839EEC2DE1BC38DC738F5AAE7B40895F3E15F4
[17] CSIRO. 2018. *Hydrogen for Australia's future.* Available at: https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf
[18] https://cleanenergypartnership.de/en/faq/hydrogen-production-and-storage/
[19] *Identifying the commercial, technical and regulatory issues for injecting renewable gas in Australian distribution gas networks,* Energy Pipelines CRC, 2017
[20] Refer to the 2018 Integrated System Plan (ISP) developed by the Australian Energy Market Operator (AEMO), and its subsequent updates.
[21] It is unclear whether a specialised ship which permanently carries the LOHC and is able to host the reformer is a viable approach to hydrogen shipping, such that liquid load / unload of the ship is not needed. Further research on the economic outcomes of such an approach is required.
[22] MCH is assumed to be the LOHC here but it could be dibenzyltoluene, methanol or formic acid, or other.



03

Identifying potential hydrogen export hubs

This section focuses on determining locations for the export of hydrogen. A list of locations has been developed through desktop research, Arup project knowledge and the stakeholder consultation process, whereby those interviewed in-person and via the online survey were prompted as to where they perceive would be an ideal location for the export of hydrogen.

Building upon the work undertaken by Geoscience Australia, our team plotted this list of suggested locations onto the geographic information system (GIS) maps. During the stakeholder engagement process, additional criteria for evaluating suitable hydrogen export locations are identified.

3.1 Export potential from Australia

Perhaps the biggest driver of hydrogen production and export in Australia is to meet the reported increasing demand of foreign countries such as Japan, China, South Korea and Singapore[23].

In the emerging market of low emissions, energy efficiency and fossil fuel elimination, Australia is well placed to supply hydrogen to the world to facilitate this shift. By 2030, Australia has the potential to export up to 500,000 tonnes of hydrogen to meet 2,489,000 tonnes of predicted demand by Japan and South Korea alone[39].

A market for export is present and rising; Australia is well positioned to meet this demand that will have both direct and indirect economic benefits to the nation. One of the biggest considerations of hydrogen export is its processing, storage and transport costs, and currently it is the cost barriers that are preventing large scale implementation of hydrogen as an energy vector.

3.2 Criteria development

The development of criteria for export hubs builds on the work undertaken by Geoscience Australia in Prospective hydrogen production regions of Australia. The Geoscience Australia report used key hydrogen production potential criteria for determining 'hot spots' in each scenario of that report.

The criteria within Scenario 2 and 3 are as follows:

- Energy:
  - Hydroelectric generation;
  - Wind speed;
  - Solar irradiance;

- Infrastructure and land:
  - Distance to existing gas pipelines (Scenario 3);
  - Distance to industrial zones;
  - Water availability;
  - Land availability;
  - Distance to port; and
  - Distance to existing power network.

Note that the difference between Scenario 2 and Scenario 3 is the inclusion of proximity to industrial zones rather than distance to existing gas pipeline infrastructure, and the lack of water-related criteria, such as proximity to coast, proximity to surface water storage and groundwater resources[24].

The criteria within Scenario 4 and 5 are as follows:

- Resource:
    - Brown coal resource;
    - Black coal resource;
    - Gas resource;
- Infrastructure and land:
    - Distance to coast;
    - Water availability;
    - CCS basins;
    - Distance to existing gas pipelines;
    - Land availability.

Scenarios 4 and 5 are the same except for the availability of storage space for CO2. Scenario 4 models a future 2030 scenario where fewer storage opportunities exist, while Scenario 5 is a longer term 2050 scenario in which more storage space is developed for use.

Criteria additional to those which lie within the above scenarios that were established via the stakeholder engagement process include:

Land availability

A hydrogen hub will require varying degrees of land with the appropriate zoning and buffer distances – dependent on the production scale, existing infrastructure and new infrastructure required. Covering considerations such as planning and licensing requirement for change of use of land, port or servitude rights, and whether the location is within a State development area. When choosing the site for the hub, land availability can be a limiting factor restricting development in terms of access and leasing or acquisition. Furthermore, some sites may restrict the possibility of future expansion which may be a decisive factor for investors. Land availability was identified as a key risk for projects during stakeholder consultation.

Gas transmission pipelines

Gas transmission pipelines are usually located near concentrations of large gas users, such as petroleum refineries, chemical plants and industrial areas. Transporting gaseous hydrogen via existing pipelines is a low-cost option for delivering large volumes of hydrogen. As noted in the COAG Hydrogen Working Group Issues papers and in a number of stakeholder responses, the existing high-pressure transmission network is not (currently) considered suitable for hydrogen. Technical concerns are related to transmission pipeline transport of hydrogen, including the potential for hydrogen embrittlement (depending on pipe material composition and operating pressure), permeation and leaks, and there are concerns around cost, reliability and durability of hydrogen compression technology.

Blending of hydrogen into existing pipelines will need to consider the capacity available within the pipeline (e.g. many are contracted to LNG supply contracts of 20 years or more), the impact on the gas quality on the end user and the cost of gas processing, injection and extraction. Gas quality variation across the network could result in calorific variation at the end-user take-off point. Precedents within Australia where there has been a variation in specification for LNG gas in transmission pipelines, indicate the agreement process in relation to acceptable gas specification for pipeline injection is in the order of years. Stakeholder consultation views varied as to whether transmission pipelines would be feasible for transport and storage of hydrogen due to similar reasons as listed above. It may require a broadening of specification, revision of legislation and access arrangements and entering into a pipeline impact agreement.

The high initial capital costs and land access constraints constitute major barriers to construction of new dedicated hydrogen transmission pipelines. Irrespective, for large scale hydrogen transport, access to pipeline easements along the existing pipeline corridor is considered the major opportunity with respect to transmission pipelines.

Gas distribution pipelines

The injection of hydrogen into gas distribution networks is currently the focus of a number of pilot test programs around the world, including in Australia (Section 4.2.3). The lower gas pressures, and the use of newer pipeline materials, such as high-density polyethylene (HDPE), mean that the opportunity to 'decarbonise' the natural gas networks exist. Injection of up to 10% of the capacity with hydrogen is being explored in the UK, with some sources indicating this could go as high as 20% without significant impact on residential and commercial consumer appliances and industrial user plant and equipment[25], and with minimal degradation of existing distribution network infrastructure[26] if conducted safely.

Electrical transmission lines

Connection to electricity transmission networks will allow the transmission of electricity from regions of abundant renewable resource to hydrogen production hubs, and allow transition towards a greener electricity generation mix over time. Where there is access to electrical transmission network infrastructure, large scale renewable energy generation potential (and in some cases, developed) and suitable water supplies exist, the surplus electricity could be used to generate hydrogen, avoiding or minimising renewable energy curtailment. Transmission network connection also encourages the development of hydrogen hubs that take advantage of low electricity market prices (such as negative power prices driven by solar PV output and low network and connection costs). Where transmission network extension is uneconomic or transmission tariffs are cost prohibitive, then it may be attractive to connect directly to renewable energy resources.

Transport access

Transport access and existing road and rail networks in and around a site is essential for any industrial facility. As a way of transporting people and goods via trucks and cars, this is an essential consideration when selecting a site for hydrogen production. Access to a port via pipeline corridor or virtual pipeline (trucking) is essential for export of hydrogen.

Water access

Water access was explored in Chapter 2. The availability of water, including the availability of, or potential for, recycled water treatment facilities, desalination plants, and/or potable water.

Interest

Consideration of interest from both the Government and investors is important to consider, and these two actors will interact. Different cities, precincts and regions will have varying abilities to attract investment. While it is not possible to place exact confidence levels on investment likelihood, there are some factors which are assumed to increase the attractiveness of investment, including:

- Cities, precincts and regions having strategies, grants or plans specific to hydrogen in place – as noted in Chapter 4, stakeholders believe Government involvement is key to creating investor confidence;
- Existing demand, pilot projects and research underway;
- Larger cities or populations with relevant or transferable skills;
- Regulations in place, as these can lag behind project development – for example current gas access agreements do not cover hydrogen.

This is important, given a key finding of the interviews was that risks including cost of technology and buyer market uncertainty were expected to have implications on success by stakeholders.

The Government, whether Federal, State/Territory or local, will also have different levels and types of interest, in particular sites. They may be interested in locations where local economic benefits can be maximised – through system coupling, job creation and future industry development – and in areas where they have already placed prioritisation on ports, industrial developments, and have already invested in infrastructure and where they can find public support.

Environmental, economic and social

Key environmental, economic and social considerations were discussed in Chapter 2.

Port Infrastructure

Particularly at the ‘start up’ scale, any project seeking to export hydrogen in liquid form or as ammonia, a requirement to construct port infrastructure may render the project commercially unviable. On that basis, it is logical to prioritise export hubs where there are existing port facilities, with sufficient berth availability, shipping channel depth access, tidal range and meteorological and ocean conditions that facilitate ship loading with limited potential for disruption.

Many existing ports in Australia are operating very economically and close to capacity. In those ports, the addition of hydrogen export shipping would likely create significant tension with existing port users, particularly where ports do not currently handle significant volumes of goods that cannot be proximate to LNG or other potentially explosive cargoes, such as hydrogen. Other ports where there is berth capacity may not be appropriate for use as hydrogen export due to current cargoes such as explosives or hydrocarbon fuel, where separation requirements between vessels would impact port efficiency.

It is also worth noting that currently there are no operational bulk liquid hydrogen tankers; the most advanced is probably the HySTRA vessel being delivered by Kawasaki Heavy Industries as part of its hydrogen supply chain project, which is currently scheduled to be operational by 2021.

Shipping distance to target market

Shipping distance to major export markets was considered as a proxy for shipping costs as longer distances will increase shipping costs, adding to the landed price of hydrogen per kg in export markets.

Table 5. Export hub specific selection criteria

CRITERIA	RATIONALE
Land availability and ownership (new terminals, production plants, storage, energy access e.g. solar PV, wind or hydro, supply and demand industries.)	Land access is a primary criterion for any project development. The quantum of land, access to land, and ownership structure all need to be well understood prior to making any investment decision. Ample land for expansion is required for scalability. The land owners need to be identified and willing to achieve a commercial outcome for any hydrogen development. A cross section of private and public (state owned enterprises) owners control the ports that have been identified. Their motivators, corporate plans, and strategies need to be understood to position hydrogen projects appropriately.
Gas pipeline infrastructure	The purpose of the hub will determine the need for gas pipeline infrastructure. If a hub is producing hydrogen for domestic use at large scale, a pipeline is essential to insert hydrogen into the reticulated distribution network or transport it to a processing facility to be mixed and then inserted into the distribution network. If a hub is an export facility with hydrogen being produced away from the port, new hydrogen pipeline infrastructure will be the most efficient means of transportation. Road and rail networks are also alternatives for hydrogen transport in smaller scale projects. Where natural gas is the feedstock for the hydrogen production, a short to moderate length lateral pipeline from a close-by major gas transmission networks is likely a viable long-term investment.

CRITERIA	RATIONALE
Grid connectivity	Energy is essential for hydrogen production. Any facility will require access to the electricity grid or sufficient land reasonably close-by to develop a large-scale renewable energy farm and electrical storage facility.
Road and rail infrastructure (site access)	The purpose of the hub will determine the modal transport links that are required. Road access will be required, rail is non-essential. If rail networks exist, this will be a bonus as it may support bulk feedstock transport, as well as either liquid hydrogen or anhydrous ammonia production outputs.
Social license, environmental concerns and weather	Similar to the development of other energy projects, access and availability of key project resources such as renewable energy (solar, wind, hydro, etc.) and water are primary criterion for site selection and project feasibility. Environmental, sustainability and community impacts will similarly influence hub location selection due to ability to efficiently gain planning and operational approvals from Government and consideration of corporate social responsibility i.e. "social license to operate". The development of hydrogen hubs should be able to overcome the operational issues associated with adverse weather conditions (e.g. cyclones, storm surge, flooding) similarly to existing LNG and renewable energy developments in affected locations such as northern Australia.
Interest (projects, priority ports, state development areas, politics etc.)	The State Government departments interviewed are already interested in the economic development potential offered from growth in a hydrogen energy sector. The difficulty will be to obtain early consensus of where initial investment focus should occur so as not to dilute national competitiveness in global markets.
Shipping distance to target market (Japan and South Korea)	Larger distances will increase shipping costs, adding to the landed price of hydrogen per kg in export markets.
Berth (berthing depth, ship storage, loading facilities, existing LNG and ammonia infrastructure, etc.)	The characteristics of existing bulk-liquid ports which can handle ammonia and those that can handle LNG, will provide for the investment needs for an emerging hydrogen export market.
Port potential (current capacity & occupancy, expandability and scalability)	Existing ports which do not need new channel development dredging, or deepening, will have an advantage over those which need development from scratch. Ports which have bulk liquids jetties, are looking for new loading volume throughput and have space available for berth extension, draught increase and land-side development, will also be attractive.
Availability of, or potential for, skilled workers (construction and operation)	Locations which currently have access to skilled workers in the gas pipeline, LNG processing, ammonia or petroleum refining sectors will have an advantage for development of a new hydrogen sector.
Availability of, or potential for, water (recycled & desalinated)	The amount of water required to produce hydrogen varies across the different production methods. Over 9 litres of water is required to make 1 kg of hydrogen. Therefore, ready access to water is critical for development of a hydrogen hub location. The available water will need to be treated to a quality required for efficient hydrogen production by electrolysis.

3.3 Potential sites

Over 30 potential hydrogen export locations have been identified in Australia through desktop research, and the stakeholder survey and consultation process. This list is not exhaustive and other ports may be able to demonstrate viable opportunities. These sites are listed in Table 6 below, albeit it is not a definitive list:

Table 6. Potential Hydrogen Export Locations (Listed alphabetically)

STATE / TERRITORY	POTENTIAL SITE
New South Wales	Newcastle (Kooragang Island suggested), Port Botany / Kurnell, Port Kembla
Northern Territories	Darwin (Middle Arm suggested), Gove (near town of Nhulunbuy)
Queensland	Abbot Point, Brisbane (Bulwer, Gibson Island suggested), Bundaberg, Gladstone, Karumba, Port Alma, Townsville, Weipa
South Australia	Myponie Point, Port Adelaide, Port Augusta, Port Bonython, Port Giles, Port Lincoln / Cape Hardy, Port Pirie, Whyalla
Tasmania	Bell Bay, Hobart
Victoria	Altona, Port Anthony, Port of Hastings, Port of Melbourne, Port of Geelong, Portland
Western Australia	Ashburton / Onslow, Albany, Dampier, Geraldton, Oakajee, Port Hedland

3.4 Primary port infrastructure requirements

One of the major outcomes for the Australian hydrogen export infrastructure development, is that development will likely occur at a small number of export hubs using different hydrogen carriage vectors.

The primary infrastructure required to support a hydrogen export hub, is related to the port infrastructure through modification of an existing liquids berth, or through development of a hydrogen specific berth.

Where liquid hydrogen is chosen as the sea transport medium, the hydrogen loading berth needs to include one or more liquid hydrogen storage tanks, a hydrogen liquification plant, a dedicated hydrogen delivery pipeline or road / rail tanker delivery receival gantry for the feedstock, and the associated cryogenic transfer equipment from pipeline / tanker to production facilities through to storage and storage to ship.

The Port of Hastings is being utilised as a pilot liquid hydrogen export terminal to support the Kawasaki Heavy Industries Hydrogen Road Demonstration project. While the pilot demonstration transport vessel dimensions and characteristics are currently unknown, a successful pilot project will see the technology expand to ship hydrogen in vessels similar to the LNG transport ships currently servicing the natural gas industry. On this basis existing berths which can support LNG import/export or bulk petroleum-products import/export are likely to define the minimum long-term sea transport industry requirements. Table 7 shows the berth dimensions of the Crib Point Jetty 1 berth at the Port of Hastings, currently used for United Energy petroleum product cargoes, which are assumed to be able to handle liquid hydrogen cargoes.

Table 7. Anticipated berth requirements for hydrogen ship export transportation[27]

CHANNEL & BERTH SPECIFICATION	REQUIREMENT (MINIMUM)
Channel depth	14.2m
Depth alongside	15.7m
DWT	80,000 tonnes
Berth pocket size	350m x 90m
LOA	300m

Specific berth requirements are still uncertain while liquid hydrogen vessels are under design and development. However, it is anticipated that ports with berth depths that can handle vessels designed as bulk petroleum-product, or liquid carriers, are likely to be able to receive new cryogenic liquid-hydrogen bulk-transport ships when they begin to manufacture and are commonly in service. Table 7 provides the dimensions of such a berth and may be treated as the minimum requirements until such a time that liquid hydrogen shipping berth requirements are properly understood.

