Renewable Hydrogen and Ammonia Feasibility Study

By GHD for BP Australia

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Contents

Figures

Tables

Acronyms, terms and abbreviations

The following acronyms, terms and abbreviations have been used in this report.

Acronym / term / abbreviation	Meaning
ADG	Australian Dangerous Goods Code
AUD	Australian Dollars
CAPEX	Capital expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBNGP	Dampier Bunbury Natural Gas Pipeline
DC	Direct Current
DG	Dangerous Goods
DNI	Direct normal irradiance
EP	Environmental Protection
EPA	Environmental Protection Authority
EPBC	Environment Protection and Biodiversity Conservation
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement and Construction Management
ERIA	Economic Research Institute for ASEAN and East Asia
ESG	Environmental, Social and Governance
FEED	Front End Engineering and Design
FP	Fremantle Port
GA	General Arrangement
GHI	Global Horizontal Irradiance
GIA	General Industry Area
GNIC	Geraldton Port to Narngulu Infrastructure Corridor
GW	Gigawatt
H2	Hydrogen
HECA	Hydrogen Energy California
HHV	Higher heating value
HPAD	Hydrogen Power Abu Dhabi
HSE	Health, Safety and Environment
HV	High Voltage
IEA	International Energy Agency
ISO	International Organization for Standardization

Acronym / term / abbreviation	Meaning
JDAP	Joint Development Assessment Panel
kV	Kilovolt
kg	kilogram
LCOH	Levelised Cost of Hydrogen
LGA	Local Government Area
LHV	Lower heating value
LNG	Liquefied natural gas
LOA	Length overall
LPG	Liquefied Petroleum Gas
MHF	Major Hazard Facility
MJ	Megajoule
ML	Megalitre
MNES	Matters of National Environmental Significance
MOU	Memorandum of Understanding
MT	Megatonne
MW	Megawatt
NIE	Narngulu Industrial Estate
NPV	Net Present Value
NW	North West
OHSAS	Occupational Health and Safety Assessment Series
OIE	Oakajee Industrial Estate
OPR	Oakajee Port and Rail
PD	Planning and Development
PDF	Portable Document Format
PEM	Polymer electrolyte membrane
PFD	Process Flow Diagram
PJ	Petajoule
PoG	Port of Geraldton
PPA	Power Purchase Agreement
QRA	Quantitative Risk Assessment
RED	Renewable Energy Directive
RFI	Request for Information
RFP	Request for Proposal
RL	Reduced level
RO	Reverse osmosis
SCA	Special Control Area
SIA	Strategic Industry Area
SIE	Social Impact Evaluation
SWIS	South West Interconnected System
t	Tonne
TEM	Techno-Economic Model
TEU	Twenty Foot Equivalent Unit
TWh	Terawatt-hour
V	Volt
WAPC	Western Australian Planning Commission

Key reference data

Description	Value
Volume equivalent	1 kg H_2 = 11.1 Nm^3 H_2
Hydrogen to Ammonia conversion[1]	1 kg H_2 = 5.67 kg NH_3
Electrical power equivalent	1 kg H_2 = 39.4 kWh HHV
	1 kg H_2 = 33.3 kWh LHV
Critical temperature of hydrogen[2]	-239.96°C (33.19K)
ENERGY EQUIVALENCE	
Hydrogen	120 MJ/kg LHV
	142 MJ/kg HHV
Petrol/gasoline	44 MJ/kg LHV
	46 MJ/kg HHV
Diesel fuel[3]	42 MJ/kg LHV
	46 MJ/kg HHV
Crude oil	42 MJ/kg LHV
	47 MJ/kg HHV
Liquefied petroleum gas (LPG)	46 MJ/kg LHV
	51 MJ/kg HHV
Natural gas	42 MJ/kg LHV
	55 MJ/kg HHV

[1] Conversion rate based on molecular mass – actual production rates lower as all H_2 not converted to NH_3

[2] If hydrogen is to be liquefied it must be below this point. Hydrogen in a fully liquid state at atmospheric pressure needs to be cooled to -253°C (20.15K).

[3] 1L of diesel fuel is equivalent to 0.297kg of hydrogen, based on lower heating values. Source: Hydrogen Tools, Accessed 4 December 2020 from: https://h2tools.org/hyarc/calculator-tools/energy-equivalency-fuels

1. Executive summary

This GHD report has been commissioned by bp (with support from ARENA) as a key component of Project GERI (Geraldton Export-Scale Renewable Investment) – a feasibility study to investigate the potential for a demonstration scale (circa 20ktpa of ammonia) and commercial scale (circa 1,000ktpa of ammonia) renewable hydrogen and ammonia facility in the Mid-West region of Western Australia. This report presents the key findings of the feasibility study including an overview of the project, and analysis from commercial, technical, logistics, regulatory, risk, compliance, environmental and planning work streams. This report also includes context and learnings from bp's international hydrogen experience. This detailed feasibility study is the first stage in bp's approach to evaluating the potential to invest in the emerging renewable hydrogen Australian domestic market and international export markets. Note that all monetary references are in FY21 Australian dollars unless referenced otherwise.

Why bp?	bp is committed to be a net zero company by 2050 or sooner and help the world get to net zero. In this context, the development of hydrogen and its derivatives (ammonia) is of strategic interest to bp. Project GERI could be an important step forward in developing green hydrogen/ammonia supply chains across Australia and globally. Through its joint venture with Lightsource bp, bp has the capability to deliver the 100% renewable energy solution for this project.
Why hydrogen?	Hydrogen is an efficient energy source, able to be produced through 100% green renewable power. Hydrogen (and its derivatives) could be adopted by industries as a decarbonising fuel, and as an energy vector for distribution over long distance. The hydrogen industry in Australia, for both domestic use and export markets, is forecast to grow significantly in the next 30 years, with even the most conservative scenarios posing a volume that can sustain multiple GERI-scale projects.
Why WA?	The Mid-West Region of Western Australia is one of the world's most attractive locations for green hydrogen production. High renewable diurnality exists, but it is far enough south to avoid cyclone season. Wind capacity factors exceed 50% compared to typical capacity factors ranging from 27% to 40% and the quality of the solar resource in the region is expected to have favourable GHI and DNI characteristics. This is supported by a stable and supportive government and regulatory environment as well as good proximity to demand markets.
Why two steps?	The project structure of a demonstration plant followed by a commercial scale plant facilitates the growth of the market, both from the perspective of the growth in demand from off-takers and improvements and cost reductions in technology. The demonstration plant would allow trialling and analysis of multiple technologies prior to scaling up and inform a range of decisions for the commercial scale plant (product mix, plant configuration, procurement, logistics routes etc.).

1.1 Project GERI may play a key role in bp's Net Zero strategy

In line with bp's commitment to Net Zero by 2050 or sooner, bp aims to substantially increase low carbon investment ($5 billion a year), develop around 50GW of renewable electricity and capture circa 10% market share in core hydrogen markets. bp views the development of a hydrogen fuels value chain as a key element of the decarbonisation of the global energy system and is eager to play an active role in shaping the future hydrogen economy. This study supports bp's ambition to become a net zero (carbon emissions) company by 2050 or sooner and to help the world achieve net zero.

1.2 Strong potential for green hydrogen export

A market study of the Australian domestic and export hydrogen and ammonia markets commissioned by bp ('the market study') as part of this wider feasibility study found that by 2050 total demand for hydrogen and hydrogen as ammonia could be as high as 62Mtpa in combined domestic (17Mtpa) and export (45Mtpa) demand.[4] Reaching the full potential hinges on competitive pricing against existing fuel sources. The price gap that currently exists needs to be closed to enable widespread clean hydrogen adoption and project GERI is an investment that could kickstart and accelerate this journey.

Whilst the potential is vast – particularly for export to Japan and Korea - a thriving Australian hydrogen industry is not guaranteed. Hydrogen industry development depends on the level of government support and policy endorsement, development of hydrogen related infrastructure (such as refuelling, roads, rail, ports and storage), and the speed of customers' energy transition from conventional energy sources.

Technology development is expected to reduce costs and will be vital for hydrogen to be competitive with alternatives while the industry scales up. For some applications, suitable alternative low-carbon technologies (e.g., battery-powered passenger cars) exist, however for other applications (marine, long distance trucking etc.) hydrogen is fundamentally advantaged. To meet global decarbonisation objectives, technology developers, industry and government must work together to reduce costs and increase demand while the industry scales up.

This market potential can support multiple projects in Western Australia (i.e., Project GERI's location) subject to appropriate levels of government support for industry development in the near term. Learnings from project GERI could enable bp to efficiently develop future global hydrogen projects. This significantly outweighs the downside risks of the low-side projections of the future hydrogen export potential.

1.2.1 Cost competitiveness is the key factor for domestic demand

The market study identified high and low case fuel energy shares for hydrogen (and ammonia) in 2050 for transport, (displacing diesel), electricity (displacing coal and diesel), and heat (displacing gas). The downside scenario for hydrogen domestically is that hydrogen and ammonia do not gain a large market share. This may happen, for example, if hydrogen fails to achieve the cost reductions necessary to become economically superior to alternative low carbon fuels, if the momentum for decarbonisation dramatically reduces, or government policy settings fail to support growth.

The cost competitiveness of hydrogen/ammonia compared to other low carbon energy alternatives is a key factor to address price-sensitive demand in some applications, which is one of the reasons to be pessimistic about hydrogen passenger vehicle fuel usage.

The absence of a carbon price or emissions cap is a key barrier to attracting investment in renewable technologies such as hydrogen.

[4] Renewable Hydrogen and Ammonia Market Study, by GHD for bp and ARENA, 31 July 2020

1.2.2 International demand drives a large potential future export market

Export demand will be driven by the following factors:

- a range of global energy demand developments,
- carbon policy developments,
- hydrogen cost developments (versus alternatives),
- landed price competitiveness of Australian ammonia export compared to other ammonia producing exporting countries.

Australia's unique landscape, location, trade relationships with neighbouring countries and ambition (as outlined in the National Hydrogen Strategy) are enablers for Australia to become a key player in the global hydrogen economy. Based on discussions to date with potential off-takers, the power, shipping and fertiliser sectors have the highest export potential. There is a strong interest shown by companies in Japan and Korea to explore renewable hydrogen/ammonia import.

1.2.3 Investment in projects such as GERI will accelerate hydrogen industry development

It is expected that hydrogen demand will be price-elastic around the price point of substitutable low carbon energy products. Hydrogen Council analysis,[5] supported by a US Department of Energy scenario,[6] is even more optimistic than the "H_2 Under $2"[7,8] key cost target announced by the Federal Government. Hydrogen Council analysis[9] suggests at US$2/kg around half of all potential applications are at a lower cost through hydrogen fuel versus low carbon alternative fuels in 2030. At 50% higher prices (i.e. US$3/kg), only 10% of the market (~12.5Mtpa) is viable through hydrogen fuel. Conversely, if hydrogen prices were 25% lower (US$1.50/kg), the market volumes increase by 60% (>80% of the market, or ~200Mtpa).

The relative price of alternative low carbon energy solutions will impact the level of profitability in the hydrogen industry and future market size. The Federal government's Technology Roadmap Discussion Paper[10] suggests strong support to enable hydrogen to become cost competitive. A transition from carbon emitting energy into a hydrogen economy will require significant investment in manufacturing technologies, infrastructure development, customer equipment and refuelling stations, together with significant innovation and scale, to achieve cost improvements within the next five years.

This study determined that a clear pathway to commercial scale production exists, but like many emerging markets and technologies, there is a gap between the current customer price points in key markets and manufacturing costs. This gap will need to be bridged in the future through cost reductions to enable a mature market supported by a competitively priced product. The closure of these gaps can be catalysed through investment in projects, such as GERI, that provide equipment and technology vendors confidence to make R&D investment decisions and provide off-takers certainty regarding long-term availability of the product. Securing off-take agreements and engaging equipment vendors therefore sets in motion the first steps on the pathway to scale. The relationship between these market drivers is shown below in Figure 1.

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[5] Hydrogen Council, "Path to hydrogen competitiveness. A cost perspective", Hydrogen Council, January 2020

[6] US Dept of Energy Ruth et al., 2019 Annual Merit Review presentation, "H2@Scale Analysis", April 2019

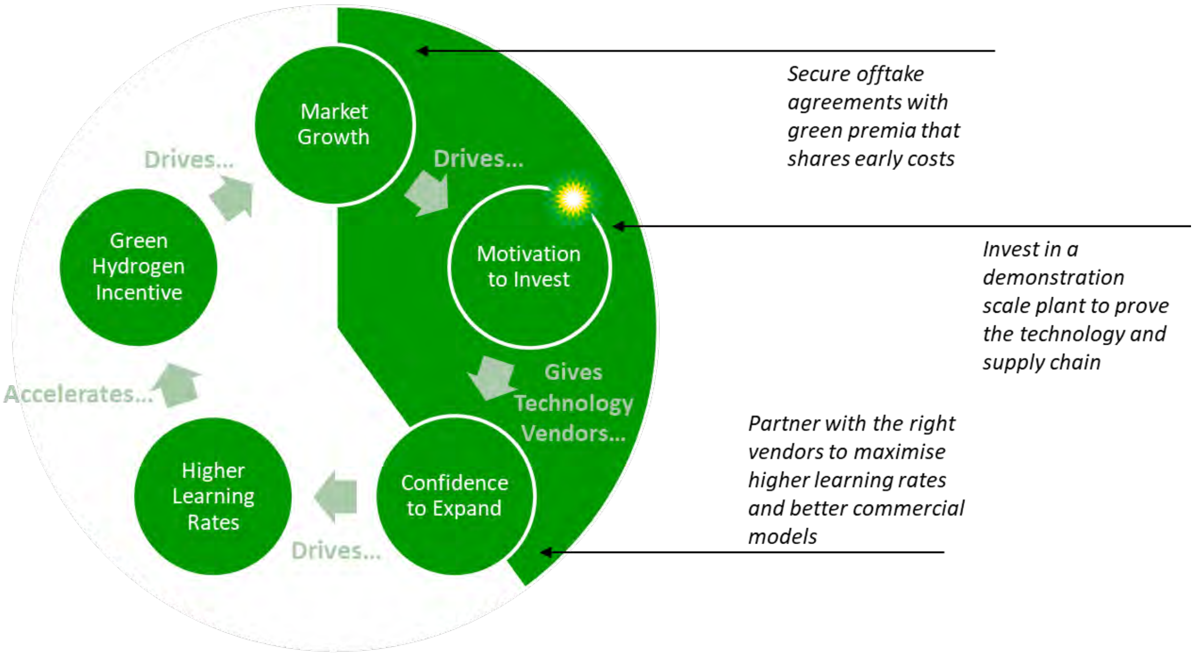
[7] Angus Taylor Keynote address at CEDA 'Future Direction in Energy Technologies' event, Sydney 28 February 2020 <https://www.minister.industry.gov.au/ministers/taylor/speeches/keynote-address-ceda-future-direction-energy-technologies-event-sydney>

[8] Note: This is the price per kg; A$2 (as at 10 July 2020) is equivalent to US$1.39

[9] Hydrogen Council, "Path to hydrogen competitiveness. A cost perspective", Hydrogen Council, January 2020

[10] Australian Government, Department of Industry, Science, Energy & Resources, Technology Investment Roadmap Discussion Paper, May 2020

Figure 1: Unlocking the pathway to commercial scale.



Customer and market engagement activities found that customer off-takes and pricing commitments, including a 'premium for green', are developing from current MOU/intent status. Promotion of fully renewable/green hydrogen by renewable hydrogen players requires a price premium above hydrogen with a higher carbon footprint.

1.3 Analysis demonstrates commercially feasible scenarios but development required to narrow the range of outcomes

A unique aspect of this feasibility study was the development and application of a comprehensive Techno-economic Model (TEM) that facilitated the investigation of a wide range of scenarios and sensitivities. The scenario analysis demonstrated the variation in potential outcomes given the uncertainty around key assumptions at this early industry stage, highlighting the importance of customer off-take agreements and vendor technology selection.

1.3.1 Project economics vary considerably depending on the selected hydrogen pricing scenario

With no current green hydrogen market to benchmark pricing, a wide range of scenarios have been analysed with regards to possible market development. The pricing scenarios considered prices between $1.50 and $17.30/kg of hydrogen.

1.3.2 Chosen pathway to customers has a material impact on supply costs

Demand pathways were chosen from analysis of likely demand hubs and the most cost-effective/ practical logistics option to deliver the product. These pathways can be further customised to meet customer needs – with a resultant impact on LCOH.

A range of hydrogen transportation scenarios were considered at demonstration scale, with varying proportions of truck, pipeline and export deliveries. The costs associated with pipeline injection are much more favourable than trucking, so market demand scenarios with a larger proportion of pipeline-delivered hydrogen have a lower breakeven price. Cost will change based on customer product delivery requirements – scenarios with a high proportion of pipeline-delivered hydrogen would put project GERI in a better competitive position.

For the demonstration scale plant, distribution of hydrogen to export markets would have the highest LCOH as ammonia synthesis costs drive up the cost. ISOtainer hire costs would also impact the cost of exporting ammonia.