Where ammonia is chosen as the sea transport medium, the ammonia loading berth needs to include one or more anhydrous ammonia storage tanks, an ammonia plant using natural gas or green hydrogen feedstock, a dedicated natural gas or hydrogen delivery pipeline or road / rail tanker delivery receival gantry for the feedstock, and the associated liquids transfer equipment from pipeline / tanker to production facilities through to storage and from storage to ship.

The Port of Dampier Bulk Liquids Berth is one of Australia's largest handler of anhydrous ammonia which is shipped to fertiliser distributors, fertiliser manufacturers and explosive manufacturing plants around Australia and globally. Table 8 provides the dimension of its berth.

Table 8. Anticipated berth requirements for anhydrous ammonia ship export transportation[28]

CHANNEL & BERTH SPECIFICATION	REQUIREMENT (MINIMUM)
Channel depth	11m
Depth alongside	12.4m
DWT	50,000 tonnes
Berth pocket size	330m x 53m
LOA	300m

It is anticipated that bulk liquid ports with this minimum channel depth are likely to be able to receive existing aqueous-ammonia bulk-transport ships which are commonly in service.

The primary gaps in existing bulk-liquids port infrastructure relate to the dedicated liquid delivery pipes from storage facilities to the flexible-pipe crane outrigger cranes used to connect the ship-side to shore-side piping systems. The existing jetty infrastructure will need to have spare carrying capacity, so this additional pipe and outrigger cranes can be retrofitted to handle these export mechanisms.

In addition, for bulk liquids ports which currently do not handle liquid hydrogen or anhydrous ammonia, large tracts of nearby available land are required close to the jetty infrastructure for port connection and hydrogen / ammonia plant production and storage.

One of the major outcomes for the Australian hydrogen export infrastructure development, is that development will likely occur at a small number of export hubs using different hydrogen carriage vectors. It is likely that investors will focus their efforts on export facilities with the best potential economics, rather than investing at all sites with some investment potential. International competition between Australian hubs and hydrogen export terminals in other countries is likely to lead to the success of the lowest cost producers with low cost shipping routes to markets in Asia and further afield.

In order to create investor confidence, the more economic ports which have existing hydrogen commitments and strategies, or are in the process of developing same, will need to have clearly stated investment plans with realistic time frames, and exhibit support from both local communities and State and Federal Governments, so that inefficient planning barriers are minimised. At the same time environmental, safety and heritage matters will need to be addressed through early stakeholder and public consultation, and adjustment in design and approach to eliminate or mitigate the concerns raised by the local community.

3.5 Export hub assessment framework

Using the criteria discussed in the preceding sections, an assessment can be conducted across various sites across Australia.

Two fictional ports have been qualitatively analysed in Table 9 for each of these criteria including a short description of how each location meets or does not meet the criteria. A ‘traffic light system’ is used to visually highlight strong and weak performers relative to other ports. This traffic light system is a measure of relative performance. A red rating may signal significant deficiency in infrastructure against other options considered. Amber may signal a slight deficiency infrastructure that may be addressed through appropriate action. A green rating may signal the criteria faces no significant barrier and the hub site is preferable for that criteria.

This a concept level framework only, used to help to inform decision makers about rating different sites for potential for further investigation. There are many dynamic factors that go into selecting a location for an export hub. Stakeholders will need to complete detailed feasibility assessments based on specific site considerations when deciding on export hub sites.

Table 9. Export hub assessment framework example

CRITERIA	PORT 1	PORT 2
Land availability & ownership (new terminals, storage, solar PV, industries etc.)	Government owned and operated.	Port land is leased to private operator by the Government.
Gas pipeline infrastructure	Yes. Extensive network direct to port.	Yes. Extensive network direct to port.
Grid connectivity	Yes. 132kV and 275kV nearby.	Yes. 220kV depending on location; additional transmission line or on-site generation may be required.
Road & rail infrastructure (site access)	Yes. Key road and rail freight routes exist direct to the port.	Key road freight route bypasses port and key rail freight route direct to adjacent port, but not other State ports.
Community and environmental concerns and weather. Social licence consideration	Depends on location within port, community concerns may be present. Cyclone prone region.	Environmental and community concerns unlikely to be an issue but important wetlands nearby.
Berths (berthing depth, ship storage, loading facilities, existing LNG and/or petroleum infrastructure etc.)	Exceptional. Bulk gas and liquid export infrastructure (incl. existing anhydrous ammonia trade globally) is publicly available.	Inadequate. Fertilizer exports exist but berth at 12.2m min. deep is inadequate. Channel may need deepening.
Port potential (current capacity & occupancy, expandability & scalability)	Crowded ports and berths; high shipping rate; growth potential exists but will be in heavy competition.	Limited scope to expand at port.
Availability of, or potential for, skilled workers (construction & operation)	Good availability of skilled workforce for construction and operations.	Good availability of skilled workforce for construction and operations.
Availability of, or potential for, water (recycled & desalinated)	Water available via desalination; 1x waste water treatment plant (WWTP) nearby.	4x WWTP nearby.
Interest (projects, priority ports, state development areas, politics etc.)	Proximity to Hydrogen Roadmap Zone identified by the Government.	No priority or pilot projects developed in the region. No strategic development identified.
Shipping distance to target market (Japan & South Korea)	12 – 13 days.	12 – 13 days.

3.6 Summary

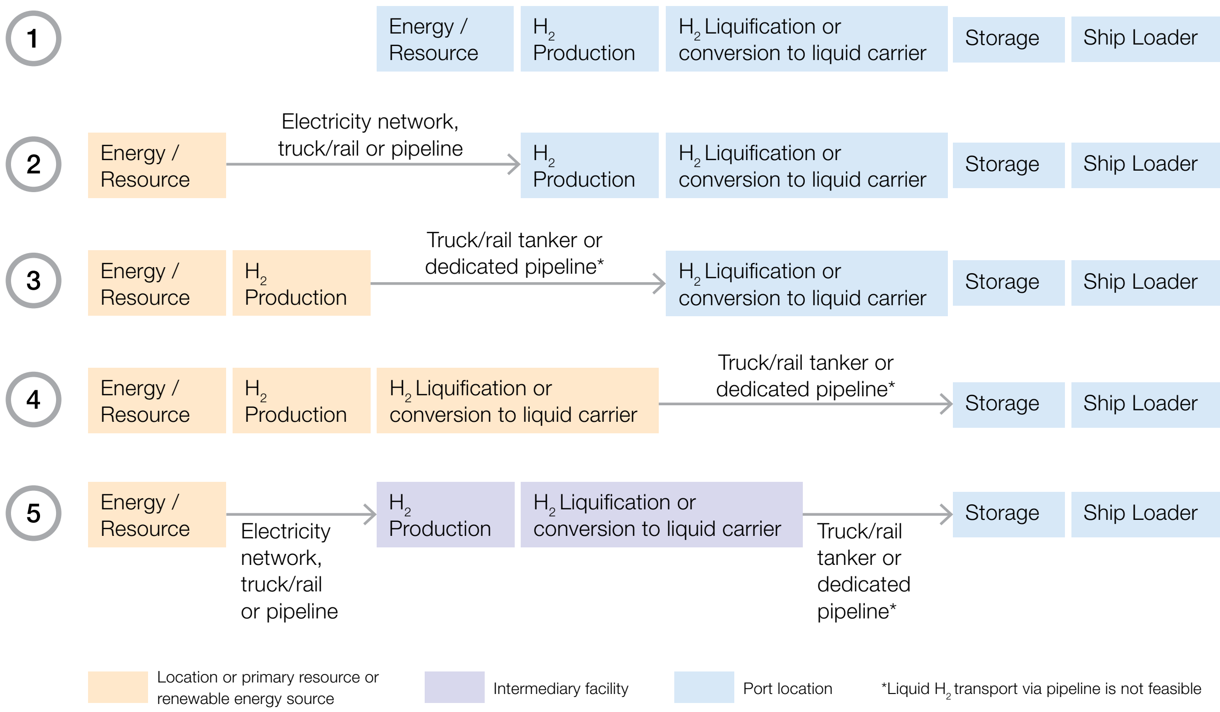
The identification and selection of suitable export hubs is still in the early stages of development. Further analysis needs to be undertaken to identify potential hydrogen export hubs, assess their suitability and then make strategic investment decisions for missing or limited capacity infrastructure. This study report describes the criteria and a framework for assessing export hubs. Stakeholders who are examining specific sites will need to complete detailed assessments based on specific site considerations when deciding on which export hubs are more likely to be economically viable. The following section provides a summary of the investment opportunity for the development of export hubs and identifies the primary infrastructure gaps which are site specific and may arise.

3.6.1 Investment gaps

The potential for a particular port to be economically viable in each state depends on the choices made by investors in the feedstock, its transport, hydrogen production process, storage technology, and the shipping transport mechanism. mechanism. Both standalone export opportunities and those integrating with domestic opportunities exist. The stakeholder engagement process identified a range of investment opportunities with a common theme; the industry is prepared to share the risk with Government to see the creation of sustainable domestic and export markets for a decarbonised hydrogen future. In addition to this, there was a consistent message that a robust domestic market would support a burgeoning export industry. Investment must focus on introducing and then driving down the price of hydrogen for domestic usage and production to increase competitiveness as an exporter. There is a natural cohesion in the policy drivers for both an export and domestic market for decarbonised hydrogen.

To access export opportunities, there is a need to invest in export infrastructure and transport links (if production and conversion is not collocated at the export hubs). Investment may be required in dedicated hydrogen pipelines or truck / rail tanker fleets. Common pipelines, storage, and co-location of production facilities investment near export hubs would help to address the transportation infrastructure gap and support the development of export hubs. The decision upon required transport and port infrastructure will depend upon the shipping method and production pathway. The possible configurations for hydrogen production, transport and export are explored in Figure 5.

Figure 5. Production, transport and export pathways to inform site selection



In Figure 5 there are five potential export pathways explored that may be feasible for different sites in Australia. There is possibly another pathway where there are two intermediary sites for separate hydrogen production and liquification or conversion to carrier; however, this seems unlikely. Briefly the hub combinations represented in Figure 5 are:

1. Co-location of energy / resource, production, conversion to liquid carrier and storage at the port location.
2. Co-location of conversion to liquid carrier and storage at the port location. Energy / resource is transported via the electricity network, truck, rail or natural gas pipeline.
3. Co-location of production, conversion to liquid carrier and storage at the port location. Energy / resource is co-located with hydrogen production, then hydrogen transported via truck, rail or dedicated hydrogen pipeline.
4. Co-location of energy / resource with production and conversion to liquid carrier at primary site. Then transport via truck, rail or dedicate liquid pipeline to port location. Note that liquid hydrogen is unlikely to be transport via pipeline.
5. Co-location of production and liquid carrier conversion at an intermediary facility, that is dislocated from energy / resource and port. Energy / resource is transported via the electricity network, truck, rail or natural gas pipeline to this site. Liquid carrier from intermediary facility then transported via truck, rail or dedicate liquid pipeline to port location.

The preferred pathway and siting decisions will be dependent upon the shipping method, availability of transport infrastructure and suitable land availability.

The first consideration is the shipping method, which itself poses a barrier to the economic export of hydrogen. As a gas, hydrogen is not dense enough to be commercially viable to long-distance transport. Therefore, three options can be either liquefaction, conversion to ammonia or combining with a chemical liquid carrier. Liquid hydrogen facilities would likely be best installed at export hubs, due to the difficulties in moving liquid hydrogen. However, anhydrous ammonia or indeed liquid carrier facilities could be located away from the export hubs provided economic domestic road / rail tanker transport is available.

The end-user at the overseas destination may influence the preferred shipping method. As on import they would then need to either convert the anhydrous ammonia to hydrogen, extract the hydrogen from the MCH or other liquid chemical carrier and return the carrier fluid to destination for recharge, or have the appropriate facilities for handling liquid hydrogen. The shipping of liquid hydrogen on tankers is in development with various pilot studies occurring[29]. Facilitating liquid hydrogen tankers through use of existing or added infrastructure at ports which handle gas or liquid petroleum-product ship loading would be valuable to support the development of export hubs.

The second consideration relates to the availability or feasibility of domestic road / rail transport networks (to carry coal, ammonia or liquid chemical carriers, or tube hydrogen), and pipeline networks (to carry either natural gas, hydrogen or carbon dioxide). The distances for input or output product carriage will be a significant driver of the economics of each hydrogen export pathway and should be carefully considered when siting the hydrogen hubs.

The third consideration is land availability with suitable zoning and buffer distances for the preferred pathway. There may be limited suitable land at the source of energy / resource or port location that may limit the preferred export pathway. Additionally, the preferred pathway for viable blue hydrogen production will depend on the availability of suitable CCS locations close to natural gas and/or coal mine locations.

Development of different export pathways would help to facilitate the development of various other domestic market opportunities.

[23] Acil Allen Consulting. 2018. *Opportunities for Australia from Hydrogen Export.* Available at: https://arena.gov.au/assets/2018/08/opportunities-for-australia-from-hydrogen-exports.pdf

[24] This could include the use of sewerage water mining and treatment to recover water for hydrogen production.

[25] The outcomes of the UK programs such as Hy4Heat and Leeds H21, as well as Australian pilots under the ARENA banner will help identify the gas distribution pipeline opportunities for Australia.

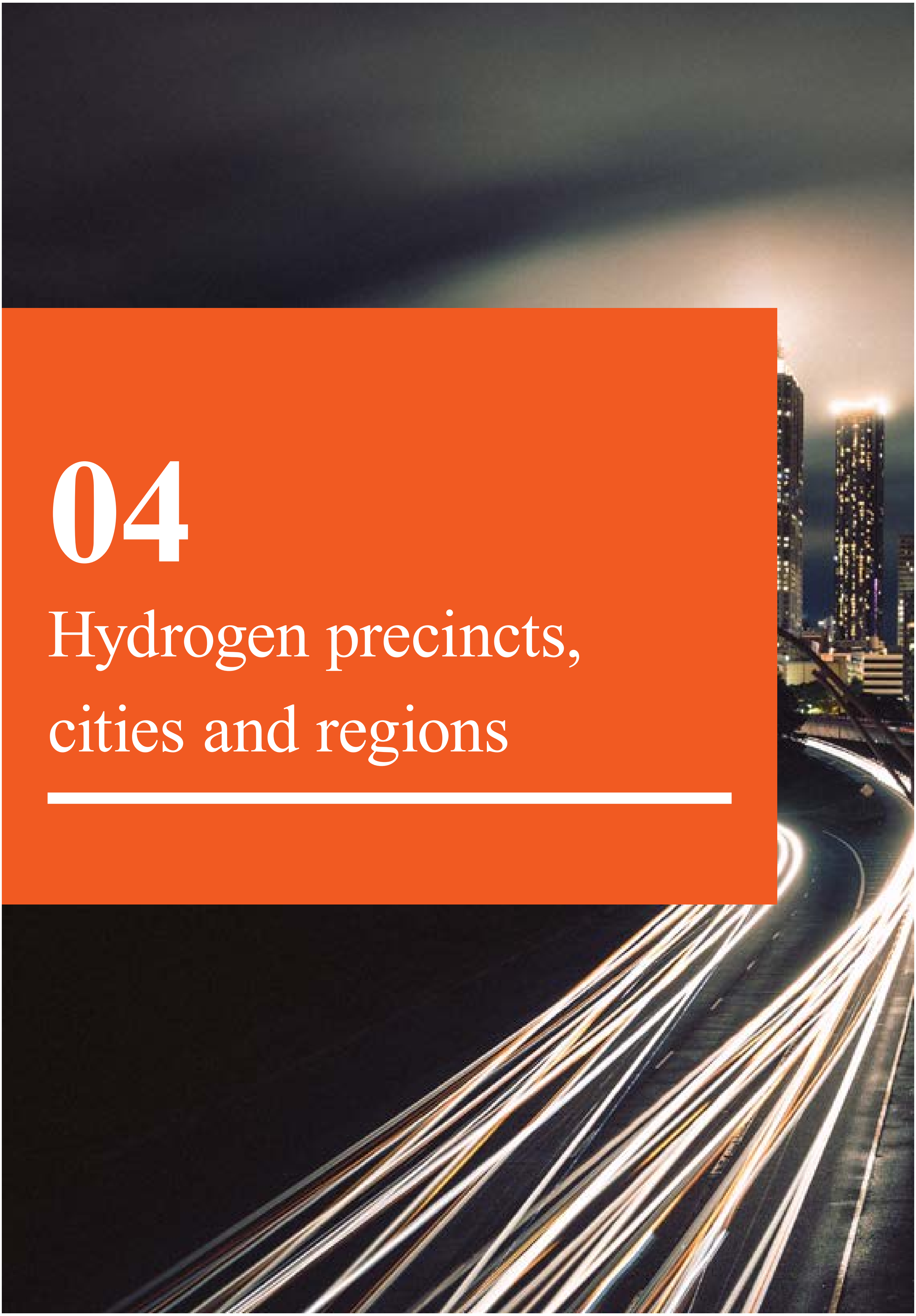
[26] Noting that this is subject to further studies, and is highly dependent on existing pipe materials and operating pressures.