Increasing scale improves the project economics through the assumed scaling factors of technology. The costs of exporting reduce significantly for the commercial scale project as bulk shipping removes the costs associated with ISOtainer hire, storage and transport. Significant efficiencies are also gained in overheads and shipping costs.

Table 1: Domestic and export distribution pathways

DEMONSTRATION SCALE		
Product	Destination	Pathway
Hydrogen	Pilbara	Liquid Road Tanker
	Geraldton	Vehicle Refuelling at Gate
	Goldfields	Liquid Road Tanker
	Perth	Liquid Road Tanker
	Perth	Pipeline to Gas Pipeline for blending
Ammonia	Geraldton	Liquid Road Tanker at Gate
	Perth	Liquid Road Tanker
	Japan	Fremantle via Road ISOtainer
COMMERCIAL SCALE		
Hydrogen	Pilbara	Liquid Road Tanker
	Geraldton	Vehicle Refuelling at Gate
	Perth	Pipeline to Gas Pipeline
Ammonia	Japan	Bulk shipping

1.4 The Mid-West Region of WA has a global advantage in potential for green hydrogen production

Geraldton in Western Australia has been selected as the study location. This region:

- Is one of the world's best locations for diurnal renewable energy supply (wind and solar).
- Has abundant access to low-cost rural land.

- Provides access to key domestic markets (e.g., Dampier Bunbury Natural Gas Pipeline).[11] as well as competitive and established routes and access to export customers (e.g., Japan, South Korea, Singapore).
- Has low sovereign risk with strong evidence of ability to support large scale industry sector creation (as experienced in mining and LNG), with strong Federal and State support for decarbonisation and development of critical at scale supply chain infrastructure (e.g., support for development of Oakajee port and power and water infrastructure).
- Provides for lower ESG risk relating to cyclones which are more prominent in northern parts of Australia.
- Provides access to a highly skilled workforce with technical capability near the location of world-leading energy/resources research hubs (Perth), supported by energy and minerals industries fostering innovation across the energy value chain.

1.5 Technical, logistics and process feasibility of Project GERI has been established

The key technical, logistics and enabling infrastructure requirements at each stage of the supply chain (renewable power, water, process and products, domestic logistics and export logistics) for the demonstration and commercial scale projects have been assessed and technical feasibility established.

1.5.1 Renewable power

For demonstration scale, renewable power would be provided under a Power Purchase Agreement (PPA) to meet the load requirement of 35.4MW. Infrastructure investment in the existing transmission network would be required as the current system is unable to support the load requirements.

Load requirements for the commercial scale plant are circa 1370MW. The commercial scale base case scenario assumes wind and solar capacity of 2000MW each, resulting in 77% electrolyser capacity utilisation. This would mean that the plant would be ‘turned down’ reasonably regularly.

The commercial scale plant would have a nameplate capacity of 1,000ktpa of ammonia per annum. Downstream plant has currently been sized at 1,000ktpa so that utilisations up to 100% can be assessed. A firm capacity factor should be defined later in the project so that the downstream equipment can be ‘right-sized’. Optimising renewable power generation against plant utilisation will be key in managing costs.

1.5.2 Process and products

The process technology required to produce hydrogen and ammonia is generally mature and employed in large scale industrial process operations globally. There are known and emerging hydrogen production technology options with the potential for material economy of scale improvements.

A mix of technologies and vendors is recommended at demonstration scale to retain optionality and improve learning for the commercial scale investment decision.

For the Demonstration Base Case scenario, a representative sample of three electrolyser vendors were chosen for modelling an annual production of 4ktpa of hydrogen.

Our analysis also considered the impact on costs of using multiple small electrolyser units in lieu of a single large one but found it to be more expensive.

[11] See Section 5.4.4 for further details

Uncertainty in vendor electrolyser cost estimates is large and this significant variability impacts on LCOH. Further vendor engagement would be needed in the next phase to refine price and inclusions.

1.5.3 Logistics

The Narngulu industrial precinct, 5km south east of the Geraldton Central Business District, is the location modelled for the demonstration scale facility.

The export port locations for the commercial scale facility currently do not have facilities suitable for bulk liquid ammonia export operations and would require significant upgrades to accommodate export. The cost of these upgrades have been excluded from project economics.

The Oakajee location is more straightforward from a technical perspective. The relative proximity of the port to the process plant (circa 3km) allows transport of ammonia to the port via a low temperature pipeline. The port development options considered would allow the port to be ultimately expanded/developed as per the Oakajee Port Master Plan to enable multi-user, multi-product operations as more industrial activity opens up in Oakajee. The length of the pipeline (circa 15km) and buffer requirements of the pipeline corridor make Geraldton a less preferable option than Oakajee, however this location is still technically feasible.

1.6 Regulatory requirements are complied with and risks are understood

Facility regulatory requirements are covered under existing health, safety and environmental legislation and are discussed within this feasibility report. Preliminary evaluation of risk profiles for the two sites under consideration for commercial scale (Oakajee and Narngulu) indicate that the Narngulu site is suitable based on the preliminary risk assessment, however the Oakajee location would offer several advantages and a lower overall risk profile.

Risk profiles for the demonstration scale production and export infrastructure have been assessed through a preliminary QRA with the conclusion that risks could be managed and mitigated appropriately to comply with regulatory requirements. Risk contours are conservative and are consistent with those developed for larger facilities for the storage and handling of ammonia. The current land use and land use planning zones in the vicinity of the selected site are consistent with the development. Application of targeted risk mitigation measures in subsequent project design phases would reduce the risk contours.

The proposed road transport of containers for ammonia is considered suitable and is consistent with processes approved and undertaken in other parts of Australia, with risks managed to acceptable levels. Final confirmation of transport routes to the selected port or other off-take destinations should be determined in consultation with the regulator and local authorities and supported by specific risk assessments.

The concept study proposed the use of the Port of Geraldton for the export of ammonia in bulk containers, however it was found that PoG didn't have suitable infrastructure so the Fremantle Port (FP) is now proposed as the base case for the demonstration scale. FP is currently capable of exporting and receiving Dangerous Goods containers.

Product quality regulations will be largely governed by end-user requirements. Product regulation for hydrogen and ammonia is primarily concerned with product purity and the levels of contamination present in the final products. Electrolysis as a method of production results in a very low contaminant hydrogen stream, typically greater than 99.99% pure. Ammonia produced from the hydrogen and nitrogen extracted from air separation will therefore be low in contaminants and suitable for downstream processing or, where required, converted back to a hydrogen feed.

1.7 Meeting environmental standards and community expectations

Consistent with large industrial projects of a similar nature in Western Australia, environmental and planning approvals would be required, supported by a series of technical studies.

The project would generate local and regional employment opportunities and assist with expansion of the new energy sector. Greater Geraldton and the Mid-West Region would be positioned as a centre for new energy technology and a hub for new energy production and export. Discussions with key stakeholders have indicated an appetite for a hydrogen facility such as that proposed by Project GERI.

Community confidence in the safety of hydrogen production processes is a critical success factor for the industry's development. Although community understanding of hydrogen is relatively low there is an expectation that industry will operate in a safe and responsible manner.

The Social Impact Evaluation (SIE) identifies that there would be a range of employment and business opportunities during construction and operation. However, the project may have the potential to impact:

- Property and land use
- Local amenity during construction and operation
- Traffic and transport
- Community values, perceptions about safety

It is essential that projects like GERI demonstrates responsible leadership in stakeholder and community engagement, to build a positive foundation for the project and the broader industry.

While social impact assessment and stakeholder engagement may be unique for a hydrogen project given the emergent stage of the industry, the actual engagement strategy and process would be typical for a greenfield project of this scale.

1.8 There is a pathway forward, provided some key challenges can be navigated

At demonstration scale, the key challenges relate to securing anchor customers at an acceptable price point. All other project execution requirements are consistent for a project of this nature and could be managed through appropriate project planning and execution.

A key focus area for the commercial scale project is to engage with relevant stakeholders including the Federal Government and Western Australia State Government, Development WA, Mid-West Ports Authority and other relevant local bodies to understand support and funding that could be made available for enabling infrastructure requirements at either location.

Ensuring government support (both Federal and State) will be key for the project to move forward. The key areas where government support and funding are vital are:

- Ensuring reliability of power supply for the demonstration scale plant: the current power network would require upgrades to take on the additional load from the demonstration scale facility.
- Transmission upgrades for the commercial scale plant: load requirements for the commercial scale would necessitate transmission upgrades including new power lines and a substation.
- Port development for the commercial scale plant: either port (Geraldton or Oakajee) would require substantial investment to allow for large scale export of bulk hazardous liquids. Options presented in this report provide relatively low-cost solutions. The development options at Oakajee would also allow the port to be ultimately expanded/developed as per the Oakajee

Port Master Plan to allow multi-user, multi-product operations as more industrial activity opens up nearby.

- Supportive tax structures: tax structures that support the development of the hydrogen industry and ensure continued investment until the industry matures will be key to unlocking Australia's hydrogen potential.
- Prioritised approval pathways: accelerating timelines for approvals would increase confidence to invest as early movers can ensure speed to market.
- Government decarbonisation incentives: incentives to decarbonise such as a carbon price and/or clean fuel subsidies and requirements for hydrogen blending into gas networks will play a pivotal role in early widespread adoption of clean fuels such as hydrogen.
- Continued investment in hydrogen R&D: investment in R&D on emerging hydrogen technologies would assist in speeding up the progression down the cost curve.
- Negotiating favourable options for securing land.

2. Overview of Project

2.1 Purpose and scope of this feasibility study

The purpose of this Renewable Hydrogen and Ammonia Feasibility Study ('the feasibility study' or 'this feasibility study' or 'this study') is to provide preliminary information to bp regarding the potential for a renewable hydrogen and renewable ammonia facility in the Mid-West Region of Western Australia.

The scope of this report is to present the key findings of the feasibility study and an assessment of the techno-economic viability of a demonstration (circa 20ktpa of ammonia) and commercial scale (circa 1,000ktpa of ammonia) project.

2.2 Overview of Project GERI

Renewable hydrogen and renewable ammonia have the potential to be the fuel for a wide variety of purposes in Australia and internationally in a decarbonising economy. Australia has significant potential to develop a domestic and export market for renewable hydrogen, as outlined in the National Hydrogen Strategy[12].

bp Australia, Lightsource bp and GHD, with ARENA funding support,[13] have undertaken this feasibility study to explore the potential of a renewable hydrogen / ammonia exporting facility in Western Australia. This study examines commercial, operational, technical, environmental and other areas of research for demonstration and commercial scale production facilities. This study also provides findings on a pathway to a fully integrated renewable supply chain with significant global scale.

In line with bp Group's commitment to Net Zero by 2050 or sooner, bp is committed to absolute reduction of emissions in its own operations, in upstream oil and gas production and 50% reduction of carbon intensity of the products bp sells. In mid-term (by 2030) bp aims to substantially increase low carbon investment ($5 billion a year), develop 50 GW of renewable electricity and capture 10% market share in core hydrogen markets. bp views the development of a hydrogen fuels value chain as a key milestone in decarbonisation of the global energy system and is eager to play an active role in shaping the future hydrogen economy. bp aims to make a material impact on global emissions and build partnerships with countries, cities and industries in decarbonisation efforts.

2.3 Project GERI Principles

The feasibility study has been developed under the following key principles:

- Outline a pathway to produce zero carbon hydrogen / ammonia
- Leverage existing infrastructure wherever possible at the demonstration scale
- Utilise existing technology and minimise process complexity
- Minimise impact on existing port operations

[12] Australia's National Hydrogen Strategy, COAG Energy Council, November 2019 and Australian and Global Hydrogen, Demand Growth Scenario Analysis, COAG Energy Council – National Hydrogen Strategy Taskforce, November 2019 and Erratum May 2020

[13] ARENA, 8 May 2020, BP Australia study looks to scale up renewable hydrogen for export, Accessed 7 June 2020 from: https://arena.gov.au/news/bp-australia-study-looks-to-scale-up-renewable-hydrogen-for-export/

- Harness community and Government support early and demonstrate a viable, safe and economic pathway to scale

Demonstration scale (circa 20ktpa ammonia):

- Develop a pathway forward for the demonstration facility which forms the basis of Front-End Engineering Design (‘FEED’), this subsequent stage leading to a funding-ready estimate for the facility. Customer engagement and market demand assessment are important elements to secure viable commercial operations and to make an investment decision.

Commercial scale (circa 1,000ktpa ammonia):

- Develop a pathway to a fully integrated renewable supply chain with significant global scale.

The fundamental building block of this study is the usage of ammonia as a carrier of hydrogen for bulk export, however the techno-economic model also includes an analysis of direct domestic hydrogen supply options.

2.3.1 Project GERI Location

Consideration was given to a number of potential locations in Australia based on a range of key characteristics. Development of a demonstration scale plant with the potential to grow to commercial scale was a necessary criterion for location selection.

Geraldton (Western Australia) has been selected as the study location as it satisfied the following requirements:

- Suitability for intensive, carbon-free energy production: Western Australia's mid-west has world-class resources of wind and solar energy with high diurnal complementarity (i.e. solar by day & wind by night).
- Existing infrastructure at Geraldton, together with trucking options to WA ports, that enables ammonia export opportunities.
- Supportive, resource-focused Government.
- Existing HV electricity connection to the SWIS (South West Interconnected System).
- Proximity to large, long-term domestic markets (e.g. Pilbara region and the Dampier Bunbury Natural Gas Pipeline).
- A skilled workforce with technical capability near the location of world-leading energy/resources research hubs (Perth), supported by energy and minerals industries fostering innovation across the energy value chain.

The Narngulu industrial precinct, 5km south east of the Geraldton Central Business District, is the study location for the demonstration scale facility. The potential site is zoned ‘general industrial’ under the city of Greater Geraldton local planning scheme. Note that this study did not evaluate the location choice from the commercial/economic perspective of highest returns on investment - additional commercial analysis and business options appraisal is recommended for the final investment decision.

Narngulu was selected on the basis of its established industrial infrastructure and zoning, road networks and the proximity to the Port of Geraldton. Utilities are available to the boundary of the site however these may require upgrades to meet the site demand. The site is broadly level with no significant vegetation or other overlays. Some onsite solar can be included in the buffer zone however additional land would be required for the solar generation.

Two location options were considered for the commercial scale feasibility assessment (Narngulu and Oakajee) and these are outlined in detail in Section 5.2.

2.3.2 Project GERI proponent and other involved parties

The project is led by bp Australia as the principal, being advised by GHD Advisory.

About bp Australia:

bp is a global energy company with over a century of experience operating in Australia. It is the only oil and gas company which engages across the energy value chain in Australia (exploration, development, production, trading, distribution and retail of fuels), which uniquely places it to participate and assess the opportunities for renewable hydrogen in Australia.

- bp is a committed, long-term investor in Western Australia
  - bp has demonstrated long-term commitment to Western Australia. bp is one of the largest international investors in Western Australia, with billions of dollars of capital invested and thousands of employees over half a century in the North-West Shelf LNG, Kwinana Refinery (future import terminal) and Fuels Marketing businesses.
- bp is addressing the climate change concerns of shareholders, partners, staff and customers
  - bp is committed to addressing climate change challenges. bp Group and its shareholders have committed to the Paris climate goals. On 21 May 2019, Resolution 22 (proposed by members of investor group Climate Action 100+ and backed by the bp board) was passed at the 2019 AGM with a resounding 99.1% of the vote. This is a historic mandate, and in Australia, bp employees and business partners are already working hard to find ways to reduce our carbon footprint.
- bp has set out its ambition to become a net zero company by 2050 or sooner and help the world get to net zero.
  - bp is looking into low carbon / renewable energy business opportunities and to progressively reduce the carbon footprint of existing bp operations.
  - In WA, bp is exploring opportunities to reduce to Net Zero the carbon content of upstream oil & gas production, including CCS technologies.
  - bp is also aiming to cut the carbon intensity of products sold by 50% by 2050 or sooner, through exploring low carbon fuel technologies, e.g. biofuels, plastic recycling into energy, natural gas, electrification and hydrogen.
  - bp set a strategic target to increase its investment in low carbon / renewable energy to US$5 billion a year. bp is already expanding its renewables footprint across Australia, through its joint venture partner Lightsource bp. Lightsource bp has so far secured 2000MW of renewable power developments in NSW, Victoria, SA and Queensland and is looking into WA for more opportunities (see Australian Financial Review, 22 May 2019).
- bp is actively exploring hydrogen-based business opportunities
  - bp sees hydrogen playing an important role as an energy vector and industrial feedstock on the road to decarbonisation. bp set a strategic target to capture a 10% share in core hydrogen markets by 2030. bp recognises that hydrogen has broad applications including heating for industrial applications and buildings, and fuel for heavy transport. bp also sees interesting potential for hydrogen to distribute low-carbon energy across sectors and regions.
  - bp has existing capabilities in hydrogen with a dedicated global hydrogen technology team and international operational experience in utilising renewable hydrogen in the oil refining process. In 2018, bp's Lingen refinery in Germany conducted a four-week demonstration

project and was the first refinery globally to produce fuel with renewable hydrogen. bp's Rotterdam refinery is undertaking a similar project.