[27] Source: Crib Point Berth 1, Port of Hastings

[28] Source: Dampier Bulk Liquids Berth, Port of Dampier

[29] Refer to Kawasaki Hydrogen Road, https://global.kawasaki.com/en/stories/articles/vol74/

04
Hydrogen precincts, cities and regions



The focus of this chapter is on domestic demand hubs. It provides a list of criteria to guide decision-making processes when it comes to supporting agglomeration of domestic demand. The key considerations explored are based on demand, supply chain infrastructure, and investment and policy areas.

This chapter considers current demand, primarily from the ammonia production industry, as well as emerging sources of demand such transport and residential heat, and also possible future sources of demand, such as “green steel” production, around Australia.

Based on these considerations, the list of criteria has been developed. The assessment criteria provides a guide to aid decision makers, rather than recommending specific locations that would be most appropriate for a hub. This is because there are many dynamic factors that go into selecting a location for a domestic hub, that it is not appropriate to be overly prescriptive or prevent stakeholders making decisions based on its own research. This framework rather provides information and support to enable these decision-making processes.

4.1 Uses of hydrogen

Understanding the current and future uses of hydrogen is important, as these are the factors that create domestic demand. Locations that can find multiple uses and therefore sources of demand for hydrogen will have an improved chance of success and the ability to deliver hydrogen efficiently, affordably and with maximised benefits. In some locations, infrastructure will act as a barrier to certain use cases, though this can be overcome through economic investment. The following section explores these current and future uses of hydrogen in the Australian context.

According to the CSIRO, "…in practice, a single hydrogen production plant could secure offtake agreements in a number of applications depending on available infrastructure, policy and demand profiles".

Hydrogen has promising applications within many different industries, and the opportunity for one production plant or one hub to serve a variety of uses exists and will reduce the risk of investments. Broadly, the applications for hydrogen are either as a feedstock into industrial processes or as energy for transport, electricity networks, and residential and industrial heat. Based on the stakeholder engagement process, export customers, industrial feedback and land freight transport were the preferred customer base for the future hydrogen supply.

4.1.1 Industrial feed stocks

Hydrogen is already used as a feedstock for ammonia production, oil refining and other small-scale industries in Australia. Hydrogen is currently in use by the chemical industry, and this is where most of the supply goes. Globally, 90% of production is used in this context and about 50% used for ammonia specifically[30]. According to Deloitte, Australia produces over 2 Mtpa of ammonia annually that has the potential to require over 350 ktpa of hydrogen as a feedstock[31]. Australia is a significant producer of ammonia for its size, with 1% of global production from Australia, and 1.8% of global exports[32]. Some industries use smaller quantities of hydrogen, including semi-conductor fabrication, glass making and the food industry.

4.1.2 Transport

The CSIRO have done work investigating at what stage hydrogen would be commercially competitive for these industries in the future, and therefore when uptake would be expected to occur. Their work suggests that hydrogen fuel for transport is already cost competitive in terms of the cost per kilogram[33], but is constrained by infrastructure barriers. Once infrastructure and capital cost barriers are overcome, it is expected that transport use cases could expand rapidly around 2025. Already States and Territories are beginning hydrogen vehicle pilots, including Victoria, South Australia and the ACT, with public transport and trucks as common starting points. Refuelling stations are also beginning to be developed, with the first set to be in the ACT. Hydrogen vehicles will be useful for both long haul transport and intra-city transport, and so both types of transport needs should be considered.

4.1.3 Electricity storage

Hydrogen will also have a role to play in improving electricity supply through seasonal storage. Improving electricity supply will be relevant in areas with significant population density due to the demand on grid. In more rural areas, hydrogen will be important to support remote area power systems (RAPS). It could be transported to RAPS to replace diesel; the CSIRO estimate hydrogen-based RAPS (using dedicated renewable energy inputs) could be commercially competitive with diesel equivalents before 2025[31]. In remote mining contexts, the possibility of a micro-grids for remote mining sites exists. The Clean Energy Innovation Hub by ATCO is already developing a micro-grid powered by clean hydrogen to power their facilities in WA.

4.1.4 Industrial and residential heat

In the residential and industrial heat supply chain, hydrogen can act as a natural gas substitution since it can be directly burned to produce energy or heat. Hydrogen in its gaseous state is a suitable option to replace natural gas for domestic heating, pending further studies, and mains, meter and appliance conversion being required for 100% H2. Similar to natural gas, hydrogen is combustible and can be distributed through the same existing infrastructure networks making it a quick and viable substitution. Natural gas through mains or bottled propane gas provides up to 44% of household energy needs for up to 70% of homes across Australia[34]. Throughout the household there are several low-temperature applications of hydrogen through space heating, water heating and cooking appliances. The use of this can be further extended to commercial uses in businesses and industry utilizing existing or retrofitted gas networks.

It is unlikely to be competitive before 2030. Historically, gas networks in Australia had a large share of hydrogen until the 1970s when the changeover to natural gas began. Newer networks may not need adaptation to carry hydrogen, however the meters and appliances that burn the gas will need to be replaced. This sort of demand will be associated with population density, given a focus on residential heat provision.

4.1.5 Other uses

While the use cases are distinct, the use of hydrogen in the transport, buildings and industry applications should not be thought of as separate. System coupling – the idea of integrating these energy consuming sectors with the power producing sector – provides the opportunity to share energy between different industries depending on demand patterns and store it in different forms. Since hydrogen can be used as a gas or to generate electricity, it would have a role to play in system coupling.

By replacing carbon in steel production, Australia could develop a zero-carbon metals industry. 'Green steel' is the topic of research in Australia and a pilot project in Sweden called HYBRIT, where a plant is being constructed. The demonstration project is expecting to have full industrial production by 2035[35]. This provides an opportunity for Australian steelmakers and the transition to a greener product. As such, the location of steel manufacturing in Australia is a consideration.

4.1.6 Existing and future industrial demand

Based on the current use case for hydrogen in Australia, the industrial demand for hydrogen is important to understand since it provides the starting point for growth. Ammonia is a focus in the short-term; as Australia produces over 2 Mtpa of ammonia annually that has the potential to require over 350 ktpa of hydrogen as a feedstock.

The maps in Appendix D show where current and known ammonia and other chemical producing facilities ('demand sites') are operating in Australia, and oil refineries in Australia. These represent the majority of the existing industry demand. In the future, it is possible that green steel will emerge as another demand source, and so current steel manufacturing sites have been highlighted. Stakeholder interviews and surveys, along with publicly available information have been used to develop these maps. Additionally, in the future hydrogen could be used to replace gas in industrial processes for power or heat. The opportunity for heat includes fuel production and the manufacturing industry. The energy industry includes petroleum refining, gas processing and solid fuel manufacturing. The manufacturing industry includes steel, non-ferrous metals, chemicals, food processing, ceramics, cement, and pulp and paper. The Hydrogen Strategy Group anticipates that 154 petajoules of hydrogen per annum could be used to supply high temperature industrial processes where natural gas is currently used[36].

In Australia, process heating and steam production require a large amount of energy, with a typical industrial site having 60% of their energy costs attributable to boilers[37]. Sites like this are spread across Australia, providing opportunities for hydrogen to play a role in heating in every State and Territory. For this transition to occur, industrial appliances will need to be upgraded and the cost of hydrogen reduced. The Renewable Energy for Process Heat Opportunity Study by Australian Alliance for Energy Productivity aims to accelerate the adoption of renewable energy in industrial and commercial process heating[38]. Trials will focus on agriculture, dairy, food and beverage manufacturing, textiles/leather, paper manufacturing, and commercial laundries.

4.1.7 Future non-industrial demand

The transport and residential sectors will be key to unlocking future demand for hydrogen.

The size of the population acts as a proxy for these kinds of demand, especially for public transport and personal vehicles. It is also applicable for residential heat demand, though the current gas distribution networks (Table 10) dictate which populations can and cannot receive gas supply, and so this is considered later.

Table 10. Australian residential gas distribution network[39]

STATE	RESIDENTIAL CONNECTIONS (000S)	RESIDENTIAL GAS CONSUMPTION (GJ P.A. PER CONNECTION)	DISTRIBUTION NETWORK (KM)	TOTAL RESIDENTIAL GAS CONSUMPTION (TJ)
ACT	139	35	4,620	4,853
NSW	1,332	28	26,290	36,636
QLD	182	8	5,760	1,482
SA	427	17	7,950	7,199
TAS	12	34	710	418
VIC	1,958	49	31,090	96,812
WA	710	15	14,000	10,506
National	4,762	33	90,420	156,920

For residential heating, early trials in Australia indicate that existing gas distribution networks should be able to accept the blending of some hydrogen[40]. Gas network trials and further information is provided in Section 4.2.3.

HDPE pipe, which is suitable for transporting hydrogen (i.e. ‘hydrogen ready’) in being installed through a number of replacement programs are underway throughout Australia.

All major cities have distribution networks which could or may eventually be replaced with HDPE network. If hydrogen gains the social license to operate, safety issues are properly managed, and the other supporting infrastructure is put in place, then this could allow for higher percentages of hydrogen introduction into distribution networks.

The number of potential customers and energy consumption is listed in Table 10. This could represent an upper limit for hydrogen demand (if 100% substitution of current demand were achieved).

The maps in Appendix D looks at the population density across Australia, providing a high-level indication of where urban centres will create demand in the future.

4.2 Assessment criteria

4.2.1 Criteria development process

This Chapter of the report brings together mapping, stakeholder engagement and literature review activities.

Overlays for GA maps were generated, including information on key infrastructure, projects and demand considerations. By integrating these data sources, we can start to see where agglomeration of domestic demand is available and identify where additional infrastructure may be required. Scenario 2 was focused on for all States and Territories except for the Australian Capital Territory (ACT) because of anticipated constraints induced when targeting the use of inland water sources and pipeline/transmission infrastructure. Given the ACT is landlocked and away from the coast, Scenario 3 was applied. The criteria were developed in three groups:

- Demand
  Criteria that explore the potential demand in an area;
- Supply chain for domestic demand
  Criteria that assess the current infrastructure available;
- Common criteria
  Criteria that is a common consideration with supply chain and export hub criteria already discussed.

The criteria developed are explained and justified below.

4.2.2 Demand

This section takes a closer look at potential demand across Australia, through examination of uses of hydrogen, existing and future industrial demand and future non-industrial demand.

Population size and density

Given the importance attributed to transport and residential heat sectors by stakeholders and international literature, a proxy for assessing the levels of demand for these sectors is required. Where large urban centres are located, the demand for freight, public and private transport, and the number of residential dwellings is assumed to be high, and thus potential demand for hydrogen high too. In these areas of dense population, the role of hydrogen in increasing grid reliability is also expected to be important.

Of course, it is not a perfect proxy, given the influence that infrastructure such as gas networks has over who demands a particular form of energy.

Co-location with industrial uses of hydrogen

As in Chapter 2, the use of hydrogen as an industrial feedstock was highlighted as the second most important use by stakeholders after exports. A large portion of current demand for hydrogen is ammonia production and Australia is a significant exporter of ammonia for our size. This industry provides an important starting point for understanding demand within the emerging market. Ammonia for industrial processes, producing fertilisers and explosives is a major user of hydrogen. There are 11 sites for ammonia plants and oil refineries, all using a form of SMR hydrogen. The current demand for hydrogen domestically at these sites is 500,000t per year. Converting these users to green hydrogen, through subsidisation, co-investment, or policy design will demonstrate Australia's capability to produce green hydrogen at scale.

Co-location with future agricultural, manufacturing and industrial opportunities

Exporting higher value products, as opposed to the commodity of hydrogen, has the potential to diversify the economy.

The use of green hydrogen in fertilisers could be used to develop high value agricultural products such as carbon neutral food, for example.

Green steel, formed with hydrogen rather than fossil fuels, is a promising future application, though the timeline and quality of development is uncertain. Locations where there is currently steel production from raw materials are assumed to be potential sites for future hydrogen demand, as they may make the transition. Metal melting and metal hydrides in value-add industries have also been noted as significant future opportunities, as have cleaning fuels derived from biomass is another future application, however there are not many sites and examples to map yet.

The Renewable Energy for Process Heat Opportunity Study, partially funded by ARENA, is currently underway and will provide a more comprehensive understanding of where renewable energy technology, including hydrogen, can play a role in reducing fossil fuel use from Australian manufacturing[41].

Proximity to export hubs

Creating domestic demand hubs will be essential to the development of an Australian hydrogen economy. As noted in the key findings of Chapter 2, the preference of stakeholders was to develop export hubs where there is domestic demand. With export hubs a top priority for stakeholders and a significant opportunity for Australia, collocating export hubs where there is domestic demand will provide:

- Efficiencies in production and in the portfolio of assets;
- Diverse sources of demand and therefore increased economic resilience for hubs;
- Assurance and confidence for trade partners and investors that the market is viable. Japan is one such trade partner that has highlighted the importance of Australia building the domestic market before exporting, as well as the desire to develop a reciprocal trade relationship;
- Export of products (such as ammonia) that are produced by industrial hydrogen demand;
- Greater public acceptance and understanding of hydrogen generation as exposure increases with increased production and value generated.

4.2.3 Supply chain for domestic demand

The hydrogen supply chain consists of production, transport, storage and end use. This section considered the elements of supply chain that are specific to domestic demand, gas transmission and distribution networks, low pressure storage and refuelling stations. Further details on other elements within the supply chain are discussed in Chapter 2.

Gas pipeline infrastructure

The purpose of the hub will determine the need for gas pipeline infrastructure. If a hub is an export facility with hydrogen being produced offsite, gas transmission infrastructure will be the most efficient way of transportation. If a hub is producing hydrogen for domestic use at large scale, a pipeline is essential to insert hydrogen into the reticulated network or distribute to a processing facility to be mixed and then inserted into the network.

Gas distribution networks

Existing gas distribution networks comprises mains pipes, meters and behind the meter appliances. Pipes comprise materials such as polyethylene, nylon, steel, PVC and cast iron. Gas distribution network size and number of connections are provided in Table 10 in Section 4.1.7.

For domestic transmission of hydrogen to consumers, early trials in Australia indicate that existing gas distribution networks should be able to accept the blending of some hydrogen. Energy Networks Australia and its members are strongly involved in a project to allow up to 10 % hydrogen in the domestic gas network, both for use in place of natural gas and to provide at-scale storage for hydrogen. AGIG is proposing for mid-2020 the first hydrogen production and supply of 5% renewable hydrogen blended gas to homes. ATCO created the Clean Energy Innovation Hub, with the aim of supplying a demonstration house, refuelling station and with the remainder to be injected into the natural gas grid. Jemena's produced hydrogen will be injected into the gas network, providing enough energy to meet the cooking, heating and hot-water requirements of approximately 250 homes. South Australian (HyP SA) project is aiming to blend 5% hydrogen into the gas distribution network to 770 customers by mid-2020.

The outcomes from Australian programs would then inform other generic decisions that may need to be made to mitigate risks. For example, in relation to ignition control such as this may include hydrogen monitoring, odourisation, electrical equipment safety and strategies around human behaviour, in addition to the appliances themselves. Solutions to these challenges are readily available pending appropriate research and or pilot programmes. For example, computational fluid dynamics (CFD) analysis coupled with gas detection is an area of research which can determine gas behaviour inside buildings. Considerations requiring blending commercial, legal and safety aspects are similar to transmission pipelines.