- bp is a member of the Global Hydrogen Council and is actively evaluating business opportunities around the world. WA was selected as a preferred investment destination (including - but not limited to - export-led ammonia, stationary power / storage and transportation fuels).

About GHD

GHD is one of the world's leading professional services companies operating in the global markets of water, energy and resources, environment, property and buildings, and transportation.

- GHD provides engineering, architecture, environmental, advisory, digital and construction services to private and public sector clients. Established in 1928 and privately owned by our people, GHD operates across five continents - Asia, Australia, Europe, North and South America - and the Pacific region. We employ more than 10,000 people in 200+ offices to deliver projects with high standards of safety, quality and ethics across the entire asset value chain. Driven by a client-service led culture, we connect the knowledge, skill and experience of our people with innovative practices, technical capabilities and robust systems to create lasting community benefits.
- Committed to sustainable development, GHD improves the physical, natural and social environments of the many communities in which we operate. We are guided by our workplace health, safety, quality and environmental management systems, which are certified by Lloyds Register Quality Assurance to the relevant international standards (ISO and OHSAS).
- In alignment with the global demands of water, energy and urbanisation, GHD's aim is to exceed the expectations of our clients and contribute to their success.

2.3.3 The feasibility study approach

The feasibility study approach involves four key phases with the methodology for each outlined in Table 2:

1. Desktop phase (March 2020 – May 2020)
2. Validation and Stakeholder Engagement (May 2020 – July 2020)
3. Scenario Modelling and Analysis (August 2020 – November 2020)
4. Findings and Recommendations (November 2020 – December 2020)

Table 2: Project methodology

Approximate timing	Key Activities	Notable tasks
	DESKTOP PHASE	
February 2020 / March 2020	• Mobilising, Planning and Desktop Research	• Planning includes customer engagement e.g. questionnaire design, contact identifications
April 2020	• Drafting Desktop market assessment • Techno-economic model (TEM) development	• Draft view on guarantee of origin and domestic and export demand scenarios • Develop production plant, pipelines, transport logistics
May 2020	• Engaging potential customers • Refining market study	• Engaging potential export and domestic customers, assessing interest, product/volume preferences and potential issues

Approximate timing	Key Activities	Notable tasks
VALIDATION AND STAKEHOLDER ENGAGEMENT		
June 2020	• Obtain MOUs for off-take for demonstration plant • Finalising market study • TEM validation commences	• Formalising written MOUs (for domestic plant only) including pricing and volumes • Site option narrowing • Customer engagement feedback enables ongoing maintenance of datasheets to support TEM
July 2020	• TEM validation, production process, logistics and associated costing continues as per customer feedback • Vendor engagement commenced - RFIs and RFPs sent	• Multidiscipline concept design and deliverables • Key vendor preliminary engagement
SCENARIO MODELLING AND ANALYSIS		

August - October 2020	• TEM maturation and operation - Business Case exploration:
	  ○ Verification of TEM scenarios and assumptions
	  ○ Building sensitivities and output dashboard
	  ○ Updating financials (as per operational and technical areas of the TEM) to inform the business case
	• Production process, logistics and associated costing is updated and validated based on vendor feedback
	• Technology availability analysis
		• Scenario modelling and optimisation - TEM explores demonstration and commercial scale viability
		• Clarification with vendors regarding RFIs and RFPs received
		• Vendor budget pricing
		• Capex and Opex estimates

FINDINGS AND RECOMMENDATIONS		
November – December 2020	• Findings and recommendations compiled and validated	

The Techno-economic model (TEM) is a dynamic simulation of the supply chain, with detailed technical information relating to operational parameters of each part. The TEM is developed by understanding and mapping out the overall process and key assumptions. As the program develops and customer feedback is obtained this information is used to update and validate the TEM. In parallel, technical work streams that developed the production process and logistics continually feed information into the TEM, which is further enhanced by ongoing customer and vendor feedback. In addition, the TEM links with bp financial metrics to provide a robust and fully developed package.

This culminates in the development of a dashboard for decision making. This enables key information to be extracted from the TEM as each scenario is run, allowing for continual refinement and feedback in the final phase of the project, where outputs from the TEM enable the technical and commercial work streams to further refine the process, logistics and commercial pathways.

2.3.3.1 Techno-economic model (TEM) development approach

The main purpose of the TEM is to track the physical flow of hydrogen through the supply chain from production to delivery and provide visibility of the associated operating and capital costs of each part of the process. The plant and supply chain options can be simulated for physical process outcomes (e.g. reliability, production, product delivery) as well as financial outcomes, including implied profit/loss when combined with revenue inputs from the market study.

The upstream boundary of the model is the water and power supply. The power generation is modelled by Lightsource bp, given demonstration and commercial plants' requirements. The downstream boundary of the model is the delivery of hydrogen to domestic customers, either at the production facility or at the customer, and to international customers upon the loading of ammonia onto vessels at the port. Multiple distribution channels are examined with associated costs, including ISOtainers or bulk shipping options. Demand volumes for each product has been given as a model input, as informed by the results of the market study and direct customer engagement. Of note, demand volumes are flexible inputs to allow for market development.

Objectives - Demonstration Scale

- Evaluation of 3 different hydrogen production technologies (Alkaline, PEM, and a prototype electrolyser technology) by considering potential Capex costs and efficiency gains for H_2 production at scale.
- Evaluation of Haber-Bosch hydrogen into ammonia conversion technology by estimating costs, efficiency, and potential energy losses.
- Evaluation of hydrogen liquefaction technology by estimating costs, efficiency, and potential energy losses.
- Evaluation of financial break-even points for the demonstration project under a range of revenue scenarios based on different NH_3/H_2 price points and production mix, end-user market segments and major cost/Capex drivers.
- At demonstration scale, the viability of supplying H_2/NH_3 to domestic market segments is of relatively greater importance than in a world-scale export model; the techno-economic modelling has estimated revenues from local use cases and the potential size of domestic economic benefits.

Objectives - Commercial Scale

- Evaluation of the dimensions of a commercial-scale plant (circa 1,000ktpa ammonia) including the identification of any additional risks, plus associated mitigating strategies or solutions.
- Completion of a deeper evaluation of the renewable energy requirements at commercial scale:
    - A more sophisticated techno-economic model that evaluates the optimal mix and sizing of electrolysers, ammonia synthesizers, and required renewable energy generation capacities to deliver the most economic rate of production at scale.
    - The power modelling is undertaken outside of the current feasibility report and provides the following inputs into the TEM: the resulting cost of energy, load/capacity and renewable generation profile (wind and solar).
    - Central to the commercial scale design is the required power demand, cost and capacity (for both on and off grid), which is linked to power modelling work done by Lightsource bp.
    - The primary benefit of this model is that it provides project developers with the ability to determine the optimal operating point of equipment capacity, efficient rates of equipment utilisation, optimal penetration rates of renewable energy from both off- and on-grid sources, and the associated cost of energy and required capital.

2.3.3.2 Production Process, Logistics Methodology and Cost Data Preparation

The Production Process, Logistics Methodology and Cost Data is prepared in parallel with the TEM development. Initially the production process is developed using the assumptions outlined in the TEM approach (as outlined above) and datasheets are then developed to outline all TEM inputs. As inputs are being developed and process design finalised, vendors are engaged to outline preliminary costings for the production process.

Similarly, the logistics methodology develops an approach that ties in with the TEM logic and underlying assumptions. A schematic of the logistics chain is initially developed with datasheets compiled for each logistic node. These datasheets are updated based on stakeholder information that is compiled through ongoing stakeholder engagement activities. An iterative process between the TEM, production process and logistics development is central to the overall approach for the feasibility study, so that an optimal, validated TEM is achieved.

3. Market/Commercial Overview for renewable hydrogen and renewable ammonia market prospects

As a component of this feasibility study, bp commissioned a market study for renewable hydrogen and renewable ammonia.

This market study provided an assessment of domestic and export renewable hydrogen and ammonia demand, and further commercial assessments of aspects of this project, including:

- Market forecast and analysis: domestic and exports, volumes and values
- Identification of potential customer demand
- Certification developments

The key findings of this market study (with updates made regarding customer engagement and the global hydrogen landscape) are outlined in this section to provide an overview of the renewable hydrogen and renewable ammonia market.

3.1 Potential market size

There is a great opportunity for an Australian hydrogen industry; by 2050 total demand could be as high as 62Mtpa combined domestic (16.7Mtpa) and export (45Mtpa).

As noted in Australia's National Hydrogen Strategy[14], while the potential is vast – particularly for export to Japan and Korea - a thriving Australian hydrogen industry is not a given and will depend on negotiating a pathway to industry development. The level of government support and policy endorsement, development of hydrogen related infrastructure (refuelling, roads, rail, ports and storage) and the speed of customers' energy transition from conventional energy sources are enablers for the future hydrogen industry. Technology development and execution standardisation must reduce costs to the necessary levels while the industry scales up. It is acknowledged that for some applications, late hydrogen industry progression poses a risk of alternative low-carbon technologies gaining market share or alternative export geographies gaining ascendancy. However, for other applications, hydrogen appears fundamentally advantaged and a market share can be gained without the need for expediency. The market study found that, should favourable economic conditions, accelerated hydrogen industry development and government support be realised in medium- and long-term, high case demand prospects are unlocked. This aligns with positive industry sentiment, most notably from large companies who are investing or showing significant interest in hydrogen projects.

3.2 Domestic demand potential

Growing focus and momentum in Australia

[14] Australia's National Hydrogen Strategy, COAG Energy Council, November 2019 and Australian and Global Hydrogen, Demand Growth Scenario Analysis, COAG Energy Council – National Hydrogen Strategy Taskforce, November 2019 and Erratum May 2020

There is widespread agreement across the political, scientific and resource sectors that hydrogen can be a significant part of our future energy supply mix.

Over the past two years there have been a number of actions, announcements and reports released to inform and support the development of a national clean hydrogen industry (refer Table 3).

Table 3: Actions, announcements and reports released to inform and support the development of a national clean hydrogen industry.

Date	Policy/project
2019 (November)	Report by Clayton Utz for the Department of Industry, Innovation and Science: scoping legislation, regulations and standards relevant to the development of an Australian hydrogen industry. The report identifies relevant Commonwealth, state and territory legislation and regulations that may be essential to the production, transport, storage, export and domestic use of hydrogen. It recommends high-level priorities for review and potential reform.[15]
2019 (November)	Release of Australia's National Hydrogen Strategy sets a path for the development of Australia's hydrogen industry. The Strategy identifies the need to set clear regulatory frameworks, ensure the industry's development has a positive influence on energy prices and energy security, and that development occurs without any compromise to safety, cost of living, water availability, access to land or environmental sustainability. In particular, it highlights that 'Governments and industry have the responsibility to ensure community safety, confidence and trust in the new industry, and deliver benefits to all Australians.".[16]
2019 (July)	Western Australian Renewable Hydrogen Strategy – developed in consultation with industry, the strategy's mission is: [to] develop industry and markets to be a major exporter of renewable hydrogen. Western Australia will develop domestic production capabilities and applications of renewable hydrogen…improving the State's hydrogen industry expertise, contributing to global decarbonisation, and decarbonising the State's economy".
2019 (March)	Federal Government announces public consultation process for public input to inform the development of a new clean hydrogen strategy. Commits to publicly release the strategy in September 2019.
2019 (January)	Opposition Leader commits to $1b funding to support development of National Hydrogen Plan.
2018 (December)	COAG Energy Council's Meeting Communique confirms: • Ministers' agreement to develop a national hydrogen strategy for consideration by the end of 2019. • Support for the development of a clean, innovative and competitive hydrogen industry that benefits all Australians and is a major global player by 2030. • Establishment of a dedicated Working Group chaired by the Chief Scientist, to lead activities that achieve this vision. • Working Group has six work streams: hydrogen exports; hydrogen for transport; hydrogen in the gas network; hydrogen for industrial users; hydrogen to support electricity systems; and cross-cutting issues.
2018 (November)	Minister for Resources releases a statement on the future of Australia's hydrogen industry, backing the production, use and export of hydrogen.
2018 (August)	ARENA – report on; Opportunities for Australia from Hydrogen Exports. Exporting renewables including hydrogen is one of ARENA's four investment priorities.
2018 (August)	CSIRO National Hydrogen Roadmap: seeks to build on the work already undertaken nationally and internationally to quantify the economic opportunities associated with hydrogen and analyse how those opportunities might be realised.

[15] Hydrogen Industry Legislation, Prepared by Clayton Utz for the Department of Industry, Innovation and Science, 21 November 2019, Accessed 23 July 2020 from: http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-hydrogen-industry-legislation-report-2019_0.pdf

[16] Australia's National Hydrogen Strategy, COAG Energy Council, November 2019

Date	Policy/project
	The Roadmap aims to provide a blueprint for the development of an Australian hydrogen industry, including mapping the future investment among stakeholders including industry, government, and research, so the industry can progress in a coordinated manner. Recommendations on regulation/s across the supply and application spectra.
2018 (August)	Chief Scientist Dr Alan Finkel Briefing Paper: Hydrogen for Australia's Future: produced in conjunction with the Hydrogen Strategy group, highlights Australia's potential, its competitive advantage, and the range of opportunities across the states and territories. The Hydrogen Strategy Group's membership includes experts and leaders from the aligned spaces of science, technology, industry and government.

3.2.1 Direct Customer Engagement

The market signals are promising. The mining and heavy transport sectors are showing signs of proactivity with strategic initiatives in place to utilise hydrogen energy as a fuel source, driven by internal decarbonisation targets.

The customer engagement activities for Project GERI found that the domestic market in Australia is currently in early stages, with few players being ready to receive hydrogen. Most of the Australian market requires further development, further investment in energy transition, or greater government support to become hydrogen or ammonia off-takers.

3.2.2 Modelling

The market study identified high and low case fuel energy shares for hydrogen (and ammonia) in 2050 for transport, (displacing diesel), electricity (displacing coal and diesel), and heat (displacing gas). The downside scenario for hydrogen domestically is that hydrogen and ammonia do not gain a large market share. This may happen, for example, if hydrogen fails to achieve the cost reductions necessary to become economically superior to alternative low carbon fuels, if the momentum for decarbonisation dramatically reduces, or government policy settings fail to support growth

The cost competitiveness of hydrogen/ammonia compared to other low carbon energy commodities is a key factor to address price-sensitive demand in some applications, which is one of the reasons to be pessimistic about hydrogen passenger vehicle fuel usage.

Total current Australian energy consumption is 6,300PJ of which most (4,700PJ) relates to domestic applications that hydrogen can contest. Federal Government support and funding[17] for hydrogen appears strong, as indicated by ARENA's July 2020 hydrogen funding round for $70 million.

3.3 Export demand potential

In a high scenario, export hydrogen demand could reach 45Mtpa by 2050.

Export demand will be driven by a range of global energy demand developments, carbon policy developments, hydrogen cost developments (versus alternatives), Australian hydrogen costs (relative to other hydrogen-exporting nations) and landed price competitiveness of Australian ammonia compared to domestic production and/or other ammonia producing exporting countries.

[17] For example, as recently announced in the (green) technology roadmap discussion paper: https://consult.industry.gov.au/climate-change/technology-investment-roadmap/

3.4 Cost developments and price elasticity of hydrogen demand (including as ammonia)

Customer engagement for Project GERI to date found the prevailing belief is that customers are looking for pricing comparable to their current energy supply.

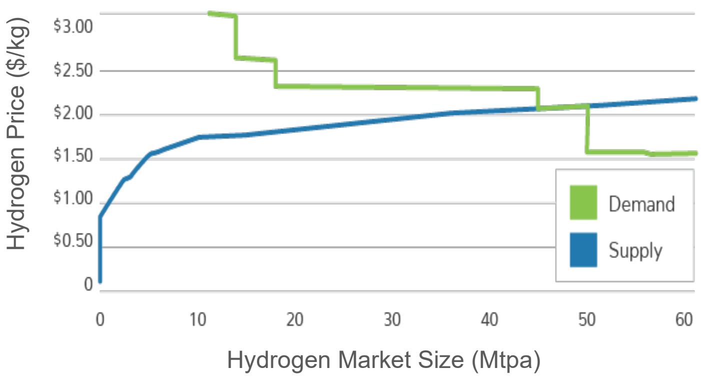
It is expected that hydrogen demand will be price-elastic around the price point of substitutable energy products.

Hydrogen Council analysis[18] suggests at US$2/kg around half of all potential applications are at a lower cost through hydrogen fuel on a hydrogen fuel versus low carbon alternative fuels basis in 2030. At 50% higher prices, (i.e. US$3/kg) however, only 10% of the market (~12.5Mtpa) is viable through hydrogen fuel. However, if hydrogen prices were 25% lower, (US$1.50/kg) the market volumes increase by 60% (>80% of the market, or ~200Mtpa).

A US Department of Energy hydrogen fuel cells program[19] identified all technically feasible US market uses for hydrogen as 166Mtpa, with a preliminary scenario analysis suggesting a large portion (50Mtpa) is winnable at prices above US$1.50/kg, again suggesting significant demand even above "H_2 Under $2".

The relative price of alternative low carbon energy solutions will impact the level of profitability in the hydrogen industry and future market size. Domestic and export volumes are dependent on the relative cost competitiveness of hydrogen solutions. All cost elements of the hydrogen supply value chain, including normal industry margin, will build up an off-take cost. These cost elements include renewable electricity and water supply costs, electrolysis production costs, hydrogen storage and distribution (pipeline, truck, rail, ship) costs, government subsidies, fees and taxes, labour and other cost components. A key driver will be the implementation of a well-designed carbon pricing policy, which is anticipated by investment funds in asset pricing but is not yet a reality. A carbon price or emissions cap would enhance the investment case for emerging renewable and lower carbon technologies such as hydrogen.

Figure 2: US Department of Energy hydrogen demand curve scenarios ('Low-cost electrolysis' scenario)



"The first specific goal will be "H_2 under 2". That is hydrogen at or under (AUD) $2 per kg. That's the point where it competes with alternatives in large-scale deployment across our energy system….. At (AUD)$5 it is likely to be well and truly competitive for long-haul transport – assuming continued cost reductions for fuel-cell vehicles, particularly heavy vehicles – but not yet at $5 for broader energy substitution."

-Federal Energy Minister Angus Taylor, 28 Feb 2020

These estimates do not predict fuel market shares or even fuel preferences. Preferences will take time to accumulate into market share as asset lifecycles drive equipment replacement. Preferences are

[18] Hydrogen Council, "Path to hydrogen competitiveness. A cost perspective", Hydrogen Council, January 2020

[19] US Dept of Energy Ruth et al., 2019 Annual Merit Review presentation, "H2@Scale Analysis", April 2019

driven by the relative total cost of fuel solutions, including fuel cells/distribution, compared to high and low carbon alternatives.

Cost reduction is a key market driver for the hydrogen industry to unlock a scale-up potential. Applications such as fuel cells have, to date, not dramatically reduced costs and distribution such as refuelling is not yet widespread. This presents the main challenge of reducing cost and scaling up without initial large-scale demand - a "chicken and egg" problem.

Shaping and harnessing government policy support to catalyse the industry is important. The Federal government's Technology Roadmap Discussion Paper[20] suggests strong support to enable hydrogen to become cost competitive. As hydrogen investors increase support for hydrogen-economy research and development (R&D), (e.g. ammonia shipping/rail engines), the likelihood of technology breakthroughs increases.

3.5 Key players in the hydrogen / ammonia market

Australia's renewable hydrogen industry is rapidly developing, with interest from several large energy market players. Hydrogen – produced from either coal or gas with carbon capture, or from renewable energy – was among the top five priorities in the Federal Government's technology roadmap for emissions reduction. ARENA has shortlisted seven projects in its latest $70 million round, which is expected to play a significant role in supporting the pathway to commercial scale renewable hydrogen facilities in Australia and achieving the Federal Government's 'H_2 under $2' goal.

3.5.1 Domestic hydrogen supply market

There are early signs of activity in the domestic market, especially around distributed gas blending and land transport. A number of projects that focus on local hydrogen demand are currently in development.

3.5.2 Export-scale hydrogen supply market

The development of an Australian hydrogen sector is progressing rapidly, with a number of significant market players announcing their entry through feasibility / demonstration scale projects. The race to supply hydrogen to the South East Asian market is becoming increasingly competitive. Most of these projects have a focus on renewable hydrogen and are still early in their development phase.

3.5.3 Global H_2 / NH_3 landscape

Europe and Australia are taking the lead on renewable hydrogen developments around the globe, with total global capacity in the form of proposed renewable hydrogen projects exceeding 60 gigawatts.[21] Around 30 gigawatts of capacity is expected to become operational by 2035.

The EU hydrogen strategy, released in 2020, looks at large scale deployment of clean hydrogen across Europe with Spain, Germany and France committing 4, 5 and 6.5GW of renewable hydrogen capacity respectively by 2030. The EU's current pipeline of announced electrolyser concepts stands at 27GW of capacity. Major offshore wind powered hydrogen projects include the 10GW NorthH2 project, proposed by a Shell-led conglomerate in the Netherlands, and the 700MW Westküste 100 project in Germany, being developed by Ørsted and EDF.

China's current hydrogen production comes from fossil fuels. However, recent announcements, such as the 'Net Zero by 2060' plan, suggest a shift in focus in Chinese energy policy. State-backed

[20] Australian Government, Department of Industry, Science, Energy & Resources, Technology Investment Roadmap Discussion Paper, May 2020

[21] Rystad Energy, 8 October 2020, 'Green hydrogen plans already top 60 GW, but less than half is likely to operate by 2035 as costs bite', accessed 12 November 2020 from: https://www.rystadenergy.com/newsevents/news/press-releases/green-hydrogen-plans-already-top-60-gw-but-less-than-half-is-likely-to-operate-by-2035-as-costs-bite/

corporations such as SPIC, Beijing Jingneng and CNOOC all have projects aimed at renewable hydrogen production. The first of these expected to become operational is the 5GW Beijing Jingneng facility in Inner Mongolia.

Saudi Arabia is also looking to develop a gigawatt-scale renewable hydrogen project valued at $5 billion.

The US currently does not have a national hydrogen strategy but could see a shift in its energy policy following the 2020 election.

In October 2020, Japan announced a 2050 net zero emissions goal, up from an existing target of reducing emissions by 80% by 2050 and bringing it level with the UK and EU.[22]

Germany plans to tender for 40GW of solar and wind capacity between 2021 and 2025 as it strives to hit a 2030 target of 65% renewable energy in its power mix.[23]

3.6 Certification and premium for green

Guarantee of Green Origin and Certification is a developing area which could support a price premium for renewable hydrogen above other forms.

International standard definitions for renewable hydrogen or ammonia do not currently exist, nor do international standards for guaranteeing renewable origin. However, bilateral origin-guarantee agreements are becoming more common, including the use of independent assurance (e.g. third-party audit of contracts by hydrogen source).

A number of national frameworks are evolving for Green Energy Certificates for parts of an industrial process. No singular renewable hydrogen/ammonia standard has emerged, but various methods are surfacing. For example, Europe's CertifHy scheme is a lifecycle emissions scheme that applies to hydrogen production only, offering two certificates; 'green hydrogen' (which must be produced from renewable energy) and 'low emissions' hydrogen (which must be <4.4kg CO_2e /kgH_2).

Project GERI assumes renewable hydrogen (including as ammonia) production; therefore, it is expected to obtain externally audited estimates of lifecycle carbon plus green certificates (if certificates are introduced for renewable technologies). Although Project GERI could use net zero shipping and reconversion of ammonia solutions (thus factoring into the export product's lifecycle carbon footprint) the transport through the supply chain may not be fully renewable, depending on the customer.

Promotion of fully *renewable/green hydrogen* by renewable hydrogen players may permit a price premium above hydrogen with a higher carbon footprint, and potentially also above carbon-captured or offset hydrogen with comparable carbon footprint. This is based on discussions with potential off-takers, but the extent to which a premium may be paid is yet to be determined.

3.7 Local and national benefits of Project GERI

The local and national benefits of hydrogen industry investment like Project GERI are compelling, and developing a large (circa 20ktpa NH_3) demonstration plant (before a circa 1,000ktpa NH_3 commercial mega-scale plant) would provide a strong risk-adjusted path for investment.

Nationally, investment in a commercial-scale renewable hydrogen plant in WA would have intergenerational benefits for risk mitigation, e.g. less reliance on coal exports and liquid fuel imports.

[22] New Scientist, "Japan steps up climate ambition with 2050 net zero emissions goal", Accessed 4 November 2020 from: https://www.newscientist.com/article/2258163-japan-steps-up-climate-ambition-with-2050-net-zero-emissions-goal/

[23] SP Global, "Germany plans to tender 40 GW of wind, solar by 2025", Accessed 4 November 2020 from: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/germany-plans-to-tender-40-gw-of-wind-solar-by-2025-60205094

Investment would also create employment opportunities, harness renewable resources, build exports, grow national income (delivering fiscal stimulus), enhance energy security and boost geo-political influence.

Locally, investment in a commercial renewable hydrogen plant in WA would create employment for plant construction/operation and develop local skills which would, in turn, attract more investment. This income would have a multiplier effect through the local economy. The area's residents and industry could also leverage hydrogen sector investment at scale through enabling infrastructure investment in water, power and port assets.

Commissioning a demonstration plant prior to commercial scale would reduce uncertainty and facilitate testing and learning for investors, customers, governments and regulators – encouraging investment in the development of a new industry.

3.8 Summary

A finite window of opportunity is open to fully develop a hydrogen and ammonia industry in Australia. Notwithstanding that, in many applications, hydrogen holds a potential deployment advantage, investment over the next three to five years and supportive government policy will be pivotal to achieve industry momentum. This requires a bold and coordinated approach to industry development across the value chain, to scale-up despite the risks of an initially inferior cost position and uncertainty about decarbonisation rates. The public policy settings and role of government are important in this regard - a government price on carbon, plus other government policy settings in support of hydrogen, will support renewable hydrogen viability.

Hydrogen could displace high carbon energy incumbents by 2050 - we expect decarbonisation to be well advanced in 30 years' time given the current levels of inertia. However, hydrogen will not automatically become the low carbon leader. Hydrogen will require significant investment (i.e. billions of dollars) in manufacturing technologies, infrastructure development, customer equipment and refuelling stations, together with significant innovation/scale, to achieve cost improvements within the next five years and compete with low carbon alternatives.

Progress will need strong corporate and government resolve and action, but the potential payoffs are momentous. Encouraging industry commentary suggests hydrogen may have leaders with the necessary courage to shape the 21st century energy landscape.

4. Key Findings – Demonstration Scale

4.1 Commercial and Economic

4.1.1 Key findings and implications for project GERI

- There is no current market for pricing of green exported hydrogen, therefore a range of hydrogen prices has been applied for each supply scenario.
- Assumed prices for hydrogen – both value and profile over time - have a critical impact on NPV.
- Project NPV is particularly sensitive to build Capex and power prices.

4.1.2 Key assumptions

Several assumptions have been made to develop the TEM and the scenarios that have been modelled. These have been developed through the inputs and insights developed from the technical, logistics, risk, and commercial work streams.

4.1.2.1 Electrolyser Vendors

A study of supplied and estimated information regarding the critical process plant technology, as well as drawing out a framework considering key strategic and business factors differentiating the vendor landscape, has been conducted. It is noted that vendors provided a lot of data for this feasibility study, and this is greatly appreciated. A formal procurement approach would be required to obtain the increased detail required for the next level of analysis as, due to the complexity of this growing industry, a fully detailed comparison of all vendor responses was unable to be achieved at this early stage.

The vendor responses received, at this stage, do not provide enough detail or confidence to recommend a single technology or vendor. Furthermore, the Total Installed Cost (TIC) varies greatly across vendor quotes, highlighting the uncertainty and need for further vendor engagement on price and inclusions. For the TEM Base scenario a representative sample of three electrolyser vendors was chosen to achieve an annual production of circa 4ktpa of hydrogen.

Six scenarios were run by the TEM, considering varying levels of local domestic, remote domestic and export volumes. The configuration of the plant varied between scenarios, impacting the capital cost not just the market optionality.

4.1.3 Economic findings, including key drivers, sensitivities and considerations

Based on the assumptions that have been outlined in this section, the TEM calculated a project NPV for each scenario considered. In addition, the LCOH for each scenario was calculated. A number of key drivers and sensitivities were identified and are summarised in the remainder of this section.

The cost of electricity and the Capex build costs are the two most significant cost drivers, with the Capex build costs driving most of the overall demonstration scale expenditure. As the cost of electricity carries less control and relatively less materiality on project financials, opportunities to reduce the Capex build should be prioritised to reduce the project NPV.

Another key driver is the selling price of hydrogen and ammonia. With no current green hydrogen export market to benchmark pricing, a wide range of scenarios has been analysed with regards to possible market off-taker developments, with the differing scenarios having a material impact on project economics.

The pathways to customers were chosen based on market customer engagement (refer Section 3) and from the likely demand hubs, together with the most cost-effective / practical logistics options to deliver the product. The levelised costs for each distribution channel vary significantly. All distribution channels have been included in Table 4 regardless of economics, as there may be strategic reasons to invest in that channel.

The build costs of the liquefaction plant drive up the cost of Liquid H_2 Road Tanker distribution channels.

ISOtainer hire costs have an impact on the cost of exporting ammonia, but ammonia export is also a key aspect in demonstrating a pathway to scale.

Table 4: Customer pathways assumptions

Product	Destination	Pathway
Hydrogen	Pilbara	Liquid Road Tanker
	Geraldton	Vehicle Refuelling at Gate
	Goldfields	Liquid Road Tanker
	Perth	Liquid Road Tanker
	Perth	Pipeline to Gas Pipeline
Ammonia	Geraldton	Liquid Road Tanker at Gate
	Perth	Liquid Road Tanker
	Japan	Fremantle via Road ISOtainer

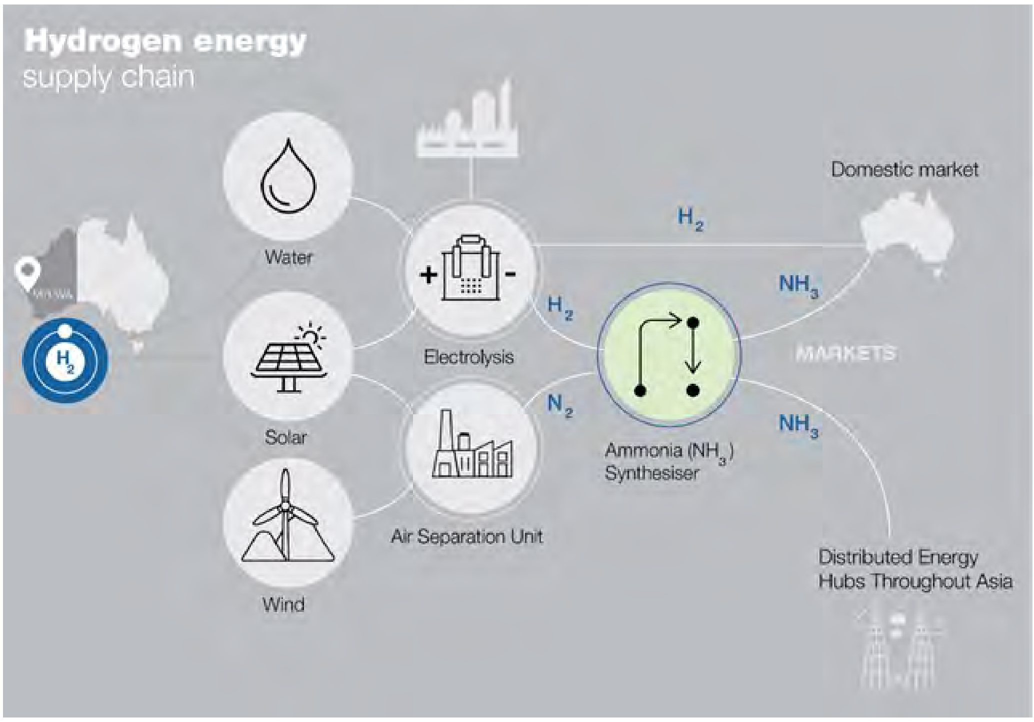
4.2 Technical & logistics, including process, products and renewable power solution

This section sets out the process inputs, process technology, utilities and product logistics solutions that support project GERI at demonstration scale. These include:

- Renewable power supply to produce renewable hydrogen
- Water supply as the feedstock to produce hydrogen
- The process technologies to produce hydrogen
- Process technologies for converting hydrogen to ammonia, with oxygen as a by-product
- Transport for the range of product options from the demonstration facility, including hydrogen, ammonia and oxygen.

Critically, based on the studies undertaken to date, indications are that a demonstration scale facility is feasible in Narngulu and that logistics options exist for the range of potential outputs.

Figure 3: Demonstration scale facility – 35.4MW of power input for an output of circa 20kt renewable ammonia p.a. / 4kt renewable hydrogen.



The technology required to produce hydrogen and convert to ammonia is mature and has been tested at large scale (several megawatt) in the case of alkaline electrolysis,[24] ammonia synthesis and the storage and handling of products. Polymer Exchange Membrane (PEM) electrolysis technology is emerging and considered at an advanced level of development, with commercial offerings available from major international suppliers.

In addition, domestic and export logistics solutions are under development to align with the final product profile (off-take solutions include hydrogen, ammonia and oxygen) at the demonstration scale. Road,

[24] ScienceDirect, Alkaline Water Electrolysis, Accessed 9 November 2020 from: https://www.sciencedirect.com/topics/engineering/alkaline-water-electrolysis

rail and pipeline options exist and will be evaluated based on economic and risk factors to develop a preferred solution.