As mentioned in Section 4.1.7, HDPE pipe, which is suitable for transporting hydrogen (i.e. 'hydrogen ready') in being installed through a number of replacement programs are underway throughout Australia.

All major cities have distribution networks which could or may eventually be replaced with HDPE network. Some states, for example the ACT and Tasmania, already have HDPE distribution networks in place. If hydrogen gains the social license to operate, safety issues are properly managed, and the other supporting infrastructure is put in place, then this could allow for higher percentages of hydrogen introduction into distribution networks. There is strong evidence that mains that are 100% HDPE could be deemed "hydrogen ready", pending case by case review by appropriate parties. Many gas distribution networks have a program of mains replacement that will see substantial parts of the network replaced in the near future. Existing gas meters and gas appliances would not be appropriate for 100% H2.

Low pressure tank storage

Hydrogen is most easily stored in a gaseous state. This can then be used for injection into the reticulated gas network for industrial, commercial, and residential usage, as demand response for energy, or for transport applications. Specific infrastructure requirements will be required at each storage application; tanks, compressor, electricity source, dispensing (for transport).

Refuelling stations

Refuelling stations are a focus for many States and Territories. There is a challenge in that many possible providers are waiting for the number of hydrogen vehicles to increase, while potential hydrogen vehicles owners are waiting for refuelling stations are constructed. The result is a low uptake of both. A focus on freight and public transport, where demand is more regular and significant, will enable improvements to the provision of infrastructure.

4.2.4 Common criteria

There are several infrastructure requirements that are common with export hubs.

These are covered in Chapters 3 and 4 and include:

- Transport access;
- Transmission lines;
- Water access;
- Health and safety;
- Environmental considerations;
- Economic and social considerations;
- Land availability;
- Interest;
- Green hydrogen production:
    - Renewable energy source;
    - Weather data;
    - Backup energy supply;
- Other hydrogen production:
    - Gas pricing;
    - Coal fire assets;
    - Electricity pricing.

4.3 Domestic hub assessment framework

Using the above criteria, an assessment can be conducted across various sites across Australia. By first selecting the desired production process and final consumption use-case, sites can be assessed accordingly to their various needs. It is intended that the criteria for essential considerations is consistent throughout each site with varying degrees of importance.

Two fictional sites have been qualitatively analysed in Table 11 for each of these criteria including a short description of how each location meets or does not meet the criteria, as in Chapter 3. A ‘traffic light system’ is also utilized to visually highlight strong and weak performers relative to other domestic hub options. This traffic light system is a measure of relative performance. A red rating may signal significant deficiency in infrastructure against other options considered. Amber may signal a slight deficiency infrastructure that may be addressed through appropriate action. A green rating may signal the criteria faces no significant barrier and the hub site is preferable for that criteria.

As indicated earlier, this a concept level framework only, used to help to inform decision makers about rating different sites for potential for further investigation. There are many dynamic factors that go into selecting a location for a domestic hub. Stakeholders will need to complete detailed assessments based on specific site considerations when deciding on domestic hubs.

Table 11. Domestic hub assessment framework example

CRITERIA LEVEL 1	LEVEL 2	SITE 1	SITE 2
Production (Green)	Renewable source	Wind and solar connectivity	Limited potential for renewable generation
	Weather data	High uptake of solar and wind availability – low cyclone possibility	Cyclone prone area
	Backup energy supply	Grid connected	Grid connected
Essential considerations	Transport access	Good road and rail connectivity	Narrow road access
	Transmission lines	Close to suitable transmission lines	Close to suitable transmission lines
	Water access	Intermittent potable water access	Excess capacity from local treatment plant
	Health and safety provisions	Zone industrial park	Zone industrial park
	Environmental considerations	World heritage area nearby	Ecologically sensitive area identified
	Economic and social considerations	Far from dense area	Far from dense areas
	Land availability	Zoned land available for use	Limited land available
Demand	Population size and density	Significant population and density	Sparse population
	Co-location with industrial ammonia production	No ammonia production facilities demand nearby	Ammonia production facilities nearby
	Co-location with future industrial opportunities	Nearby steel manufacture facility	None identified
	Proximity to export hubs	Selected export hub nearby	Far from export hub
Supply chain to domestic demand	Existing gas networks	HDPE gas distribution network can handle 100% hydrogen	Modification to gas networks required
	Gaseous hydrogen storage	Salt caves nearby	Construction required
	Refuelling stations	Already in place in key locations	Plans in place to construct

4.4 Summary

A number of steps need to be taken to develop domestic hydrogen hubs. This includes identifying potential sites, assessing their suitability and strategically investing in projects and infrastructure. We have described the criteria and a framework for assessing hydrogen cities, precincts and regions. Stakeholders will need to complete detailed assessments based on specific site considerations when deciding on domestic hubs. The following then provides a summary of the investment and project opportunity for the development of domestic hubs.

4.4.1 Domestic investment gap

There are a range of infrastructure investments that could support the development of domestic hubs. A variety of transportation options will be required for domestic applications including generation at source, road trucking from hydrogen source to point of demand, distributed gas networks which can and are willing to accept hydrogen injection, and hydrogen suitable transmission networks most likely to be from business-to-business fuel transfer. Investment in refuelling and community pilot projects can also help develop domestic hydrogen hubs. HDPE mains replacement in the distributed network is already being deployed across Australia to address natural gas leakage, old pipe replacement programs and to provide better service to existing consumers. Over time networks that have appropriate pipe, valve and meter technology can support hydrogen will incentivise more hydrogen production as the distributed market becomes more accessible and focus on decarbonised gas delivery. Communities that use decarbonised hydrogen as a fuel source will develop and emerging social licence from their efforts related to sustainability, reliability, and efficiency.

Longer term domestic opportunities relate to mobility and supply. There will be a demand for ‘tube and trailer’ tanker trucks to transport hydrogen to communities that are not connected to the reticulated natural gas networks or seek to support hydrogen as a transport fuel. However, tube and trailer systems may not be economical where hydrogen transport is required at export scale and in these circumstances co-location of elements of the hydrogen production and/or industrial value chain, may provide better economics. Incentives that could support transport operators to adopt hydrogen fuelled vehicles that might be considered by Governments include subsidisation, rebates, offtake agreements, or taxation benefits to operate hydrogen transport. Stakeholders feedback in the interview process are seeking Government support from operating bus fleets to secure offtake supply contracts for hydrogen production. Barriers for bus operators have been the purchase of hydrogen buses and current absence of refuelling infrastructure. Land freight transport is also a target market due to the relative weight advantage and refuelling characteristics of fuel cell hydrogen-fuelled vehicles over current battery technology but will require additional enablers to secure the appropriate vehicles.

Focus on: Pilot for gas network

The use of 100% hydrogen for a test project may require a new build network or a suitably selected part of an existing network and would certainly require new downstream equipment and appliances. The regional location would ideally need to have ample water supply, high potential for renewable energy generation, a current reliance on costly ($, GHG, Air quality) energy and willingness to participate. To build public awareness, it should ideally be in an area that is well visited by the public, as well as being accessible to influencers from many different stakeholder groups. Due to the requirement for public acceptance, it would be prudent to invite towns to register interest. By way of example, Arup is conducting a feasibility study for the Scottish Gas Network in the UK for 100% H2 network with 300 homes in the Central Belt of Scotland, where there is high population density and the Scottish Government is supportive. Within metropolitan areas a small demonstration project in a new subdivision is feasible. An extension to an existing demonstration project in the southern Perth metropolitan corridor is being considered, for example, or as currently proposed in the southern suburbs of Adelaide.

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05

Conclusion

The outcome focus areas include; collating demand and supply, coupling of industrial sectors, decarbonisation of supply chains and to support the maturing of hydrogen technology through the creation of centres of industrial and academic excellence in the established hubs.

The COAG Energy Council committed to developing and implementing a national strategy for hydrogen in December 2018, in close consultation with industry and the community. Arup was engaged to support this initiation with the completion of this Australian Hydrogen Hubs Study focused on the creation of hubs that has the potential to aggregate demand for a product (hydrogen in this instance).

The principle behind this is based on creating an intelligent system such that the end-product provides greater benefits than the sum of its individual parts. The outcome focus areas include; collating demand and supply, coupling of industrial sectors, decarbonisation of supply chains and to support the maturing of hydrogen technology through the creation of centres of industrial and academic eminence in the established hubs.

Arup have utilised private and publicly available data sources, building on recent work undertaken by Geoscience Australia and Deloitte, and a comprehensive stakeholder engagement process to inform our research and produce a “Hydrogen Hubs” report. Arup have also conducted interviews with stakeholders from both Governmental and industrial bodies, the purpose of which were two-fold. The primary aim was to gather data and perspectives from key potential players in the hydrogen landscape to support the development of this Hydrogen Hubs Study report including to investigate key issues such as; perceived barriers & enablers, existing pilot projects, investor & jurisdictional appetites to pursue hydrogen. Key themes where highlighted during the stakeholder engagement process which were then used to inform recommendations made with regards to the establishment of future export, and domestic hydrogen hubs around Australia.

The following conclusions were reached on the three key topics address in this study report:

1 - Hydrogen Supply Chain and Infrastructure

Determining which sites should be developed into hydrogen hub is a complex process that requires many considerations. From weather data, existing infrastructure and utilisation cases there is a long list of criteria that should be used to select the site.

When selecting a site, key considerations include how the hydrogen is produced and form in which it will be transported and utilised. The hydrogen production method requires specific conditions relating to energy production, feedstock type and location, and grid connectivity. Similarly, the offtake market of hydrogen will also require specific conditions such as port accessibility for export or road/rail or storage pipeline infrastructure for domestic use.

A selected site will exhibit trade-offs that must be accounted for during the planning and development phases of the project. These project risks and limitations should be identified and mitigated early in the concept stage of hub development. The economics of the value chain, domestic uses, and export approaches should define which hubs are most attractive for further investment and development.

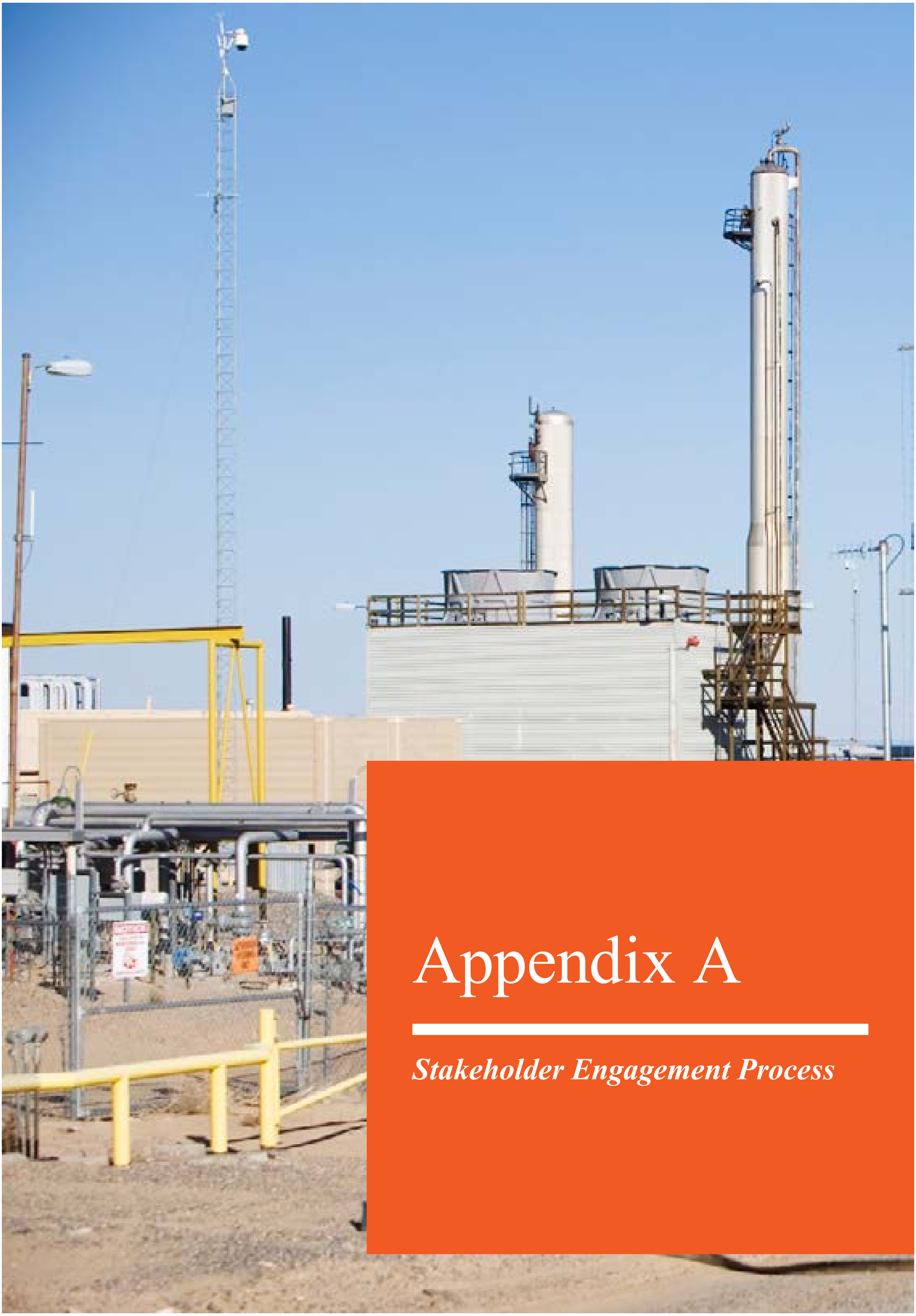
2 - Hydrogen Export Hubs

The stakeholder engagement process completed identified a range of investment opportunities with a common theme; Industry is prepared to share the risk with Government to see the creation of a sustainable domestic and export market for a decarbonised hydrogen future. Investment should also focus on driving down the price of hydrogen for domestic usage and production to increase competitiveness as an exporter. There is a natural cohesion in the policy drivers for both an export and domestic market for decarbonised hydrogen.

To access export opportunities, there is a need to invest in both transportation and exportation infrastructure. Common pipelines, storage, and co-location of production facilities investment near export hubs would help to address the transportation infrastructure gap and support the development of export hubs.

3 - Hydrogen Cities, Precincts and Regions

An overview was provided of a number of considerations required for identifying hydrogen cities, precincts and regions. These are dependent on local demand, and in many cases the market will make its decisions facilitated by Government initiatives. The discussion on investment criteria was presented and a starting list and point of discussion for decision makers provided and can be used by both public and private industry to consider to further support the development of suitable domestic hubs.



Appendix A

Stakeholder Engagement Process

A1 Introduction

As part of the study, consultation was conducted with State and Territory Governments, regulators and selected industry participants to determine key interests, opportunities, drivers, technology preferences, barriers and mechanisms for further investment in the hydrogen economy. Consultation included information on current pilot projects and developments underway in Australia. The consultation included an online survey and interviews.

The first part of the section summarises the key findings that were observed during the survey and interviews. Further details are provided together with insights as to what were polarising findings (opposing views on the same topic) and marginal findings (raised by few, if any, respondents but could have key impact). Following the findings of the consultation process, details as to how the process was undertaken are provided. The section concludes with a summary of the findings of the process and how they are utilised in later sections of the report.

A complete list of the stakeholders approached is presented in Appendix B. A list of stakeholders interviewed is provided in the Consultation Process section below. Some stakeholders preferred their involvement to remain confidential and as such they are referred to by a generic description. The interview agenda is provided in Appendix C.

A2 Consultation process

The consultation process between 23rd September and 3rd October comprised an online survey and interviews. The following section provides information about the topics, process and composition of respondents.

A2.1 Interview process

As part of the stakeholder consultation and following confirmation from COAG to proceed, 21 face-to-face or telephone interviews were conducted between the 23rd of September and 2nd of October 2019. The interviews were conducted with representatives from State and Territory Governments, regulators and industry. A list of stakeholders approached for survey and interviews is provided in Appendix B.

Each interview consisted of a series of structured questions with key feedback captured and recorded in the minutes. A copy of the meeting agenda and questions can be found in Appendix C and a summary of minutes is provided in the Key Findings, Polarising Findings and Marginal Findings. Minutes for each meeting can be made available on request (if indicated as acceptable by the interviewed party), noting that some participants have expressed for their responses to remain confidential as the information provided was not currently in the public domain. The interviewees are gratefully acknowledged for their time and contribution.