4.2.1 Key findings and implications for project GERI

- The 35.4MW of electricity required for the demonstration scale facility would require infrastructure investment to provide sufficient power at the site boundary. The project is engaging with the asset owner to identify optimal connection locations and understand the impact on overall project implementation.
- Water supply to the site is assumed to be met from existing water distribution networks. Water recovery, recycling, and reuse options have been preliminarily investigated and would need to be examined in detail in subsequent stages of the project, to reduce overall demand.
- The demonstration scale facility should be designed to convert hydrogen produced from water by electrolysis to ammonia as the main product output. However, this study has also considered a range of alternative potential outputs to suit the market, including compressed hydrogen for transportation applications, hydrogen injection to gas distribution networks, liquid hydrogen and industrial oxygen.
- The process technology required for the demonstration scale facility is generally mature and employed in large scale industrial process operations globally. PEM technology to produce hydrogen is emerging at the scale proposed, with a number of commercial providers capable of meeting the target capacity. Capacity expansion for electrolysis is achieved through modular addition of units, with no specific cap other than availability of power.
- Both domestic and export market logistics play a key role in the overall process and distribution chain design. A range of domestic hydrogen and ammonia off-take options are feasible by road or pipeline. In all cases, the logistics associated with product handling and transport are expected to be a key factor in the decision-making process to determine optimum cost profiles.

4.2.2 Renewable energy generation and connections

Detailed analysis conducted in conjunction with Lightsource bp has formed the estimate of the expected price and energy availability (utilisation rate) of the energy supply. The summary of these findings is outlined in this section of the feasibility study.

A renewable PPA has been estimated for the 35.4MW demonstration power supply. The assumptions made for the demonstration PPA grid connection include that:

- there is a grid connection with bi-directional capacity of 35.4MW;
- the cost of connecting to the grid is included in the project estimate; and
- any spilled energy is sold to the grid.

A firming PPA is best suited for the demonstration plant to maximise utilisation of the electrolysers given the Capex intensity of the project. Power supply options without grid firming would result in low electrolyser capacity utilisation and a higher LCOH, which would reduce the economic viability of the project.

Of note, other associated costs (connection agreements, site reticulation, substations, etc.) have been captured in the TEM as part of the project costs.

The demonstration facility proposes to connect to the South West Interconnected System (SWIS) which is owned and operated by Western Power, a state government regulated enterprise. The facility is located in the North Country load area and is in reasonable proximity to existing 132, 33 and 11 kV network infrastructure.

Connection to a distribution network is typically a significantly lower capital cost than a transmission connection, however, the distribution network in the region of the proposed facility will not accommodate the anticipated power demand.

The SWIS network is constrained, which may present a challenge to the connection of the project at Narngulu. In addition, the project load would be curtailed at times due to network constraints, potentially impacting on plant availability. Further analysis is required in the next stage on the feasibility of operating the plant through a PPA on the SWIS. Optimal behind-the-meter renewable capacity would also be reviewed.

4.2.3 Water

Water would be expected to be supplied by WaterCorp via the mains water supply connection currently available close to the site boundary.

Site water consumption is driven by cooling water demand, with the balance consisting of electrolyser water demands and other general purposes. Incoming raw water feed to the demineralisation plant will be stored in buffer tanks to provide supply continuity.

Dedicated fire water storage tanks will provide sufficient capacity to respond to events at site and will be fed from the main supply connection or alternative sources in an emergency event. The fire water supply and storage configuration will be further defined through the appropriate risk assessment processes.

4.2.4 Products and Process

This project considers a range of feasible product outputs and end-user applications that should guide the production, storage and transport requirements of the demonstration facility.

4.2.4.1 Products

The feasibility study for the demonstration scale project has been developed to evaluate potential product options including hydrogen, ammonia and oxygen. The final product range at the demonstration scale should be determined by near-term customer demand and the longer-term outlook for the commercial scale facility, with the intention to build on established off-take demands.

4.2.4.2 Process

The assessed demonstration facility consists of a series of interconnected process unit operations required to achieve the target product range. The unit operations are housed separately, in a similar manner to a chemical manufacturing facility, providing segregation for safety, operational and maintenance capability with incident management and shutdown.

Water Treatment

Potable water is planned to be supplied to site via a pipeline and stored in tanks. These tanks will provide buffer capacity to allow production to continue should the mains water supply be interrupted, allow for short-term high flow requirements, and provide a positive break point in the supply, eliminating any risk of contamination of the mains system.

Hydrogen Production and gas conditioning

Primary hydrogen production would be achieved by a combination of Alkaline and PEM electrolysis.

Poor grid reliability would impact on plant operation. Electrolysers are typically equipped with a small uninterruptible power supply to keep the units online for a period until power supply is restored, alternate power supply comes online, or safe shutdown commences. Therefore, electrolyser packages can absorb short periods of power interruptions.

The impact of power intermittency on cost and performance for different electrolyser technologies should be further assessed through additional dynamic modelling in the next project phase, prior to being tested during the demonstration plant operation.

The power required for the electrolysers and all other site requirements would be provided via a mix of behind the meter generation and off-site PPA certified as renewable power.

Hydrogen produced from the electrolysers is typically saturated with water and is contaminated with low concentrations of oxygen. The gas is conditioned for subsequent manufacturing stages through drying and deoxygenation to the required purity for the downstream applications or off-take.

Medium Pressure Hydrogen Compression and Buffer Storage

Hydrogen is compressed to 20MPag and stored in a medium pressure buffer vessel. This equipment is to provide a level of process buffering so that downstream processes can continue operating for a period if there is an interruption to the electrolysis.

The final operating pressure of the medium pressure buffer vessel will be evaluated once the product options have been selected. This pressure can be optimised to reduce/eliminate compression equipment and minimise energy input.

Downstream Hydrogen Options / Products

From the medium pressure storage vessel, hydrogen is routed to the various downstream options:

- **Ammonia synthesis** via catalytic reaction. A nitrogen generation unit is also required to supply nitrogen to the ammonia synthesis unit.
- **Filling and road transport of hydrogen via tube trailers** (design pressure of 20MPag) to market.
- **Compression to 35MPag and refuelling of vehicles**, where the unit consists of compression, buffer storage vessel, loading bay and metering and loading equipment delivered as skids to site.
- **Compression to 70MPag and refuelling of vehicles**, where the unit consists of compression, buffer storage vessel, loading bay and metering and loading equipment delivered as skids to site.
- **Hydrogen transfer pipeline** for injection into a natural gas pipeline.
- **Hydrogen liquefaction**. Liquefied hydrogen (-253ºC) is stored in a buffer vessel before being loaded for road transport to an insulated tanker unit.

Ammonia Synthesis

In the current configuration, the medium pressure hydrogen buffer vessel feeds to several plant areas, including the ammonia synthesis unit and hydrogen liquefaction, and various compressed hydrogen gas units such as vehicle refuelling. Gaseous hydrogen buffer storage is expensive and requires a large volume for a small mass of hydrogen (hydrogen has a low density even at high pressures). Reducing the hydrogen buffer storage to a minimum, without compromising on process safety, is one way to reduce the overall plant investment. The buffer storage will be optimised to suit the selected plant configuration, dependent on the product off-take arrangements and feed conditions.

Should hydrogen liquefaction be selected as the main downstream processing unit, other requirements would dictate the sizing of the hydrogen buffer storage, as the turndown for the hydrogen liquefaction unit may be different from that of the ammonia synthesis unit. However, the principle of trying to keep the unit online through internal recycle would remain.

Nitrogen is supplied from the integrated air separation plant and combined with the hydrogen at pressure and high temperature in the synthesis reactor.

Ammonia produced is captured and refrigerated for subsequent storage as a low temperature liquid (or under pressure as a compressed and liquefied gas).

Oxygen Products

Where sufficient market scale is available for an oxygen off-take, the oxygen produced from the electrolysis units, as well as potentially the nitrogen generation unit should a cryogenic air separation unit be selected, is stored in a buffer vessel at 3MPag and then routed to a downstream unit.

Wastewater Treatment

Wastewater is predominantly generated from the demineralisation plants and cooling tower blowdown.

4.2.5 Logistics

A comprehensive analysis of potential logistical options has been completed as part of this feasibility study. This includes:

- Mid-West infrastructure overview and analysis
- Analysis of port options for shipping logistics
- Land transport specifications
- Detailed cost modelling for each component of the logistics supply chain
- Industry engagement for testing and validation of assumptions

Each component of the logistics analysis provided detailed inputs to be included in the TEM.

A wide range of transport options are available for both domestic and export markets. A summary of the options that have been considered by the TEM is provided in Table 5.

Table 5: Summary of domestic transport options

Products	Format	Logistics assumptions
Hydrogen	Cryogenic Liquid	Bulk cryogenic road transport.
	MP gas tube trailers	Road transport.
	MP Pipeline to gas distribution pipework	Pipeline connection.
	MP Pipeline to domestic users	Pipeline connection.
Ammonia	Pressurised liquid ISOtainer	Road transport and shipping for export.

Products	Format	Logistics assumptions
	Pressurised (or low temperature) bulk tanker	Road transport.
Oxygen	Compressed gas	Gas cylinder filling and transport by road.
	Cryogenic liquid	Bulk cryogenic road tanker.

4.2.5.1 Domestic market logistics

Domestic market logistics are directly related to the combination of products and off-take options that have been defined through the feasibility study. Several options are available to meet specific customer demand.

The transport and logistics supply chain is informed by the conditions of the product. Table 5 is a summary of the types of transport across the product range, with key payload characteristics. These inputs assist in determining the type and number of vehicles / movements required for different types and quantities of product and form the basis of inputs into the TEM.

For domestic off-takes at the demonstration scale, road or pipeline transport options are considered based on the relatively low volume and the storage and handling requirements at the production facility and the delivery destination. For a number of products, specialist transport vessels are required to comply with the Australian Dangerous Goods Code (ADG).

Rail transport may be feasible for longer distance transport requirements where suitable intermodal loading facilities exist. While rail transport generally provides higher payload capacity than road transport, loading and unloading terminals are required at each end of the supply chain. For smaller volumes, the impact of road transport at each end of the facility requires further assessment.

The cost of the logistic supply chain is a function of the volume of product, the transport mode, the payload and the distance to market. Based on a first principles approach for each product, a road transport cost-per-trip profile has been developed.

4.2.5.2 Export market logistics

At the demonstration scale, international export routes have been considered through either the PoG as the nearest option, or the FP. Several factors reduce the suitability of Geraldton as an export option for ammonia when compared to Fremantle.

Transfer of ammonia is achievable using T50 ISOtainers. ISOtainers are pressure vessels configured to the dimensions of a 20-foot TEU shipping container and designed for transport via sea, road and rail, complying with international design codes and standards. ISOtainers provide a high degree of flexibility for transport options, can accommodate varying degrees of product, and are commonly used throughout the world to distribute ammonia to market in discrete volumes.

4.3 Regulatory, Risk and Compliance

4.3.1 Key findings and implications for Project GERI

The regulatory and compliance requirements for Project GERI are considered in the context of the obligations and responsibilities imposed by health, safety and environmental legislation. These requirements are assessed with the environmental and risk studies as well as technical and logistics considerations.

- Product quality regulations (i.e. hydrogen purity requirements) when performing electrolysis of water, as applicable to hydrogen for transport or power applications, are expected to be met. In addition, renewable ammonia quality regulations (when produced from hydrogen and nitrogen) are expected to be met. Adhering to global standards now adopted within Australia (that provide specific requirements for hydrogen quality as well as the storage, transport and handling of associated materials) will be feasible.
- The emerging hydrogen market is yet to see the establishment of a renewable hydrogen certification scheme. This scheme is considered important for effective market pricing and guarantee of origin assurances. The development of a domestic or international scheme will be monitored as the project development progresses. Subsequent project stages are expected to include a life cycle assessment of the products to support such a scheme.
- Facility regulatory requirements are covered under existing health, safety and environmental legislation. The site is expected to be classified as a Major Hazard Facility (MHF) and these requirements are understood and readily incorporated into the design process.
- Preliminary QRA studies indicate that a site at Narngulu is suitable for the proposed facility. The preliminary QRA studies highlight requirements for ongoing design development, stakeholder engagement and further risk assessment, including the transport and logistics routes. Established ammonia production and export infrastructure has been assessed to benchmark the facility and demonstrates that risks may be managed and mitigated appropriately to comply with regulatory requirements.
- The project would develop within the existing regulatory framework for management of risks and compliance with safety and environmental legislation. Australia's position at the forefront of the global renewable hydrogen industry is widely supported by government and regulatory authorities.

4.3.2 Regulation – Products

Ammonia and Hydrogen are classified as hazardous according to health and safety regulations. The production, storage, transport and handling of hazardous materials are regulated by a range of state and federal acts and regulations. The emerging renewable hydrogen industry is subject to ongoing review of the various regulations and their application to the industry. A report by Clayton Utz[25] reviewed regulations that are potentially relevant to the hydrogen industry, as well as a review of developing legislation and regulations, and found no barriers to the feasibility of a renewable hydrogen or ammonia energy facility. In general, the regulation of products in the context of the hazardous properties of the

[25] Hydrogen Industry Legislation, Prepared by Clayton Utz for the Department of Industry, Innovation and Science, November 2019, accessed 28 August 2020 from: http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-hydrogen-industry-legislation-report-2019_0.pdf

materials is considered within existing frameworks and does not present a significant concern for operators like bp, with experience in the chemicals, oil and gas industries.

Product quality regulations will be largely governed by the end-user requirements. Product regulation for hydrogen, ammonia and other products such as oxygen is primarily concerned with product purity and the levels of contamination present in the final products.

Hydrogen designated for use in vehicle applications is now considered under the recently adopted standard AS ISO 14687:2020, Hydrogen fuel quality – Product specification. Hydrogen produced from electrolysis is expected to readily comply with this standard.

In Europe, Directive 2014/94/EU on the deployment of alternative fuels infrastructure states that the hydrogen purity dispensed by hydrogen refuelling points shall comply with the technical specifications included in the ISO 14687-2 standard. ISO 14687-2 specifies maximum impurities levels for particulates and several gaseous impurities. For many compounds the limit values are very low, including total sulphur (4 nmol/mol) and carbon monoxide (200 nmol/mol). The least stringent limits are for helium (300 µmol/mol) and total nitrogen/argon (300 µmol/mol). The sum of the impurities should be less than 300 µmol/mol (i.e. H_2 purity exceeds 99.97%).

4.3.3 Regulation – Renewable ("Green") Certification

Certification, or guarantee of origin, schemes for renewable hydrogen and ammonia, once developed, could be used to demonstrate to buyers the extent to which the process used has resulted in a greenhouse-gas emission reduction compared to fossil fuels. The methods for assurance on the origin or the carbon footprint of hydrogen and ammonia will be important, however, there is no dominant certification scheme that applies in Australia or globally.

The Australian Government is considering the development of certification or guarantee of origin schemes. The Australian National Hydrogen Taskforce released a consultation paper in June 2020 that asks industry about the desirable characteristics of such schemes.[26] The Japanese and Korean Governments have indicated that a 'whole of lifecycle' approach[27] to measuring the reduction in carbon emissions of renewable hydrogen and renewable ammonia production is preferred. This is consistent with these governments' higher-level objectives of achieving overall emissions reductions aligned with Paris agreement targets. The approach extends beyond some existing certification schemes that focus on the 'green-ness' of a particular part of the production process (such as applies in the European CertifHy scheme).

Preliminary evidence suggests Australian consumers care about how their hydrogen is produced and do differentiate between hydrogen produced from renewable energy and that made from fossil fuel. However, currently there is no evidence that renewable hydrogen attracts a price premium compared to blue or brown hydrogen[28].

The implications of the current renewable certification landscape for Project GERI include:

[26] Discussion with James Hetherington from the Australian National Hydrogen Taskforce on Friday, 12 May 2020.

[27] A 'whole of lifecycle' or 'product lifecycle' emissions approach considers all the emissions associated with the production and use of a specific product, from cradle to grave, including emissions from raw materials, manufacture, transport, storage, sale, use and disposal. The main difference between the product life cycle approach and the GHG Protocol Corporate Standard is that the former focuses on emissions at the individual product level, whereas the later accounts for emissions at a corporate level.

[28] Green hydrogen is produced from renewable electricity and water, brown hydrogen is produced from fossil fuels, and blue hydrogen is hydrogen produced from fossil fuel and supported by carbon capture and storage. We do not consider blue hydrogen in depth here as the feasibility of the carbon capture and storage element of this production process is relatively novel.

- There is no existing Australian-based certification scheme or method of carbon accounting that can be directly applied in a manner that creates a marketable 'label'.
- Discussions with potential off-takers reveal the nature of the emission reductions they are seeking. The preliminary view is that a premium will be placed on renewable hydrogen, however the extent is yet to be determined. When this information is solidified it can be used to guide Project GERI, and the industry more generally, as to the kind of certification scheme or carbon accounting method that should be adopted to create a suitable label.
- Adopting a carbon emissions accounting approach that considers the complete lifecycle emissions in the production and distribution of both renewable hydrogen and ammonia could be desirable for customers targeting emissions reductions, rather than aiming to have only the hydrogen production process certified (as per international schemes such as CertifHy).

4.3.4 Risk

A preliminary Quantitative Risk Assessment (QRA) has been undertaken for the demonstration facility. The primary objective of the QRA is to evaluate the risks associated with the demonstration plant, transportation of ammonia and subsequent loading of ammonia onto ships. The assessment applies land use planning criteria and Major Hazard Facility (MHF) guidelines to identify hazards and risk contours at an early project development stage. Based on this assessment, some allowance has been made in the cost estimate for risk reduction measures.

As the project design and production profile develops, risk mitigation measures should be further considered within a detailed QRA process to confirm the individual fatality risk criteria according to HIPAP 4 and Dangerous Goods Safety (Major Hazard Facilities) Regulations 2007, can be met. The detailed QRA would also consider societal risk implications of the project.

Narngulu is considered suitable for the proposed facility. The extents of risk contours are expected to decrease once the final product output configuration is defined and further risk mitigation measures are assessed to support the final site configuration.

Australian industry currently manufactures, stores and transports ammonia in accordance with national and international safety standards, including large scale facilities in WA and Queensland. This includes the transport of anhydrous ammonia by road and pipeline. As such, the risks associated with the demonstration site and associated transport options would be expected to be no greater than standard project risk.

The preliminary QRA results have been benchmarked against those for existing commercial scale facilities and a more detailed QRA would be undertaken once product type and volume is finalised and additional engineering definition completed.

4.3.5 Compliance

The Regulatory compliance process begins at the early development stages of the project to support the approval and ongoing operational requirements over the lifecycle of the facility. Frameworks for compliance are well established within the Australian regulatory environment at state and federal levels.

As a global emerging market, standards covering the production and use of hydrogen and derivative products are likely to align with international examples, as observed by the recent adoption of some ISO-based standards.

Early engagement with regulators is expected to support the project compliance with the relevant acts and regulations. Regulators publish best practice guidelines that would be considered for each stage of the project development. Regulators and stakeholders include:

- State and local planning authorities
- Environmental Protection Agency
- State authorities responsible for the administration of HSE legislation and Major Hazard facilities.
- Local fire and emergency response authorities

4.4 Environmental, Planning and Social Impacts

4.4.1 Key findings and implications for project GERI

- The demonstration facility would require a Works Approval and Licence to construct and operate, respectively. A series of technical studies would be required to inform and support a Works Approval Application, including vegetation, flora and fauna assessment, noise assessment and stormwater and drainage management in the form of a management plan.
- Technical reports/information are required to support the development application, including traffic impact assessment, stormwater and drainage, environmental impact assessment and waste management.
- The project would generate local and regional employment opportunities and assist with expansion of the new energy sector. Greater Geraldton and the Mid-West Region would be positioned as a centre for new energy technology and a hub for new energy production and export.
- Based on the discussion held to date with key stakeholders, risks assessed by the social impact evaluation can be mitigated through appropriate development of the project.

4.4.2 Regulation – Facilities

Environmental and planning approval regulations are described in Section 4.4 - Environmental, planning and social impacts. State and federal regulations and codes such as the Occupational Safety and Health Regulations 1996 describe the requirements and obligations of operators to manage safety at the facility. The Australian Code for the Transport of Dangerous Goods by Road & Rail (ADG Code) sets out the requirements for transporting dangerous goods by road or rail.

The Dangerous Goods Safety (Major Hazard Facilities) Regulations 2007 describe the requirements for determining whether the critical quantity of Schedule 1 substances is, or will be, exceeded. The inventory of ammonia and hydrogen is expected to trigger obligations under the Major Hazard Facility (MHF) regulations.

The regulations stipulate the requirements for risk assessment, safety management and ongoing operations obligations necessary to maintain a minimum standard of safety preparedness at the facility. As an operator of existing major hazard facilities, bp is familiar with these obligations.

The design development of the project would include a series of risk identification studies in which hazards and consequences are assessed, and mitigations measures imposed to reduce overall risk to an acceptable level.

The practical interpretation of the regulations is supported by a series of best practice guidelines published by the authorities. These guidelines would be applied throughout the design process.

4.4.3 Environmental

In Western Australia, environmental impacts from proposed industrial facilities may potentially trigger primary and / or secondary assessment and approval. These processes occur under separate Parts of the *Environmental Protection Act 1986* (EP Act). The distinction between primary and secondary approvals relates to the order in which the approvals must be obtained, i.e., a secondary approval cannot be granted if a primary approval is still being assessed.

Proposed industrial facilities may also trigger assessment and approvals under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) depending on the potential impacts to Matters of National Environmental Significance (MNES). Where required, this assessment can be completed separate to, or in association with, State approvals.

The demonstration facility would require a Works Approval and Licence under Part V of the EP Act to construct and operate, respectively. A series of technical studies would be required to inform and support a Works Approval Application, including:

- Vegetation, flora and fauna assessment of the vegetation remaining (and proposed to be cleared) within the proposed site.
- Noise assessment using Computer Aided Noise Abatement (Cadna-A) software (or similar) to predict operational noise generated from the demonstration facility at the nearest identified noise receivers and/or facility boundary. Depending on predicted noise impacts, further mitigation may be required to reduce noise impacts to comply with noise criteria.
- Stormwater and drainage management plan.

Once the demonstration facility has been constructed and commissioned, it would require a Licence to operate. To transition to a Licence requires evidence that the conditions of the Works Approval have been met.

4.4.4 Planning

Given the project would cost over $20 million, the development application would be determined by a Joint Development Assessment Panel (JDAP), unless a decision to have the application determined by the Western Australian Planning Commission (WAPC) through the State Development Assessment pathway is exercised.

Development applications that are determined by JDAP are required to be determined within 60 days (calendar days) or within 90 days where advertising is required. There is no statutory timeframe for the determination of a development application under the State Development Assessment pathway. Given that the proposed demonstration scale project falls within the land use class ‘Renewable Energy Facility’ which is a discretionary use within the General Industrial zone, it is anticipated that advertising of the application would be required.

If the development application is not determined within the statutory timeframes, where they apply, it is deemed to have been refused and a right of appeal is activated. It should be noted that there are no third-party rights of appeal in relation to development applications in Western Australia.

4.4.5 Social Impacts

This section presents the findings and outcomes of a social impact evaluation (SIE) undertaken to inform the feasibility study. A SIE:

- Determines and describes the social study area, including the local and regional study area
- Identifies and describes the potential social impacts for construction and operation phase of the demonstration scale project
- Identifies the significance of social impacts
- Recommends mitigation measures

The SIE was undertaken as a preliminary desktop assessment. As the project progresses through its approval processes, the social impact analysis should be updated and informed by stakeholder and community consultation.

Construction of the project would generate local and regional employment opportunities through the construction workforce requirements for up to 200 workers[29]. This would include skilled and semi-skilled roles including labour, engineering, supervisory roles, administration and management. In addition, local and Indigenous businesses would have the opportunity to provide goods and services to the project construction. Operation of the project would employ 20-22 workers[30]. It is expected this would include skilled roles associated with the plant operation and maintenance and may provide opportunities to develop a skilled workforce in the local government area (LGA). Due to the skills required, it is possible some of the workforce may relocate to Geraldton from elsewhere.

Crucially, the project would assist with expansion of the new energy sector and position Geraldton and the Mid-West Region as a centre for new energy technology and a hub for new energy production and export. This positioning would support economic development and employment for the region.

Increased demand for accommodation is expected to benefit accommodation providers and private rental landlords. Existing tourist accommodation facilities, such as serviced apartments and private rental accommodation, are likely to have capacity to meet this demand.

This desktop SIE presents the social context and evaluation of potential social impacts and benefits for the GERI demonstration scale project. The project would provide employment, skills development and business opportunities to the Geraldton region and result in land use, amenity and public health and safety risks that require management.

[29] Based on cost estimate completed where it is expected that approximately 200 people would be required across the construction period.

[30] 20-22 FTEs have been modelled in TEM scenarios in direct labour. Overheads are modelled in the TEM as a percentage of revenue.

4.5 External Affairs, Stakeholder and Community Engagement Plan

4.5.1 Key findings and implications for project GERI

- Hydrogen is an evolving industry that currently has bi-partisan support, with State and Federal governments looking to industry proponents to take appropriate action to build broad understanding, acceptance, support and social licence for this new industry.
- Research undertaken by the University of Queensland has found that community confidence in the safety of hydrogen production processes is a critical success factor for the industry's development. Community understanding of hydrogen is relatively low, but there is an expectation that industry will listen to the community, hear their concerns, and operate in a safe and responsible manner[31].
- Project GERI would be the first large-scale demonstration project in the Mid-West Region producing renewable hydrogen and converting to ammonia. It would be essential that Project GERI demonstrate responsible leadership in stakeholder and community engagement, to build a positive foundation for the project and the broader industry, and to convey bp's high expectations of itself in this regard.
- A communication and engagement approach that strategically integrates and informs the parallel streams of activities required to deliver this Project (with its multidimensional stakeholder and community groups) would be essential. Demonstrating and articulating robust processes, including those associated with design development, environmental and planning approvals, hazard risk mitigation and health and safety matters would be important.

4.5.2 External Affairs

Low-emissions energy commodity of the future

Hydrogen is now seen as a significant clean energy commodity of the future. Countries around the world are investing in developing domestic hydrogen societies, including Japan, South Korea, China, Germany and the United States. The Japanese Government, in particular, has a clear vision (outlined in Japan's Basic Hydrogen Strategy) to become a 'hydrogen society' by 2030, powering its industries and cities using hydrogen energy as its primary source.

Western Australia's role in developing a thriving new low-emissions hydrogen export industry.

Western Australia is uniquely positioned to leverage global hydrogen demand and create a thriving, clean, low-emissions export industry for the state. Western Australia has the geographic advantage of vast land and an abundance of renewables that provide an ability to scale up and respond quickly. There are also multiple port facilities that provide great accessibility to potential global trading partners.

Geraldton has existing port, logistics and transmission network facilities available which, when leveraged, would reinvigorate regional communities through the creation of new jobs and spill-over economic growth benefits.

Commitment to support regulatory reform

[31] The University of Queensland, Developing community trust in Hydrogen, October 2019, Accessed 3 August 2020 from: http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-developing-community-trust-in-hydrogen-report-2019_0.pdf

The Western Australian Government has indicated that it will continue to work closely with the Australian Government and relevant bodies to support regulatory reform that will enable the growth of the renewable hydrogen industry, while ensuring strong safety and consumer protections.

4.5.3 Stakeholder Engagement

Project GERI would need to work proactively with stakeholders to demonstrate the appropriate development of a local industry in close collaboration with government, industry, and communities.

A range of high-level key stakeholders have been engaged in the preparation of this feasibility study, including federal and state governments, hydrogen industry and regulatory leaders and potential customers. This initial phase of engagement has included 1:1 briefings and discussions, and the completion of detailed questionnaires. Through this initial phase of engagement, these stakeholders have indicated an appetite for a hydrogen facility such as that proposed by Project GERI.

A more intensive stakeholder engagement program would need to be developed and implemented should a decision be made to proceed with the demonstration project.

4.5.4 Community Engagement

Community acceptance of hydrogen as a safe and economically feasible solution to existing energy alternatives is important to the future of the hydrogen economy. There needs to be trust in the science and technology, government's oversight, and industry's management of hydrogen.

Project GERI could provide an opportunity to build and evaluate community understanding and acceptance. For example, community attitudinal studies could help inform the progression of broader scale community education and engagement guidelines and identify where work is needed to better inform community, or correct misperceptions. Intelligence gained from the demonstration project also has the potential to assist with engagement for a commercial scale plant.

The National Hydrogen Strategy states that ***"Building a clean hydrogen industry requires public trust and confidence"***. This requirement should be the fundamental objective of bp's community engagement strategy for the demonstration and potential future commercial phase. Successful engagement requires acknowledgement and consideration of the important role that communities play in developing new industries.

The University of Queensland's *Developing community trust in hydrogen (October 2019)*.[32] proposes a set of criteria that should be considered for leading practice, referencing the Australian Public Service Framework as a valuable resource for engagement and participation.

4.6 Pathway Forward and Major Challenges

At demonstration scale, the key challenges relate to securing anchor customers at an acceptable price point. All other project execution requirements are consistent for a project of this nature and not expected to pose a major challenge, subject to appropriate project execution plans.

[32] The University of Queensland, Developing community trust in Hydrogen, October 2019, Accessed 3 August 2020 from: http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-developing-community-trust-in-hydrogen-report-2019_0.pdf

4.7 Procurement Options and Project Timelines

Various options for procuring and delivering the demonstration facility, including associated timelines and key points of consideration, are available to this project and should be considered, with the intent to identify the delivery model that appropriately balances the project risks and costs to meet the window of opportunity for the emerging hydrogen industry. The delivery model selection criteria aligns with this intent, while using bp's project objectives as a framework.

4.7.1 Delivery Overview – key considerations

bp is one of the world's largest energy companies, with a well-established track record in the delivery and operation of major processing facilities. The project governance framework that bp intends to apply to this project is critical as it impacts the delivery model, timing and costs.

For the purposes of this study, it is assumed that the project would be undertaken with the bp established guidelines for project delivery and governance as a stand-alone bp project. This includes use of bp's Capital Value Process, a stage gated approach consistent with industry best practice for this type of project.

bp's gated process is well aligned with industry practice, as marked by AACE and detailed in Figure 4.

Figure 4: Classes of estimates. [33]

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

[33] AACE International Recommended Practice No. 18R-97 COST ESTIMATE CLASSIFICATION SYSTEM – AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE PROCESS INDUSTRIES, TCM Framework: 7.3 – Cost Estimating and Budgeting, February 2005.

This feasibility study delivers a Class 4 level of project definition (with some additional uncertainty from optionality still included in the process and plant design and preliminary vendor responses) with limited design deliverables developed to date. Although each building block has been estimated, the overall configuration of a end-to-end process is yet to be determined. Thus, efficiencies would be realised once each part of the process is linked.

The project is at a stage that has been developed (where possible) under a Class 4 level definition described by AACE as:

"Class 4 estimates are generally prepared based on limited information and subsequently have fairly wide accuracy ranges. They are typically used for project screening, determination of feasibility, concept evaluation, and preliminary budget approval. Typically, engineering is from 1% to 15% complete, and would comprise at a minimum the following: plant capacity, block schematics, indicated layout, process flow diagrams (PFDs) for main process systems, and preliminary engineered process and utility equipment lists."

The design maturity not only provides for an understanding of the level of confidence in respect to potential outcomes in delivery in taking the project forward, but also marks the level of further effort required to deliver the project.

In order to develop the project to being execution-ready, the design needs to be advanced to a point where the process is well defined, product quality and volume established, and key equipment specified including performance requirements and characteristics. All other supporting disciplines would also need to be at a high level of maturity, providing detailed quantities to inform the capital cost estimate.

A mix of technology and vendors at demonstration has been maintained to hedge risk. As such, consideration for key equipment lead time and delivery and relevant approvals are provided for in the schedule and likely to drive the overall timeframes. The delivery period for electrolysers in the current market could range from 6 months to 2 years, so vendor selection may influence the ultimate delivery period of the project. The procurement model must balance a timely supply of equipment with a high quality of performance.

The intent in respect to equipment supply is for vendors to provide individual (where possible modularised) units that are to be housed within a purpose-built structure with interconnecting piping and power distribution to be designed by the project. The plant is presently conceived to consist of a series of purpose-designed structures housing each major process component. As part of the evolution of the project, it is envisaged that this approach would be optimized through value engineering workshops, providing for amalgamated structures having common elements. Such optimization would reduce capital costs and schedule duration.

Local procurement opportunities

When well engaged, a local workforce from the mid-west would provide value to the project in various forms:

- Local stakeholder goodwill, given local economic benefits
- Developing local knowledge for plant operation during build phase
- Potentially faster mobilisation and lower costs given reduced accommodation and travel needs

From discussions with the Mid-West Development Commission and the Mid-West Chamber of Commerce we understand the region provides access to a highly skilled workforce, with technical capability, near the location of world-leading energy/resources research hubs (Perth), supported by energy and minerals industries that foster innovation across the energy value chain.

4.7.2 Delivery Model

Project GERI has significant alignment with bp's global strategy, and the most suitable delivery model for the project would be guided by bp's project objectives.

Different delivery models provide alternative risk transfer profiles. Each model is characterised by the extent to which it seeks to limit design and construction cost risks and therefore requires a clear fixed scope and transfer project control. For example, models like Design and Construct (D&C) require the contractor market to bid a fixed price for a clear and defined scope, whereas models such as EPCM and Alliancing are able to respond to a more ambiguous and flexible scope.