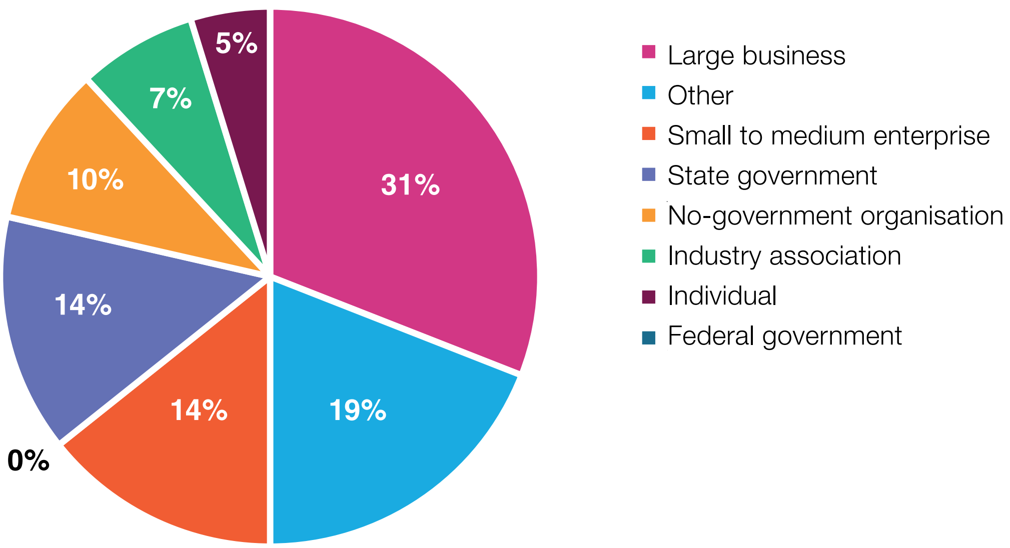
A2.2 Online survey process

To support the interview process by gathering data for the study, targeted stakeholders were sent an online survey comprising 24 questions. The survey was targeted and does not present a comprehensive sample of stakeholder views. The survey was open from Wednesday, 25th September to Thursday, 3rd October, with 42 responses being recorded during this time. Responses were aggregated by all respondents with the feedback from each receiving an equal weighting during the analysis of collected data.

Figure 6 and Figure 7 highlight the various industry sectors incorporated in the online survey and the respondents organisational position in the hydrogen industry. A significant portion of the respondents were from large businesses (31%) and were representatives of small to medium enterprises (14%). Furthermore, approximately one third of stakeholders participating in the online survey classified themselves as project developers.

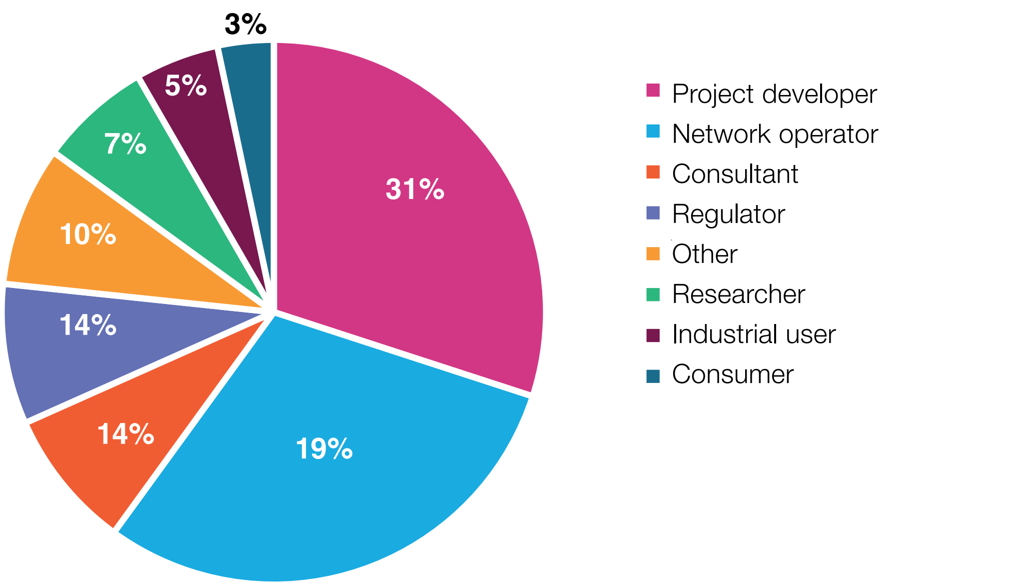
Organisational type

Figure 6. Survey respondent organisational type



Role in the hydrogen industry

Figure 7. Survey respondent organisational role



A3 Key findings

The following themes were observed from the interviews and the survey:

Clean Green hydrogen, produced from wind and solar resources through electrolysis using purified wastewater, transported by pipeline and stored in pipelines and as ammonia was the preferential supply chain for hydrogen.

Preference to develop hubs where there is existing domestic demand, lower community impact and existing infrastructure.

Existing infrastructure can and should be used or repurposed for domestic use, transportation and storage, and export of hydrogen where possible. In the future, new ports (or port expansions), pipelines, water resources and land for renewable energy will likely be required. Obtaining suitable land and water resources will be challenging.

Export customers, industrial feedstock, land freight transport fuel were considered to be the preferred/likely customer base for future hydrogen supply. Securing offtake agreements is a key project challenge.

Risks including cost of technology, buyer market uncertainty, scale and speed of development of competing technologies could have implication on the scale and success of the market in Australia.

Uncertainty as to which business models will be most profitable. While there are new technologies and business models evident, companies are tending to extend into the hydrogen market along their natural core competencies, for example exporters desire to continue to export.

Almost one half of projects and developments discussed were not in the public domain. Without collaboration, there is a risk of prisoner's dilemma (i.e. acting in protected self-interests as opposed to producing an optimal outcome for the collective) with respect to developing infrastructure and servicing the buyer market.

Land, resources, access and the ability to develop industry in parallel with current business would enable the development of hydrogen hubs.

Lack of clarity with respect to policy and regulation. Companies are progressing irrespective of relative uncertainty around climate - carbon policy, taxation, approvals, regulations and standards. A desire among Government and industry to coordinate policy and regulation (to the extent possible).

Better dissemination of research would accelerate the industry, this is seen as the role of the grant provider.

A3.1 Production, transport, storage and export preferences

Clean Green hydrogen, produced from solar and wind resources through electrolysis using purified wastewater, transported by pipeline and stored in pipelines and as ammonia was identified by respondents as the preferential supply chain for hydrogen.

81% and 76% of survey respondents noted solar and wind should be the focus of energy generation, for the development of hydrogen hubs, respectively. It was considered that these energy generation sources are where Australia has an international competitive advantage, and the costs are low and falling. However, LNG was considered a bridging technology. There as consideration that the low LNG prices in WA may inhibit hydrogen adoption for domestic demand; however on the East Coast this trend was reversed.

Respondents commented on where the focus should be for water sources, as part of water electrolysis. Wastewater was the overall first preference, with 45% selecting it as their first preference and no respondents selecting it as their last preference. Desalination was extensively mentioned in the interviews. Potable water was a highly polarising option, and not considered feasible by many respondents due to Australia's lack of water resources, particularly for inland projects or developments.

The survey showed 73% of participants believed a focus on transport (from source to hub) should be pipelines. The preferred mode of transport is dependent on distance and volume, and existing infrastructure in the area. There was a lack of consensus both in the survey response and in the interviews as to the cost vs benefit of various modes of transport, particularly between tube trailer truck and pipeline. However, it was broadly agreed that land requirements for new pipeline corridors should be planned as soon as possible, particularly near proposed export ports.

The preferred technology for hydrogen storage was not as clear, with respondents indicating that research should be greatly focused on liquid ammonia (50%), natural gas pipelines (38%) and underground storage (30%).

A3.2 Location for development of hydrogen hubs

Preference to develop hubs where there is existing domestic demand, lower community impact and infrastructure.

Stakeholders mention multiple factors and enablers related effectively identifying potential hydrogen hub location and hydrogen production facilities. Existing infrastructure will need to consider preferential access to competitive hydrogen supply through lowest cost of renewable energy, concentration of major industry users export potential (e.g. port capacity, proximity and supply cost to export markets), critical mass of supply and demand, availability and access to transmission and gas distribution networks for storage, land access, tenure and availability as well consider other sector demands including transport and mining.

Existing infrastructure fit for hydrogen development and repurposing will need to identify where there is coincident access to wind and solar renewable energy, electricity, gas infrastructure and agglomerations of domestic demand. Stakeholders acknowledge the importance of economic factors including the availability of skilled employment and the degree of regional economic development. Furthermore, stakeholders identify political factors as an important consideration - political pull has the potential to dictate Government expenditure. The utilisation of tax benefits and grants can play a fundamental role in optimising hydrogen hub placement.

A3.3 Capability of existing infrastructure

Existing infrastructure can be repurposed for domestic use, transportation and storage, and export of hydrogen. In the future, new ports (or port expansions), pipelines, water resources and land for renewable energy will be required. Obtaining suitable water and land will be challenging.

Stakeholders comment on the capability of transport and storage infrastructure: existing domestic gas distribution network, transmission pipelines, storage and refuelling station infrastructure. Some respondents commented that given recent mains replacement projects, domestic gas pipelines are considered suitable for future hydrogen blending and large-scale storage. The respondents highlight the need to for HDPE pipes for potential future 100% hydrogen storage and distribution. Views varied as to whether gas transmission pipelines would be feasible for transport and storage of hydrogen due to high operating pressure of the pipelines, hydrogen embrittlement (depending on material composition) and current low capacity for additional gas (pipeline capacity being contracted for the LNG industry). Reuse of the pipeline corridor is considered the major opportunity. Opinions on re-use of underground storage, such as CCS, were varied. Some infrastructure such as hydrogen storage tanks are under-developed and refuelling infrastructure is non-existent currently.

Respondents express the desire to reuse existing port related infrastructure, noting that availability of berths is currently low. Even so, select projects have high potential to use existing infrastructure. Large scale projects will need infrastructure purpose built, for which planning has commenced in some stages, due to the long build times (5-10 years). Some stakeholders express a desire to see a planned transition of existing fossil fuelled assets to the hydrogen industry and then from brown or blue to green hydrogen in the long term.

While tube trailers are being considered in current projects and reuse of road transport and rail infrastructure was considered by some respondents, these were not considered to be economic at large scale.

Electrical infrastructure reuse was not considered by most respondents due to network constraints and network power being more expensive than self-generation.

A3.4 Hydrogen future demand

Export customers, industrial feedstock, land freight transport were considered to be the preferred customer base for future hydrogen supply. Securing offtake agreements is a key project challenge.

- Export customers was a clear first preference for the most optimal customer base, with 50% of survey respondents selecting it as their first choice. Industrial uses (feedstocks and energy), as well as transport (particularly land freight and public transport) round out the clear top five preferences. Australia's significant LNG, coal and iron ore export experience, coupled with the potential future international demand for hydrogen (and potential replacement of some hydrocarbon-based export supply chains), were key reasons why respondents identified export customers as attractive for future hydrogen demand. Industrial feedstock was considered, however it was acknowledged that this market was unattractive due to competition with low cost existing processes using SMR. Land freight transport and public transport are target markets due to the relative weight advantage and refuelling characteristics over current battery technology. Gas blending in the distribution networks would create a huge domestic demand.

- Development of a domestic demand would have a range of benefits for the export market. Whether a developed domestic market was essential to support/launch the export market was a polarising topic and it will be discussed below.

- Respondents also highlighted the importance for economies of scale to underpin significant cost reductions if hydrogen hubs are going to be developed. Hydrogen prices should be set so that they can deliver a return on investment and a scale of consumption that warrants large-scale production. With an uncertain demand for hydrogen and many projects competing for contracts, securing offtake agreements for hydrogen was cited by almost all respondents as a key challenge. This creates a chicken and an egg scenario.

A3.5 Critical factors to success for hydrogen hubs

Risks including cost of technology, buyer market uncertainty, scale and speed of development of competing technologies could have implication on the scale and success of the market in Australia.

- Hydrogen supply costs was identified as the most critical factor, (selected by 33% of survey respondents) followed by economic benefits. Interesting to note were proximity to fuel source and public license which both received an approximated 25% response rate as last choices, signalling that these were not considerable barriers. Moreover, project financing was clearly the least critical factor, with approximately 74% of respondents placing it in their bottom five choices.

- Respondents noted that Government has an important role to create policy certainty and provide long term offtake to enable investment to flow into critical infrastructure. Buyer-market uncertainty is directly impacted by policy uncertainty, if Australia is slow to scale up production and export, other countries will have developed production capacity and executed supply contracts. Stakeholders believe the lack of policy certainty is the deterring investment, consequently Government policy and incentive programs need to be courageous and bold to kick start the industry sector as the economies of scale drive the economics. Respondents highlight the need for urgency and encourages first movers to underwrite a large-scale project.

- The potential for competing technologies, such as solar, wind and battery storage, to outpace the development of hydrogen was raised by some respondents. However, for green hydrogen, cost reductions in solar and wind will reduce the costs of energy input, which is currently the largest cost in green hydrogen input so there will be some complementary benefits. The relative cost reduction of green hydrogen generation when compared to alternative forms of energy is in relation to the other costs, such as falls in electrolyser costs. It is considered that some areas of the supply chain would be difficult to use alternatives to hydrogen, particularly hard to electrify sectors and where a molecular energy vector is required, for example gas distribution networks.

Hydrogen production by other energy sources are affected by the cost of fuel, subject to supply agreements, which vary from state to state. LNG, for example, is relatively cheap in WA, but more expensive on the East Coast.

A3.6 Industry trends and business models

There is uncertainty as to which business models will be most profitable. While there are new technologies and business models evident, companies are tending to extend into the hydrogen market along their natural core competencies, for example exporters desire to continue to export. Scalability is a challenge.

- Respondents identified a desire to participate in the supply chain in a range of potential business models:
- Renewable energy provider, production, transportation, storage and retail (international and/or domestic);
- Fuel provider, production, transportation, storage and retail (international and/or domestic);
- Production, transportation, storage and retail (international and/or domestic);
- Production, transportation and storage;
- Production;
- Transportation and storage;
- Hydrogen consumer (hydrogen and/or ammonia).

- Hydrogen production was either co-located with the energy source (and typically water source or coastline) or co-located with the distribution/transport hub. Some respondents are investigating multiple business models in parallel.

- Each business model was subject to unique risks and uncertainties. Companies are assessing which parts of the supply chain would be most profitable. While large scale operations are acknowledged as key to reducing costs, this is constrained by uncertain future demand. There were differences of opinion regarding the scale required to be commercial, preferred technology, costs of hydrogen production, transport and storage and size and importance of target markets. These factors were interlinked, for example cost to produce hydrogen $/kg in the existing hydrogen market for industrial feedstock, serviced by SMR are far lower than the potential hydrogen fuel cell transport market. Government policy and regulation uncertainty led to some parts of the value chain being more attractive than others.

- In an Australian domestic context, there is considered limited first mover advantage in the use of hydrogen.

- Scalability of project is a challenge in terms of land availability, modularisation of the technology, approach to target market and key infrastructure requirements requiring long lead times.

A3.7 Opportunities for collaboration

Almost half of the projects and developments that were discussed were not in the public domain. Without collaboration, there is a risk of prisoner's dilemma with respect to developing infrastructure.

- Many respondents were already in discussions regarding partnerships, fuel supply agreements, hydrogen supply agreements, and, to a lesser extent, infrastructure sharing agreement. Increasing collaboration with offtake partners was an emerging trend. Due to the profitability of current export activities, export infrastructure owners typically did not express a view to repurpose export infrastructure or shipping for hydrogen in the future.

- Numerous projects were not in the public arena, which indicates a large part of the hydrogen supply chain which may be developed in an uncoordinated manner. The support of current projects by Government funding agencies is considered sporadic with respect to developing hydrogen hubs. Further details in Section A3.9.

- Early identification of benefits from project collaboration is considered to be within the remit of industry, but Government involvement regarding project coordination and opportunities for collaboration with respect to land access (such as industrial zones, transport and pipeline corridors) and infrastructure sharing (new build ports) could assist.

- Respondents in the survey indicated that social license was not perceived as a critical factor for the development of hydrogen hubs. However, in the interviews, respondents requiring large areas of land for development noted that early involvement and collaboration with key stakeholders including land owners and indigenous parties is essential. Some noted access to water resources, particularly fresh water resources, may become more of an issue in the future.