5. Key Findings – Commercial Scale

5.1 Commercial scale assumptions

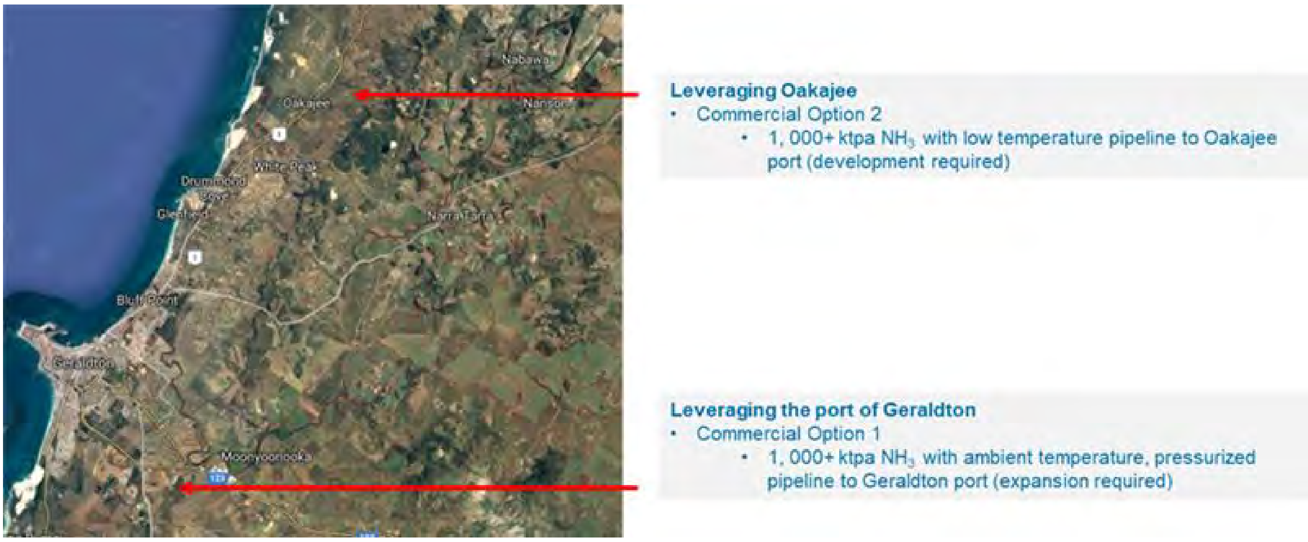
The feasibility assessment for a commercial scale renewable hydrogen and ammonia facility capable of producing circa 1,000ktpa of ammonia was undertaken based on a number of key assumptions. In further developing the commercial scale project, consideration would be given to the actual performance of the demonstration project. The process configuration at commercial scale is very similar to demonstration scale, so won't be re-described in this section.

5.2 Potential location options

Two location options were considered as part of the commercial scale feasibility assessment, with port access as a key criterion due to the large export volume:

- Expansion of the existing Port of Geraldton
- Development of the proposed Oakajee port

Figure 5: Commercial scale location options

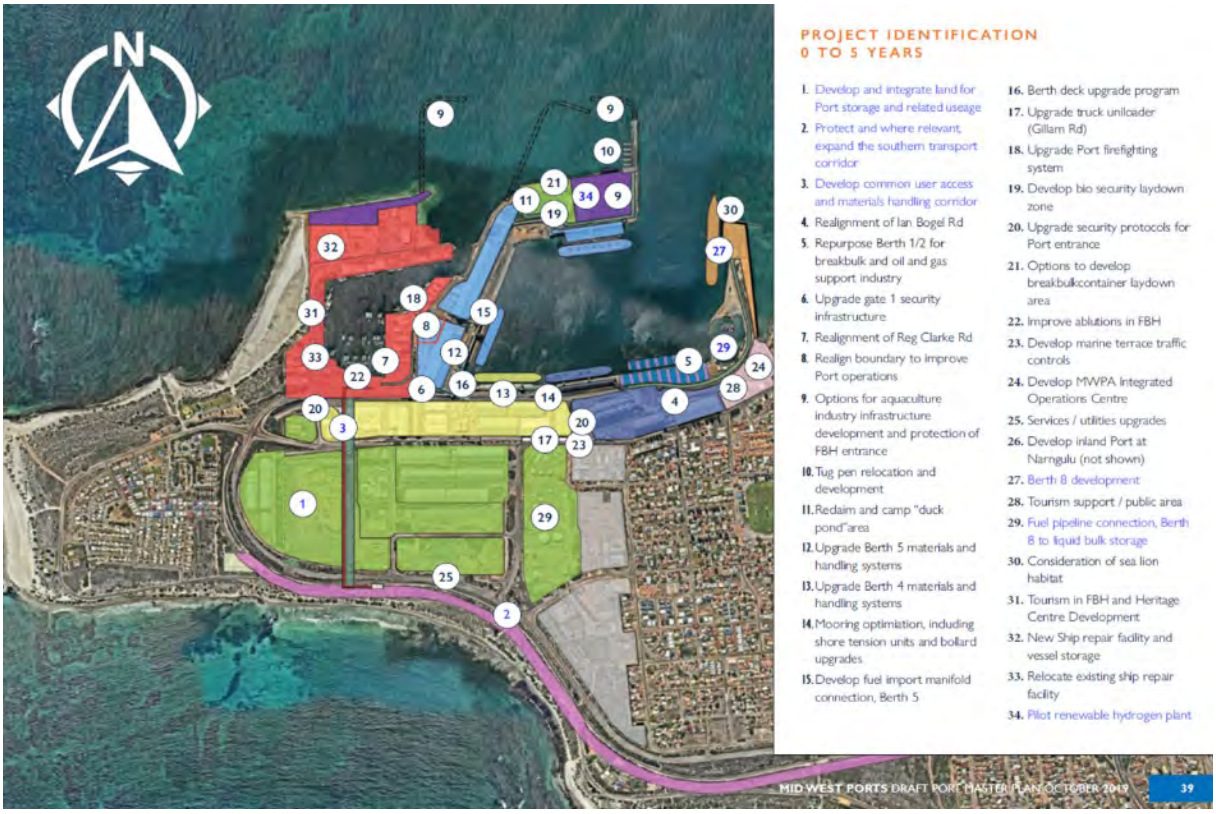


The key consideration for the location is the enabling infrastructure requirements. Locating the commercial scale plant at Oakajee would involve a greenfield development along with significant enabling infrastructure upgrades, including a new export port facility. Opting for a location along the Geraldton Narngulu Infrastructure Corridor has the potential to reduce enabling infrastructure requirements, however other issues may arise, such as increased risk profile, pipeline distance limitations and space constraints at the port location.

5.2.1 Expansion of the existing Port of Geraldton

The Port of Geraldton (PoG) is an existing port that has a commercial basin with 7 berths and an adjacent shallow-draft fishing boat harbour. The port imports bulk fuel product via a multi-user berth but does not have facilities suitable for bulk liquid ammonia export operations at present. Longer-term potential exists for a bulk hazardous liquid facility.

Figure 6: Port of Geraldton master plan



The closest viable plant location to the port is the existing Narngulu Industrial Area, 12 kilometres from the port. Narngulu is currently home to multiple industries, as well as a rail freight depot, and potentially has land options available, subject to utility upgrades (power, water etc.). The demonstration scale plant is proposed for Narngulu; however, has not been designed for straightforward expansion to commercial scale, in order to manage capital expenditure costs. The commercial scale plant could be a standalone facility, separate from the demonstration scale plant, and could therefore be located away from the demonstration plant site.

5.2.2 Development of the proposed Oakajee port

Oakajee, located just north of Geraldton, is a yet-to-be-developed deep-water port earmarked for heavy industrial activities, with extensive land immediately adjacent to proposed wharves. Concept planning of the industrial estate has been developed, as shown in Figure 7.

Successive Western Australian Governments have committed to developing the site at Oakajee for a future port and industrial estate to support the continued commercial development of the Mid-West Region. Most recently (submissions closed 24 December 2020), the Western Australian Government announced a global Expressions of Interest process for the Oakajee Strategic Industrial Area Renewable Hydrogen initiative.[34]

The Oakajee Industrial Estate (OIE) is open farmland from the southern boundary at Buller River through to Coronation Beach Road in the north. Land availability is managed by the Western Australian Government's industrial lands provider, DevelopmentWA.

[34] Government of Western Australia, Oakajee Strategic Industrial Area – Renewable Hydrogen Expressions of Interest, Accessed 6 November 2020 from: https://www.jtsi.wa.gov.au/docs/default-source/default-document-library/oakajee-eoi-document-we.pdf?sfvrsn=43f1761c_0

The master plan includes land allocated for common-user power, desalination water and wastewater providers to service industrial tenants. Common-use utilities, predominantly electrical and desalinated water, could be sized to service both the OIE and the wider public utilities networks. Options exist to open a new basin at the intended port location, or a smaller scale port facility that can be expanded as more industries open in Oakajee.

A Structure Plan has been prepared by the Shire of Chapman Valley[35] for Oakajee Industrial Estate (OIE) to guide its development.

The estate comprises the following areas:

- Strategic Industry Area (SIA) 1,135ha
- General Industry Areas (GIAs) 196ha
- Coastal Area 1,002ha
- Buffer Area 4,072ha

Alignment with WA Government objectives

This feasibility study confirms this project would fit with the Western Australian Government's objectives for the Oakajee SIA, aligning with the form of intended development in the Oakajee Structure Plan.[36] The process plant could be located in a 100-hectare lot within the SIA, with the desalination plant for water located in the adjacent service area.

The key requirements for the development of a renewable hydrogen industry at Oakajee, from an engineering point of view, including transmission upgrades, port upgrades and pipeline infrastructure, are discussed in Section 5.4.

The commercial scale project could bring together innovative solutions along the entire renewable hydrogen value chain, and work together with the WA Government to unlock the potential that the Oakajee region has to offer, in line with DevelopmentWA's structure plan. This process is expected to create common user infrastructure, such as port and electricity grid developments, that would create lasting benefit for future industries at Oakajee and ensure maximum flexibility for growth.

The bulk of the renewable energy supply for the project could be located in the buffer zone. A grid connection would offer benefits to the local community. Transmission upgrades would be required.

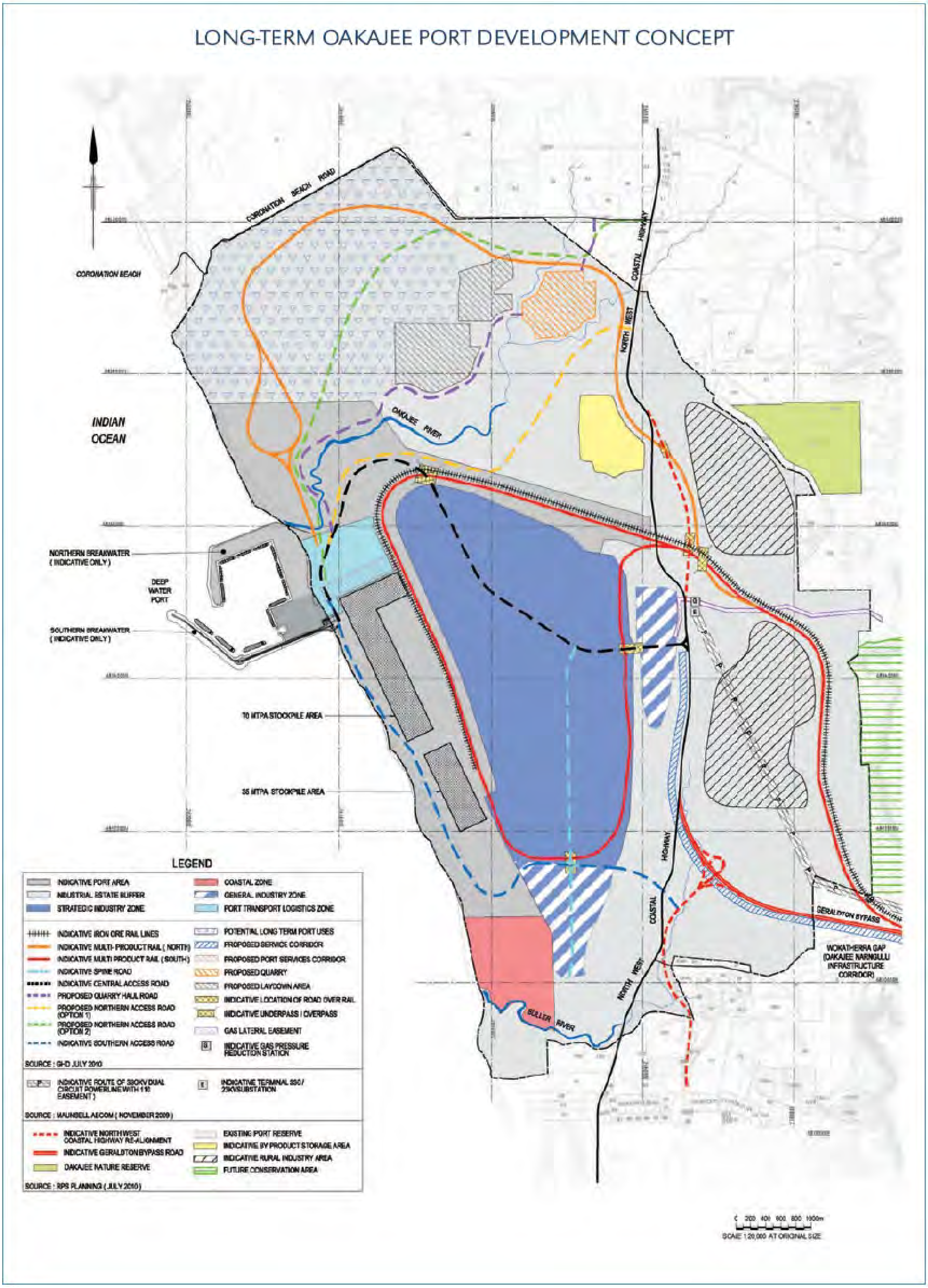
Section 5.4.5.1 also discusses enabling infrastructure requirements related to the Oakajee Port that could form part of the common user infrastructure at the Oakajee Industrial Estate. The section considers smaller scale port development concept options at Oakajee to suit the needs of the proposed commercial scale hydrogen/ammonia facility, which could be later expanded to the full-scale Oakajee port, as per the Port Master Plan[37] as commercial activity picks up at Oakajee. This scalability ensures maximum flexibility for all future industries and export opportunities while also providing the benefit of being an innovative, low-cost solution.

[35] Shire of Chapman Valley, Oakajee Industrial Estate Structure Plan, Accessed 2 October 2020 from: https://www.chapmanvalley.wa.gov.au/oakajee-industrial-estate-structure-plan.aspx

[36] DevelopmentWA (2012), 'Oakajee Industrial Estate Structure Plan', <https://developmentwa.com.au/component/edocman/946-oakajee-industrial-estate-structure-plan-report/viewdocument/946>

[37] Mid West Ports Authority (2011), 'Oakajee Port Master Plan', <https://www.midwestports.com.au/profiles/midwestports/assets/clientdata/documents/general/oakajee-master-plan.pdf>

Figure 7: Oakajee Port Concept



5.3 Commercial and Economic

5.3.1 Key findings and implications for project GERI

- Key drivers of LCOH are Capex, power, and plant scale
- Enabling infrastructure costs are significant regardless of location. It is assumed that this enabling infrastructure would be provided by government and is therefore kept separate from project economics
- The location of the commercial scale facility has a material impact on distribution costs
- There is potential to reduce costs further by optimising renewable power generation against plant utilisation

5.3.2 Key assumptions

Several assumptions have been made to develop the TEM and the scenarios that have been modelled. These have been developed through the inputs and insights developed from the technical, logistics, risk, and commercial work streams.

5.3.2.1 Electrolyser vendors

Given the modular nature of electrolysers, several units would be required to produce enough renewable hydrogen to support a commercial size ammonia plant.

As no vendor information was available for the capital cost of electrolysers at commercial scale, the capital costs were scaled up from the Class 4 estimates at demonstration scale, using both a scaling factor and an estimate of the learning rate of electrolyser technology. The learning rate is the magnitude of unit cost reduction with every doubling of global production. An assumption was made that the scaling up of GERI from demonstration to commercial scale over the relevant timeframe would be similar to overall global production increases.

For electrolysis, the learning rate has been estimated as 18% ± 6%[38]. This rate is similar to what has been observed in technologies like photovoltaic cells and lithium-ion batteries. Scaling of other capital equipment (ammonia synthesis, hydrogen liquefaction) has been executed with a scaling factor only (no learning rate), as these are more mature technologies.

5.3.2.2 Customer pathways and TEM scenarios

The pathways to customers in Table 6 were chosen based on market customer engagement (refer Section 3) and from the likely demand hubs (as provided by bp) together with the most cost-effective / practical logistics to deliver the product.

Table 6: Commercial scale customer pathways assumptions

Product	Destination	Pathway
Hydrogen	Pilbara	Liquid Road Tanker
	Geraldton	Vehicle Refuelling at Gate
	Perth	Pipeline to Gas Pipeline

[38] Saba, S.M., Mueller, M., Robinius, M., and Stolten, D. (2018). The investment costs of electrolysis–a comparison of cost studies from the past 30 years. Int. J. Hydrogen Energy 43, 1209–1223.

Product	Destination	Pathway
Ammonia	Japan	Bulk shipping

As per the customer pathway assumptions in Table 6 and guidance provided by bp, two scenarios were run by the TEM.

5.3.3 Economic findings including key drivers and sensitivities

The analysis undertaken shows a clear path to reducing LCOH from demonstration scale to commercial, with the key drivers being cost reductions achieved through scaling and reductions in electrolyser costs and power prices.

The key optimisation levers that can reduce the commercial LCOH even further are:

- Increasing scale of the facility to take advantage of further cost reductions from scaling as well as lower PPA prices.
- Capex reduction could be achieved through early vendor engagement and higher learning factors through research and development and global take-up of electrolyser technology.
- Energy management and optimisation of variable renewable energy also represents a key area that could enable a significant reduction in the LCOH. With increasing scale, power prices become increasingly impactful relative to Capex and other costs.