A3.8 Industry enablers

Land, access and the ability to develop industry in parallel with current business would enable the development of hydrogen hubs.

- A range of enablers were identified by respondents to assist in the viability of hydrogen production including additional provision of land and access, non-interference with of core businesses (e.g. not reducing the capacity of LNG carriers), more attractive costs and returns in comparison with existing businesses, carbon abatement processes and reduced third party interaction and risk. Conversely to reducing third-party risks, other respondents indicated a desire for partnership even to an extent of equity sharing. Further information provided in Section A3.7.

- Respondents also expressed a desire for further information to inform decision making, such as standards, regulations, approvals, information on infrastructure, domestic demand, etc. (in some cases, this information was pooled in a single online location for ease of access).

A3.9 Policy and regulation uncertainty and suggested enablers

Lack of clarity with respect to policy and regulation. Companies are progressing irrespective of relative uncertainty around carbon policy, taxation, approvals, regulations and standards. A desire among Government and industry to coordinate policy and regulation (to the extent possible).

- Government enablers mentioned by most respondents included tax based and pricing policies such as a carbon tax or carbon price. Government enablers which were identified to reduce buyer market uncertainty included take or pay mechanisms, backstops and contracts for difference. Transfer of Government fleet vehicles to fuel-cell electric vehicles (FCEVs), targets or mandates for hydrogen blending in the network and other policies targeted at decarbonisation were seen as mechanisms to stimulate domestic demand. Some respondents indicated increased Government involvement akin to the Scandinavian models would be a consideration, or large loans akin to the PRRT which is currently utilised for the LNG industry.

- A desire among Government and industry to coordinate policy, including taxes, regulations and standards (to the extent possible) to provide a level playing field, acknowledging that Australia is competing internationally against other countries. Government enablers with respect to facilitation of business included a "one-stop-shop" for approvals, regulatory sandbox, updating regulations and standards that currently exclude hydrogen.

- It was also considered that the Government could further raise the profile of Australia's hydrogen industry internationally. This may assist in securing international offtake agreements. Part of this involves clarifying specifications as to what is green, blue and brown hydrogen in conjunction with international off-takers. To a lesser extent a higher profile, this may enable faster equipment and technology transfer such as FCEV and electrolysers, as Australia is considered a small market and not prioritised.

- Coordination of projects to achieve collaborative outcomes is occurring to varying extent on a state by state basis but not as much at a federal level. There are a huge number of parties involved with varying levels of effectiveness (COAG, NAIF, CEFC, ARENA, AEC, State Government departments, Future Fuels CRC, etc.). While the support is gratefully acknowledged, uncoordinated efforts, particularly relating to policy and funding, distort the market and dilute the effect of a coordinated, single goal. Respondents have called for clear leadership and coordination at a federal level to support the state Governments. Respondents opined that Australia needs to scale quickly to become a key player in the industry and secure offtake before other countries (Qatar, Norway, Russia, Saudi Arabia[42] and possibly parts of Africa) which may operate at a lower cost base.

A3.10 Effectiveness of research

Better dissemination of research would accelerate the industry, this is seen as the role of the grant provider.

- Respondents identify several research projects occurring across Australian universities and private institutions focusing on optimising hydrogen production by reducing losses throughout chemical conversion processes, carbon capture during hydrogen production, novel hydrogen storage, utilizing technology to enable lower quality water to be used during electrolysis and enhancing efficiency in hydrogen transportation. Private and public investment will encourage further research and improved dissemination of information can accelerate overall industry progress.

- Current processes are not seen as effective at disseminating information. Commercial instruments such as patents and licenses could be used to speed knowledge transfer while rewarding researchers and/or early developers.

A4 Polarising findings

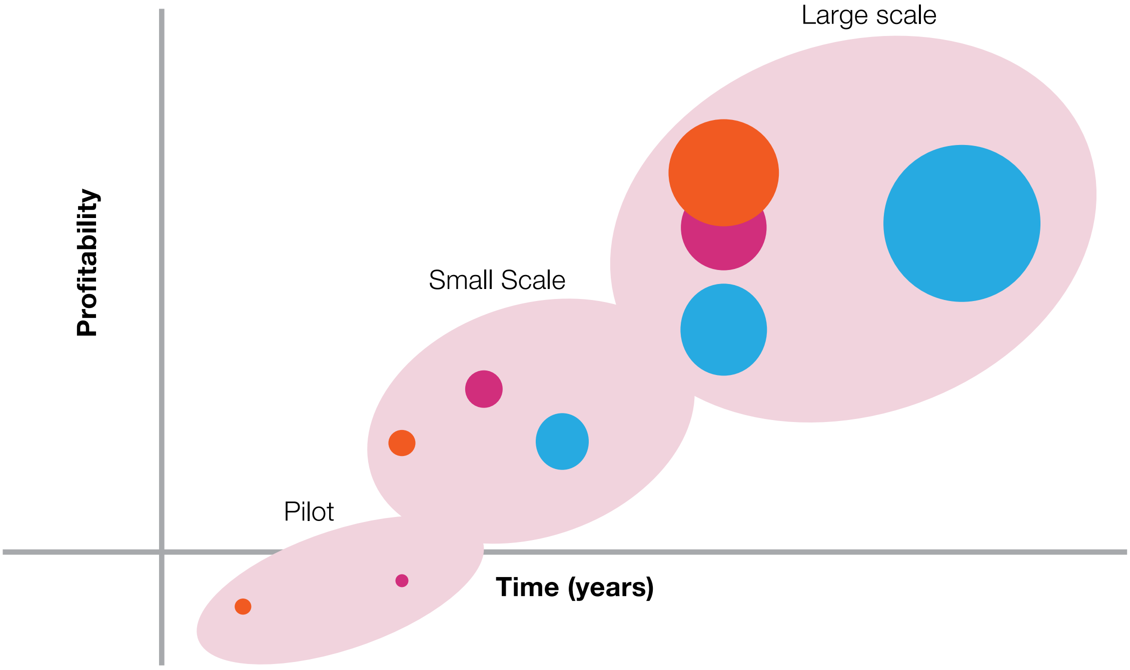
The following themes were raised by many respondents and are considered divergent or polarizing and are summarised at high level.

A4.1 What is the scale of development and sequencing of development that is required to become commercial?

- As a nascent industry, there is a lack of information as to the profit margins in each supply chain activity. While larger and more technologically complex projects are typically scaling up in 2-3 steps, with a pilot, small scale operation and the operation at scale. This is shown in the indicative Figure 8 below (not based on real data).

- Commercialisation may occur at different points in the scale up depending on the target market for the product. While it was acknowledged that typically large, co-located operations were required to compete for export on an international level, there were alternative options presented. These included local applications such as the HAZER process which uses waste bio-gas and can operate in the urban fringes and co-location of electrolysers with existing renewable energy generation and subsequent transport of hydrogen to the end market.

Figure 8. The indicative graph shows the profitability of pilot, small scale and large project vs. time (not based on real data)



A4.2 Is the development of a domestic market essential for an export market?

- Stakeholders also mentioned the need to establish crucial building blocks before Australia becomes a major exporter of hydrogen. Some respondents indicated that for Australia to become a credible trading partner (export of H2), there needs to be a focus on developing domestic applications at scale prior to exporting hydrogen. Therefore, incrementally building infrastructure and supporting demand (offtake) through public and private investment establishes an effective foundation to which hydrogen could then be exported. Furthermore, for Australia to meet upcoming demand for hydrogen, there needs to be a demonstration of effective local technology and formation of public awareness.

- Other respondents felt that development of domestic demand was not a necessary step in developing the export market.

A4.3 Is the use of potable water and/or groundwater acceptable?

- It is broadly acknowledged that availability of water sources varies widely around Australia, but they are typically constrained and politically sensitive. The consensus among most respondents is that potable water and groundwater should not be utilized in the production of hydrogen by electrolysis. Stakeholder consultation in a rural region of Australia indicated low public license for access to water supplies unless there is a value-add for the local community.

- Some survey respondents indicated use of potable water and/or groundwater may be acceptable to service domestic demand. Potable water was a highly polarizing option, in the survey, receiving the second greatest number of first preference selections at 26.2% but also the greatest number of last preferences at 50%.

A4.4 How can the developing export hydrogen industry co-exist with LNG industry?

- Respondents commented widely on how developing the hydrogen industry follows the global trend to decarbonise and reduces Australia's economic reliance on exporting LNG in the long term.

- LNG and hydrogen potentially share export infrastructure and customer base. LNG is also an input fuel for hydrogen production via SMR "blue hydrogen".

- It is noted that currently the LNG industry is a major contributor to the Australian economy. Use or repurpose of LNG infrastructure and assets such as ships or berths (or other exporting industry assets, for that matter) for the hydrogen industry would affect profitability. Some respondents noted that export of hydrogen could cannibalise their international LNG market. It was noted by many that the demand for hydrogen could be serviced by many other countries.

- Acknowledgment by many respondents that due to the lower costs of production, hydrogen production from LNG via SMR (blue hydrogen) is considered likely as a transition to green hydrogen. There was uncertainty as to what infrastructure and assets may be required to be duplicated.

- The speed of the transition ultimately depends on the decarbonisation policies of the target market, as some markets only wish to import green hydrogen. A method to decarbonise the SMR process is to use CCS. One jurisdiction in Australia indicated they would not support CCS as part of hydrogen production.

- There are alternative export mechanisms and new technologies at the end use (e.g. FCEV) which are areas where hydrogen does not compete with LNG.

A5 Marginal findings

The following section discusses items which were raised in isolation (or not at all) by respondents during the stakeholder consultation process. However, they are considered emerging or marginal topics in relation to the development of hydrogen hubs in Australia.

A5.1 Risk of unknown / unknowns

Limited discussion on major disruptors to the potential hydrogen industry including another global financial crisis, lack of development of FCEVs or rapid development of international renewable infrastructure (which could reduce international demand), resource or equipment shortages, development of a hydrogen trading hub with price fluctuation etc.

A5.2 Value odd industries

Opportunities to value-add from the development of a hydrogen hub, potential export a higher value product or service. Respondents mentioned options including metal hydride technologies, low carbon fertilizer, low carbon explosives, green steel and low carbon food (grown using low carbon fertilizer and with low carbon supply chains). Opportunity to leverage off the mining industry and develop high tech, low carbon applications.

A5.3 Role of local Government

The potential role of the local Government was mentioned by a single respondent. Opportunities to assist with approvals, land access, facilitate stakeholder discussions and build relationships with local communities.

A5.4 Role of rail

While respondents in the survey indicated that rail was a potential for transport of hydrogen, there was relatively little further comment on this mode of transport. Rail was mentioned as potentially assisting with transport of water and/or hydrogen from remote location that have access to existing infrastructure.

A5.5 Risk of oversupply

The current planned 22GW of renewable energy in Western Australia alone, predominately for green hydrogen production, will service a large portion of the declared international hydrogen demand in 2030 (e.g. Japan, Korea). When combined with 10GW renewable energy plans in Northern Territory and other blue and brown hydrogen export projects, plus all other states, then international supply, there is a huge potential for oversupply which would bring prices down. Securing offtake agreements and price is key to project development.

A6 Conclusion

The stakeholder consultation process was designed to determine key interests, opportunities, drivers, technology preferences, barriers and mechanisms for further investment in the hydrogen economy.

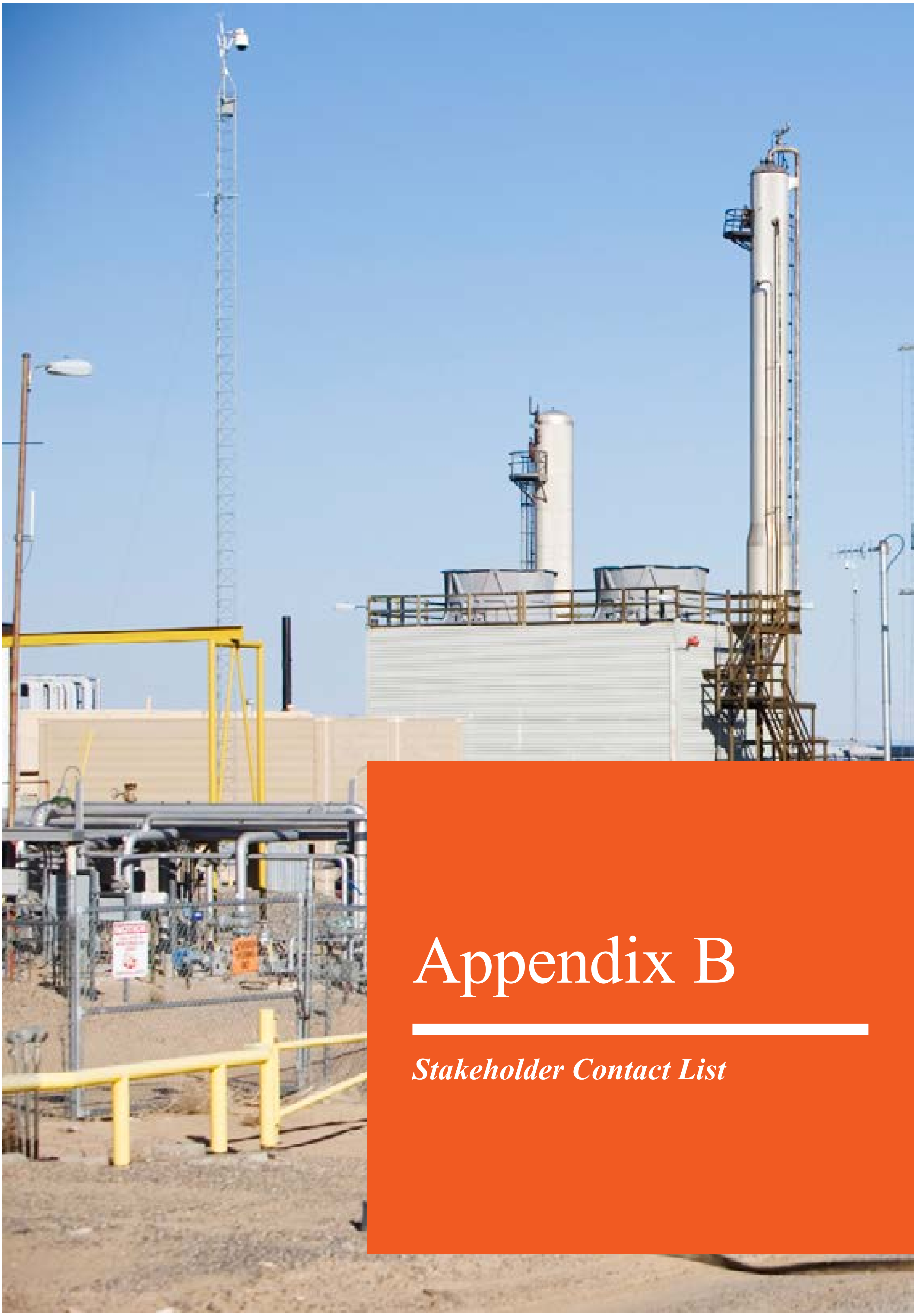
Consultation included information on current pilot projects and developments underway in Australia. The online survey and interview process provided data from which interpretations and themes were developed.

10 key themes were highlighted and detailed in this section and an overview provided of the interview and survey process followed. Data from the survey and interview process have been used within the other sections of report to support the assessment of infrastructure for hydrogen hubs in Australia.

The consultation process was conducted within a compressed time schedule to inform the National Hydrogen Strategy. While the online survey captured the views of some respondents which were unable to attend an interview due to time pressures, further time and consultation would enable the views of broader industry participants to be sought. Industry participants that could benefit from further participation include local Governments, renewable energy developers, transmission infrastructure owners (gas and electricity), port operators, energy storage owners/operators, research organisations, industry bodies and community groups. However, it is acknowledged that an open forum, in the form of the two rounds of public consultation conducted by COAG on the National Hydrogen Strategy, have enabled these members an opportunity to contribute.

The data, interpretation, themes and recommendations in the stakeholder consultation process should be read in conjunction with other sections of the report.

[42] Available at: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/supporting_documents/NationalHydrogenStrategyIssue3DevelopingHydrogenExportIndustry.pdf



Appendix B

Stakeholder Contact List

- ADME Fuels
- AGL Energy
- Air Liquide
- Alcoa of Australia
- ANZ
- APA
- ATCO
- AusNet Services / Mondo
- Australian Energy Council
- Australian Pipelines and Gas Association (APGA)
- Australian Renewable Energy Agency (ARENA)
- Australian Trucking Association
- Ballarat City Council
- Bennet Clayton P/L
- BHP
- BOC
- BP
- Chevron
- Clean Energy Council
- CleanCo
- CO2CRC Limited
- ConocoPhillips Australia
- Curtin University
- CWP
- Deloitte
- DELWP
- DEM
- Department of the Environment and Energy
- DOTAF
- DPIRD/ DJSTI
- EDL Energy (a sister company of AGIG)
- Energy Australia
- Energy Estate
- Engie
- Evoenergy
- ExxonMobil
- Fortescue Metals Group
- Future Fuels CRC
- Gas Appliance Manufacturers Association of Australia (GAMAA)
- GHD
- Gladstone City Council

- Global CCS Institute
- Grattan Institute
- Hazer Group
- Honeywell
- Hydricity Systems
- Hydro Tasmania
- Hydrogen Energy Supply Chain
- Hydrogen Mobility Australia
- Hydrogen Renewables Australia
- Hyundai
- Incitec Pivot
- INPEX
- Institute for Sustainable Futures, UTS
- ITM Power
- Jemena / Ovida
- KPMG
- La Trobe City Council
- Maritime Union of Australia
- Meridian Energy Australia
- MM Technology
- Monash University
- Mondo Power
- Origin Energy
- Protos Consulting
- Public Interest Advocacy Centre (PIAC)
- Redland City Council
- Renew
- Renewable Hydrogen Pty Ltd
- Rheem Australia
- Roads Australia
- Shell
- Siemens
- TasGas
- Territory Generation
- The Energy Change Institute, ANU
- Thyssenkrupp
- Toyota
- University of Adelaide
- University of Melbourne
- University of Queensland
- Viva Energy
- Woodside Energy
- Yara Pilbara

The following stakeholders are gratefully acknowledged for their contribution during the interview process:

- AEMC (Australian Energy Market Commission)
- AGIG (Australian Gas Infrastructure Group)
- DELWP (Department of Land, Environment, Water and Planning)
- DEM (Department of Energy and Mining)
- DENR (Department of Environment and Natural Resources)
- Department of Trade, Business and Innovation
- Department of State Growth
- DJSTI (Department of Jobs, Tourism, Science, Tourism and Innovation)
- DOTAF (Department of Treasury and Finance)
- DPIE (NSW Department of Planning and Government)
- DPIR (NT Department of Primary Industry and Resources)
- DPIRD (Department of Primary Industries and Regional Development)
- DRNME (Department of Natural Resources, Mines and Energy)
- ENA (Energy Networks Australia)
- Energy Developer x 2
- Energy/ Mining Operator x 6
- Engie
- EPSDD (Environment, Planning and Sustainable Development Directorate)
- Evoenergy
- Hydro Tasmania
- Incitec Pivot
- Territory Generation

Appendix C

Interview Agenda

1. Introduction to the study and parties involved

2. Your organisation's interest in hydrogen production or utilisation

3. Hydrogen projects that are underway or planned by the organisation

4. Identification of potential sites for hydrogen hubs (criteria and locations for export or domestic use focused hubs)

5. Infrastructure considerations and options for linking projects within hubs (and regional connection)

6. How do you envision the supply chain from production to utilisation within a hub?

   Have you identified any enablers (e.g. supply chain kit)?

   - Other questions as from the online survey

   - Which energy sources should be used in hydrogen production?

   - Which water sources should be used in hydrogen production?

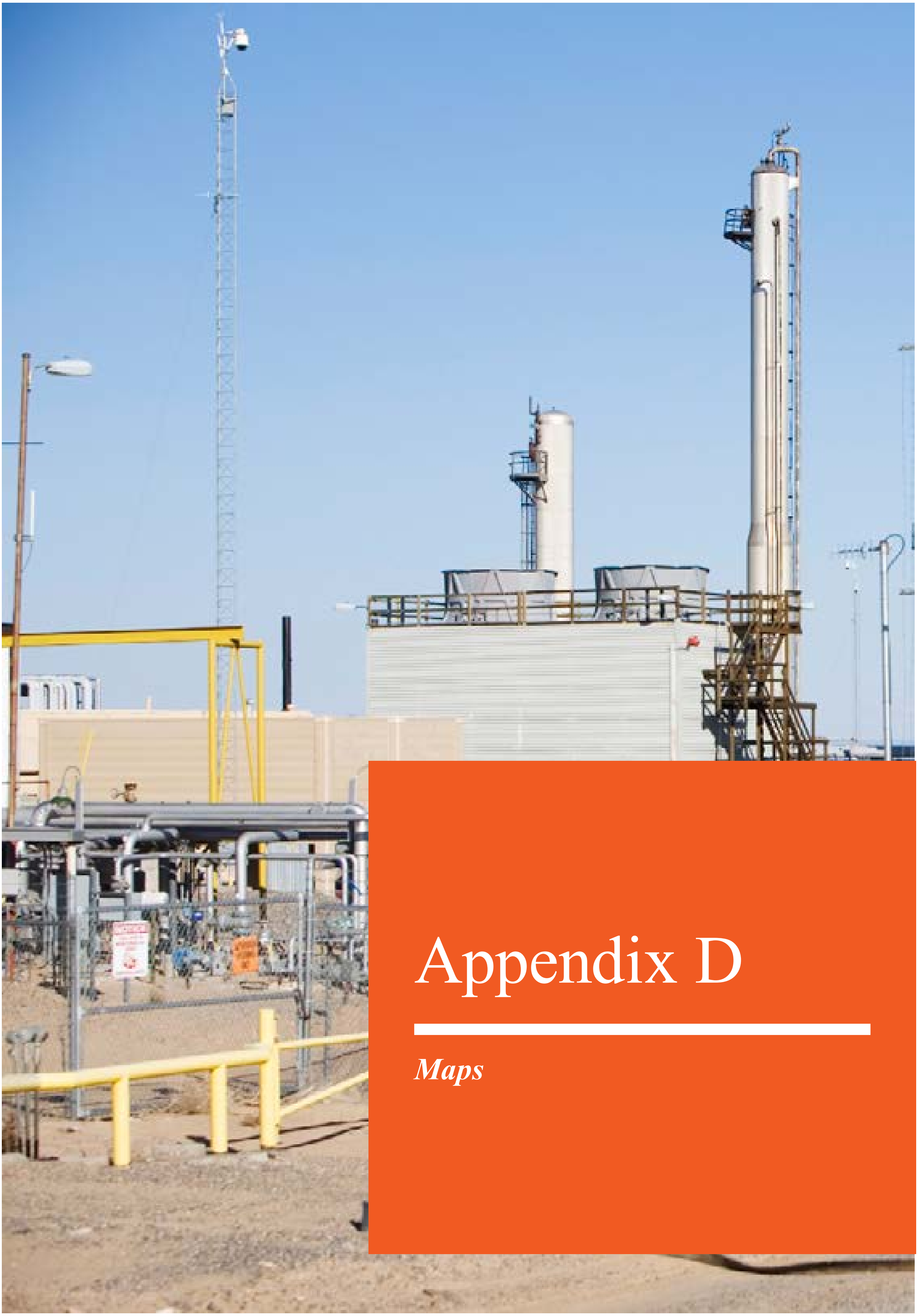
   - What is the best means of transporting hydrogen to demand centres or site of final use?

   - Which hydrogen storage options should be focused on during the planning of hydrogen hubs?

   - What are the key barriers to the development of hydrogen hubs?

7. Other Items of note

8. Close out



Appendix D

Maps

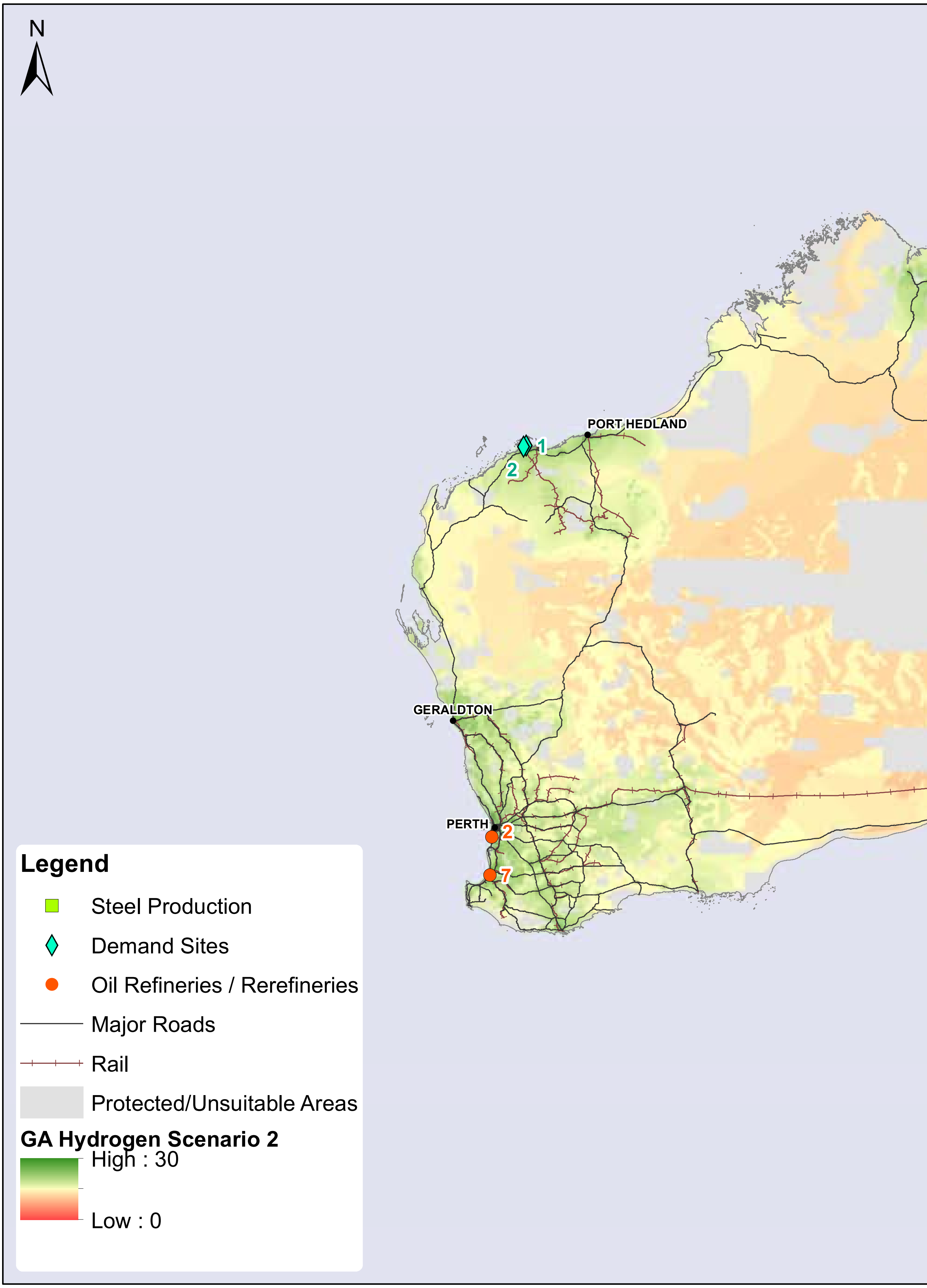
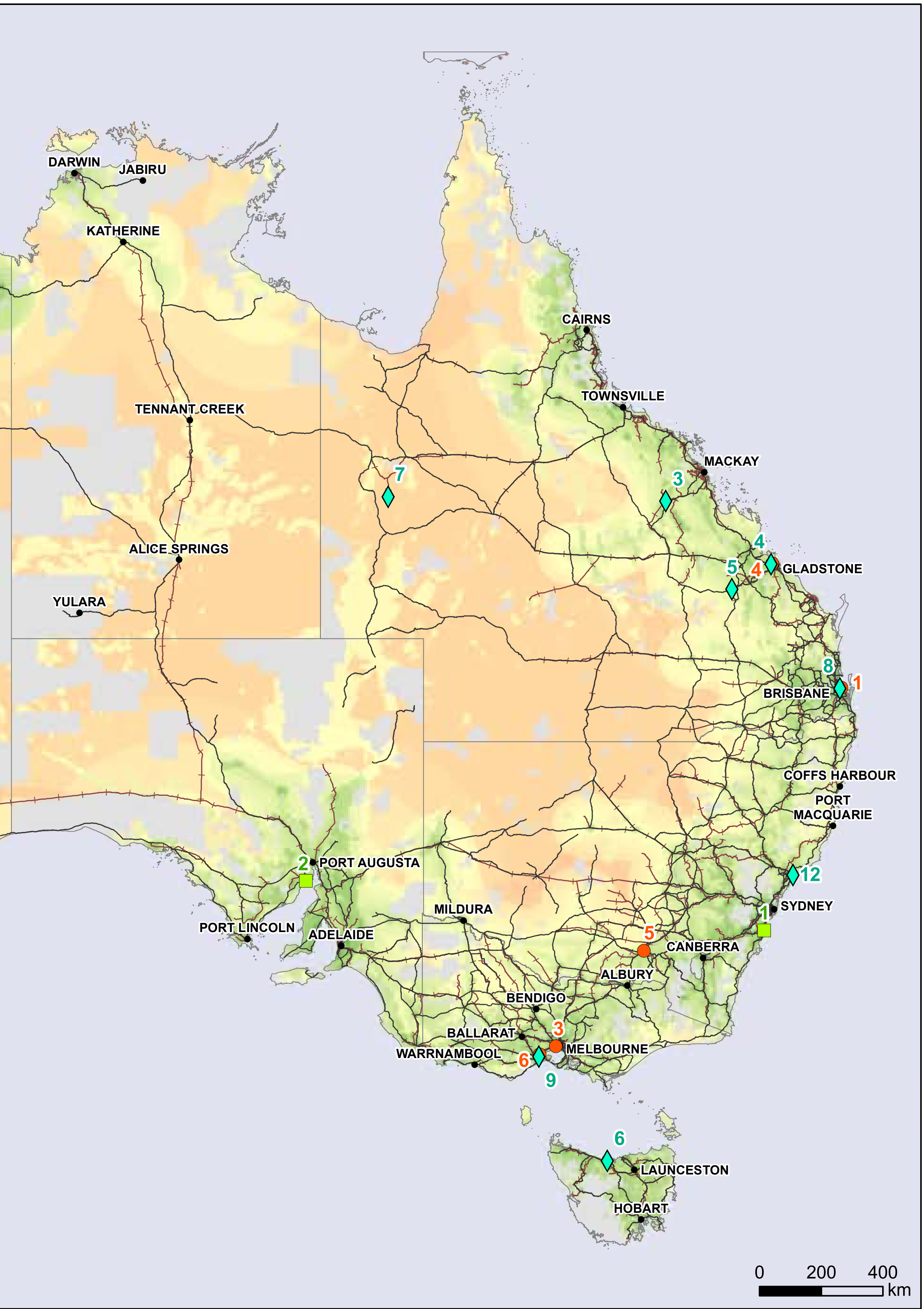


Figure 9. Domestic Hydrogen Development Potential (Scenario 2) – Australia Region


DARWIN
JABIRU
KATHERINE
CAIRNS
TOWNSVILLE
TENNANT CREEK
MACKAY
7
3
ALICE SPRINGS
4
5
4
GLADSTONE
YULARA
8
1
BRISBANE
COFFS HARBOUR
PORT
MACQUARIE
2
PORT AUGUSTA
12
SYDNEY
MILDURA
1
PORT LINCOLN
ADELAIDE
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CANBERRA
ALBURY
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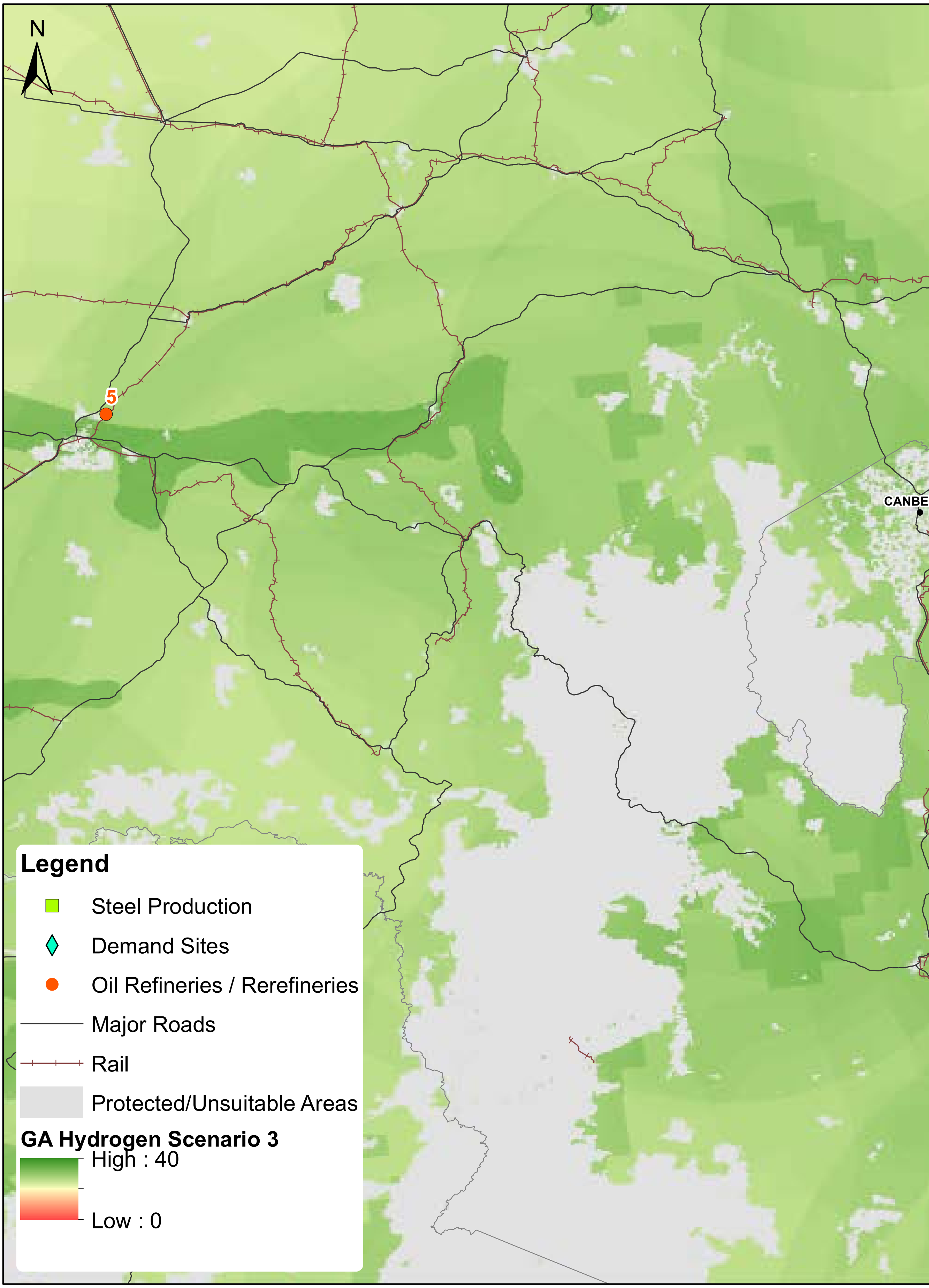

Figure 10. Domestic Hydrogen Development Potential (Scenario 3) – ACT Region

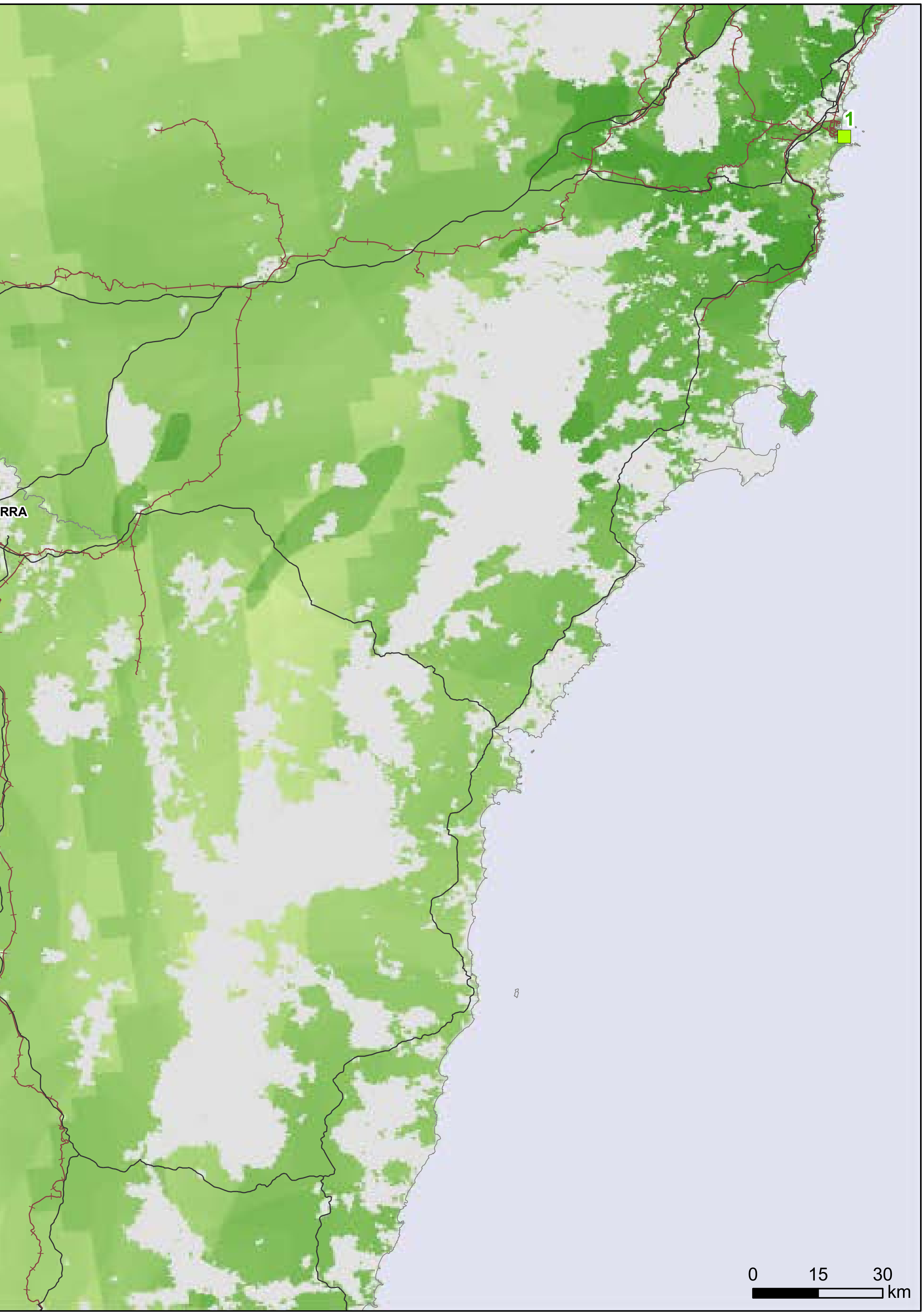
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Table 12. Domestic Hydrogen Development Potential – Demand Sites (refer to Figures 9 and 10)

ID	TYPE OF FACILITY	DESCRIPTION
1	Demand Site	Ammonia Production
2	Demand Site	Ammonia Production
3	Demand Site	Ammonia Production (Planned)
4	Demand Site	Synthetic Fuels (Pilot)
5	Demand Site	Ammonia Production (Planned)
6	Demand Site	Ammonia Production
7	Demand Site	Ammonia Production
8	Demand Site	Ammonia Production
9	Demand Site	Ammonia Production
12	Demand Site	Ammonia Production

Table 13. Domestic Hydrogen Demand – Steel Production (refer to Figures 9 and 10)

ID	TYPE OF FACILITY	DESCRIPTION
1	Steel Production	BlueScope Steel
2	Steel Production	Arrium Mining and Materials

Table 14. Domestic Hydrogen Demand – Oil Refinery (refer to Figures 9 and 10)

ID	TYPE OF FACILITY	DESCRIPTION
1	Oil Refinery	Caltex Oil Refinery
2	Oil Refinery	Kwinana Oil Refinery
3	Oil Refinery	Mobil Altona Refinery
4	Waste Oil Re-refinery	Northern Oil Refinery
5	Waste Oil Re-refinery	Southern Oil Refining
6	Oil Refinery	Viva Energy
7	Waste Oil Re-refinery	Wren Oil

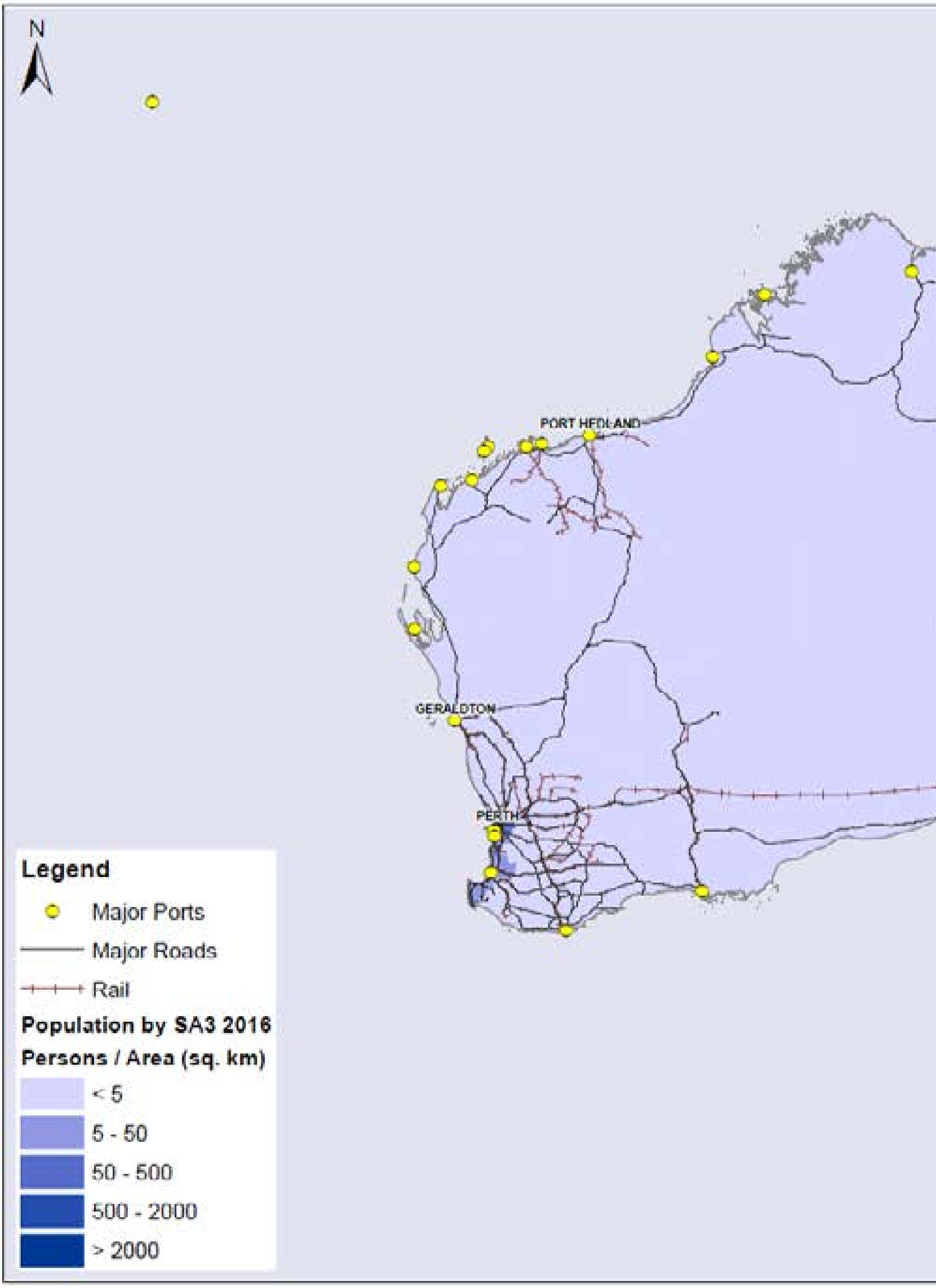
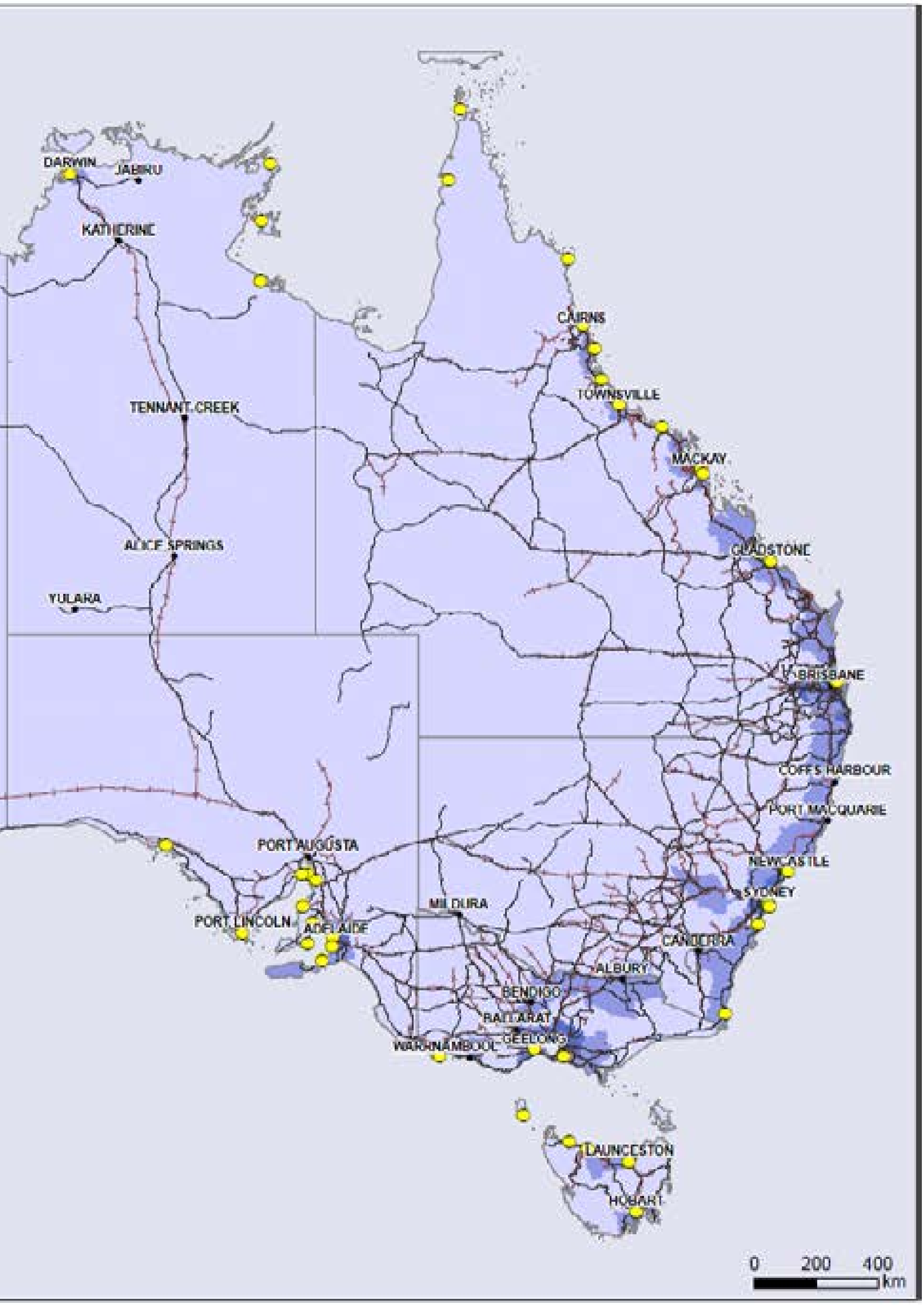


Figure 11. Future Demand in Australia – Current Population Density



DARWIN
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NEWCASTLE
SYDNEY
CANBERRA
ALBURY
BENDIGO
BALLARAT
GEELONG
WARRNAMBOOL
MILDURA
PORT AUGUSTA
PORT LINCOLN
ADELAIDE
LAUNCESTON
HOBART
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km

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