A range of pricing scenarios was used, from $1.50 to $17.30/kg of hydrogen, with the differing prices having a material impact on project economics.

The levelised costs for each distribution channel vary significantly. Options exist to reduce distribution channels to reduce build costs and prioritise low LCOH options.

5.4 Technical & logistics including process, products and renewable power solution

5.4.1 Key findings and implications for Project GERI

This section assesses the technical, logistics and enabling infrastructure requirements at each stage of the supply chain (renewable power, water, process and products, domestic logistics and export logistics) for the commercial scale project.

Detailed analysis underpins the estimate of the expected price and energy availability (utilisation rate) of the energy supply. Renewable energy generation is the first step of the renewable hydrogen / ammonia supply chain. The renewable power generated is used to meet the load requirements for:

- Process plant
- Desalination plant
- Process plant / port depending on location

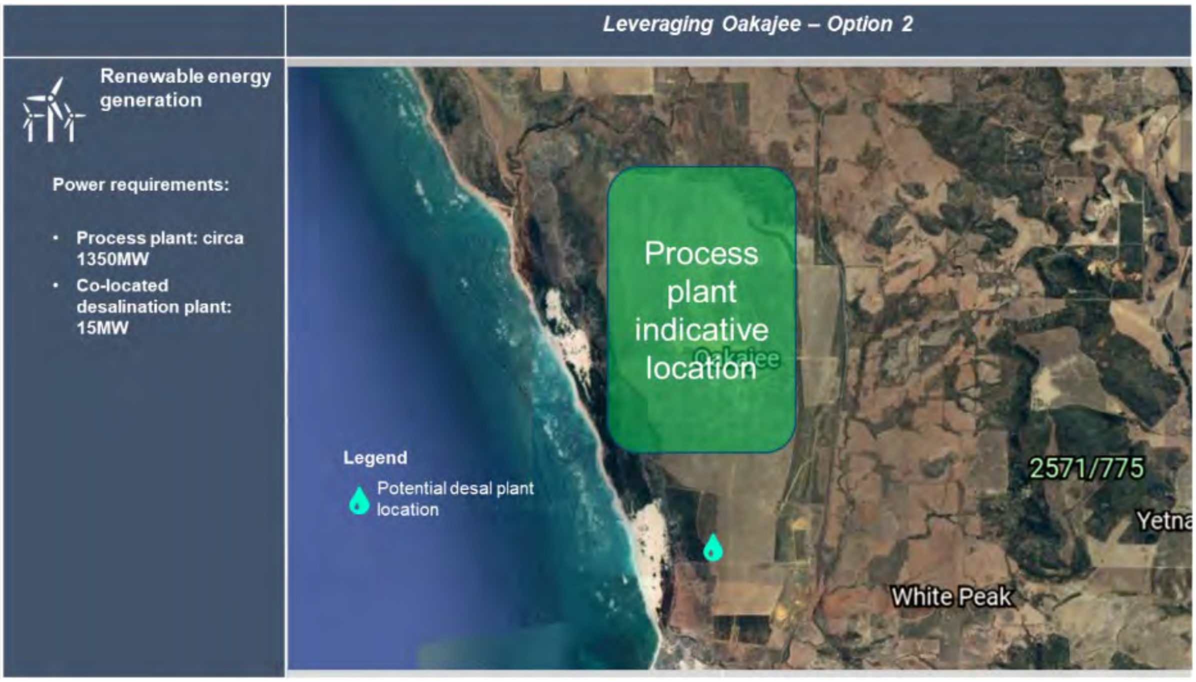
The downstream plant has currently been sized at 1,000ktpa so that utilisations up to 100% can be assessed. A firm capacity factor should be defined later in the project so that the downstream equipment can be ‘right-sized’.

PPA contract terms and duration are key considerations in order to drive the maximum economic value and the lowest cost of power for the project. Shorter terms may result in a higher cost of power in order to recoup the capital expenditure over a shorter operational life.

Figure 8 and Figure 9 illustrate power requirements at the process plant, desalination plant and port sites for the various options considered.

Figure 8: Geraldton option load requirements and indicative plant locations

Figure 9: Oakajee option load requirements and indicative plant locations



5.4.2 Water

The high requirements for water would necessitate the construction of a desalination plant irrespective of the commercial scale facility location. The commercial plant's water requirements and utilisation of desalination would align with the future water requirements of the region. The desalination plant would be sized to meet the needs of the wider public network, potentially creating an opportunity for WaterCorp participation in the initial construction phase – however, for the purposes of this assessment, the assumption is a dedicated desalination facility that solely services the needs of the commercial scale process plant.

5.4.3 Process & Products

The commercial scale feasibility assessment has been undertaken on the basis that the annual production capacity at the process plant would be circa 1,000ktpa of NH_3, which is assumed to be 90% ammonia for export (circa 900ktpa of NH_3) and 10% hydrogen for domestic sale and distribution (circa 20ktpa H_2). The process plant would have a land footprint of circa 100 hectares, excluding any renewable power generation component.

The process plant may include a hydrogen liquefaction plant for domestic distribution in addition to the ammonia plant for export. The conceptual plant layout includes:

- Water treatment / deionisation plant (taking RO desalinated sea water)
- Cooling water distribution
- Electrolysis facility
- H_2 buffer storage
- Ammonia production plant including air separation plant
- Ammonia buffer and domestic storage
- Hydrogen liquefaction plant or pipeline connection (domestic distribution)
- Liquid hydrogen storage and tanker filling
- Tube trailer filling facility
- Compression & Refrigeration systems as well as associated power infrastructure and 2 x 35ML low temperature bulk tanks for ammonia storage (located at plant for an Oakajee location and at port for a Geraldton location)

Plant configurations and equipment used would be informed by outcomes from the demonstration scale project.

5.4.4 Domestic market logistics

Three methods of distribution were considered, as follows:

- Liquid hydrogen to Pilbara. The Oakajee Structure Plan makes provisions for infrastructure corridors and infrastructure sites which link to the existing road infrastructure for transport to the Pilbara.
- Blending into Dampier Bunbury Natural Gas Pipeline. Further studies would have to be carried out to understand the potential to increase the level of hydrogen blending, including a detailed assessment to understand the impact on downstream customers and performance issues.

Studies on viability of and limits to hydrogen blending in gas networks are also being carried out in other regions of Australia.

- Tube trailer facility at process plant. A volume of hydrogen is assumed to be distributed to the domestic market via a tube trailer facility at the process plant, sufficient to service circa 250 cars per day.

5.4.5 Export market logistics

This section considers potential logistics solutions at Geraldton and Oakajee for the ammonia pipeline to port, ammonia chilling and storage, as well as port upgrades required to facilitate exports. Refrigerated ammonia is stored at -33°C prior to ship loading. This requires a compression and refrigeration facility upstream of the low temperature pipeline.

For the Geraldton option, the compression and refrigeration facility would be located at the port, as ammonia is transported to the port through an ambient temperature pipeline for approximately 15km. At the port, it is expected that the ammonia would be chilled and stored in low temperature, insulated, double skin bulk tanks. A short, low-temperature, insulated pipeline (500mm diameter) would transfer the ammonia from the storage tanks at the port to the ships. A short recirculation line (150mm) would also be required between the storage tanks and ship loading area to maintain temperature of the ammonia during export.

For the Oakajee option, the compression, refrigeration and storage facility would be located at the process plant, as ship loading of ammonia occurs directly from the process plant through a 3km long, low temperature, insulated pipeline. A recirculation/vapour return line would also be required, in parallel to the low temperature pipeline.

5.4.5.1 Port upgrades

Neither Geraldton nor Oakajee currently have facilities suitable for bulk liquid ammonia export operations and both would require significant upgrades to accommodate export.

Port of Geraldton options

Geraldton Port has a commercial basin with 7 berths and an adjacent shallow draft fishing boat harbour. The port imports bulk fuel product via a multi-user berth but does not have facilities suitable for bulk liquid ammonia export operations at present.

1. <u>Berth 8 development</u>

The 2020 Port Master Plan recognises an opportunity for a bulk liquids berth facility that can be utilised in the short-term. However, this facility could only potentially accommodate lower export volumes due to limited space. There is also significant uncertainty around locating ammonia storage tanks at the port due to the lack of vacant land and buffer distances required. As export volumes assumed for the commercial scale project would probably not be met through this upgrade, this option is not considered further.

2. <u>New outer harbour basin</u>

Port upgrades for commercial scale operations to support an ammonia export capability at the Port of Geraldton could involve development of a new outer harbour basin

This option could accommodate the full annual plant capacity of 900ktpa of ammonia, as greater space and offset allowances are possible. This is the preferred port upgrade option if commercial scale operations are located near the Port of Geraldton.

Oakajee options

The development of the full-scale, multi-user, multi-berth port at Oakajee as per the concept plan may not be economically feasible unless there is a significant uptick in export of resources and industrial activity within the Oakajee Industrial Estate. This section considers smaller scale port development concept options at Oakajee, to suit the needs of the proposed commercial scale hydrogen/ammonia facility. These concepts could be expanded to the full-scale port at a later time, as commercial activity picks up at Oakajee.

Further studies would need to be done to better understand the impacts of the port options on operability and port capacity.

1- Protected Berth - Breakwater option

This option involves constructing a nearshore facility that includes a breakwater that keeps alignment with the main breakwater described in the Oakajee Port Master plan. This would allow the port to be ultimately expanded/developed as per the Oakajee Port Master Plan to allow multi-user, multi-product operations as more industrial activity opens up in Oakajee.

2- Exposed Berth - Trestle option

This option involves constructing a nearshore causeway / trestle to wharf structure without a breakwater and no/limited dredge works. The trestle option could provide a lower capital cost profile, as reduced/no dredging or breakwater structure is required. Subject to operability requirements, the port could be expanded/developed to allow multi-user, multi-product operations as more industrial activity opens up in Oakajee.

5.5 Regulatory, Risk and Compliance

5.5.1 Key findings and implications for project GERI

- The commercial scale project is aligned with the objectives set out in Australia's National Hydrogen strategy. This strategy identifies the need for regulatory reform as a key enabling activity over the next decade. Also, there is a need to focus on developing consistent approaches for efficient supply chains, ensuring a supportive investment environment and robust training requirements and safety standards.
- Notwithstanding the evolving regulatory frameworks outlined by the National Hydrogen Strategy, the production and transport of dangerous goods will continue to be regulated by the relevant authorities to ensure the continued safe and environmentally responsible practices that currently exist.

5.5.2 Regulation - Products

As discussed in Section 4.3.2, the regulatory environment pertaining to the emerging renewable hydrogen industry is a dynamic space. Given the likely long lead time to develop a commercial scale facility, the renewable hydrogen industry (including derived products such as ammonia) is expected to have undergone significant regulatory reform before the facility is completed. This reform is expected to include rationalised approaches to standards and legislation covering product regulation, technology and renewable certification.

Product regulation is primarily concerned with product purity and the levels of contamination present in the final product. Hydrogen produced through electrolysis, and the ammonia produced from hydrogen, are low on contaminants and support clean manufacturing processes. Hydrogen produced from electrolysis is also expected to readily comply with fuel quality standards for vehicle applications. A report by Clayton Utz[39] reviewed regulations that are potentially relevant to the hydrogen industry, as well as developing legislation and regulations for the hydrogen industry, and found no barriers to the feasibility of a renewable hydrogen or ammonia energy facility.

5.5.3 Regulation - Facilities

Guidelines and legislation for renewable energy generation and a dedicated desalination facility that would support the commercial scale process plant, are relatively mature, with policy drivers supporting growth. Codes, regulations and standards applicable to the design, construction and operation of the commercial scale facility are consistent with those outlined for the demonstration scale facility. The operation of the site at a commercial scale would be aligned to similar scale conventional ammonia production and handling facilities around Australia and globally.

The inventory of ammonia and hydrogen at the commercial scale facility would trigger obligations under the Major Hazard Facility (MHF) regulations, however this is no different to the demonstration scale facility and would be managed within the existing established compliance frameworks. The regulations stipulate the requirements for risk assessment, safety management and ongoing operations obligations necessary to maintain a minimum standard of safety preparedness at the facility. As an operator of existing major hazard facilities, bp is familiar with these obligations.

Domestic distribution of hydrogen will need to comply with The Australian Code for the Transport of Dangerous Goods by Road & Rail (ADG Code) and relevant maritime transport requirements where exported by ship. Legislative requirements around gas blending into natural gas pipelines are at a relatively early stage.

Environmental and planning approval regulations are outlined in Section 5.6. Safety case approval, special berth permits, transport route approval and port storage approval would be subject to demonstration of acceptable societal risk management and tolerable impact on other operations.

5.5.4 Risk & Compliance

The process operations at the commercial scale are expected to have similar risk considerations to the demonstration scale. Production would be at a scale equivalent to existing ‘conventional’ ammonia production and would therefore be expected to represent similar risk profiles. Site selection and finished product transport models are expected to contribute to the overall risk profile.

The key differences in scaling up from demonstration to commercial include:

- Increased overall site DG inventory, however not proportional with scale. Site inventories for hydrogen may be reduced where direct off-take is via pipeline. Ammonia inventory is guided by ship capacity and frequency.
- Ammonia storage would be in bulk ambient pressure refrigerated tanks configured to suit the export model, by pipeline to ship, at the nominated export facility.
- Ammonia and hydrogen transport by pipeline with road transport of products restricted and optimised, either as cryogenic liquid or in alternative hydrogen carriers.

[39] Hydrogen Industry Legislation, Prepared by Clayton Utz for the Department of Industry, Innovation and Science, November 2019, accessed 28 August 2020 from: http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-hydrogen-industry-legislation-report-2019_0.pdf

Regardless of the scale of the facility, the same quantitative risk assessment (QRA) methodology would be applied to assess and mitigate the risks identified by the operations. The QRA would consider the location of the facility in the context of sensitive receptors and the associated risk contours.

As the project develops, a detailed QRA would be undertaken to understand risk mitigation measures and to confirm the individual fatality risk criteria according to HIPAP 4 and Dangerous Goods Safety (Major Hazard Facilities) Regulations 2007 can be met. The detailed QRA would also consider societal risk implications of the project.

At the commercial scale, road transport may be considered for a portion of the hydrogen production, to support domestic transport and mobility applications such as the "Hydrogen Highway" initiative[40] and remote mine sites. However, the majority of the hydrogen produced is assumed to be converted to ammonia and exported by ship.

Compliance and regulatory frameworks are not expected to alter significantly between the demonstration facility and the commercial scale operations. The commercial scale ammonia production facility is aligned with similar conventional ammonia production scales around Australia and compliance would be managed along similar models.

5.6 Environmental, Planning and Social Impacts

5.6.1 Key findings and implications for project GERI

- The environmental assessment requirements, environmental approvals, planning requirements and associated costs for a commercial scale facility are similar when comparing a Geraldton or Oakajee location. The environmental assessments and approvals required may involve technical studies focusing on different environmental aspects, specific to the constraints of each site option.
- The environmental assessment requirements, environmental approvals, planning requirements and associated costs are similar when comparing a demonstration scale facility to a commercial scale facility.
- The social impacts for a commercial scale facility are similar when comparing to a demonstration scale facility. It is envisaged that there would be a significant increase in opportunities for the Greater Geraldton workforce, the local housing market, and that the project would drive economic development for the region, supporting local and regional community values and aspirations for developing the Mid-West Region.

5.6.2 Environmental assessments and approvals

Locating the commercial scale facility near Port of Geraldton, within the Narngulu Industrial Area, is expected to minimise the number of relevant environmental factors and potential impacts to sensitive receptors as the area is mostly used for farming, and therefore highly disturbed, with limited vegetation or environmental values likely to be impacted. Furthermore, via the demonstration facility, the environmental assessments and approvals would be well understood, providing a known pathway for commercial scale assessments and approvals.

Similarly, although the Oakajee site would be a greenfield site, much of the area is understood to be highly disturbed and vegetation modified so potential for flora and fauna values being present are

[40] The Hydrogen Highway: Australia's Opportunity for Global Leadership in Clean Heavy Transport, accessed 30 September 2020, https://treasury.gov.au/sites/default/files/2019-03/360985-InfraNomics-supporting-document.pdf

reduced. As a greenfield site, Oakajee could garner considerable support due to the long-standing state government commitment to use the proposed site for a future port and industrial estate - even specifically noting a renewable hydrogen hub opportunity.[41] This would not preclude the necessary environmental studies being completed to inform the independent assessment process. The environmental assessments and approvals required for the Oakajee option would be consistent with those outlined above for the Narngulu option, although the technical studies may focus on different environmental aspects, specific to the constraints of each site.

5.6.2.1 Approvals pathway

The environmental approvals pathway is the same for each location, with both primary and secondary environmental approvals required.

The scale and operation of a commercial facility has the potential to directly and indirectly significantly impact the surrounding environment. It is reasonable to assume the commercial facility would require referral to the EPA as a minimum and, depending on outcomes of the environmental studies, may be formally assessed under Part IV of the EP Act[42]. A commercial scale facility would require a Works Approval and Licence under Part V of the EP Act to construct and operate, respectively.

Based on the findings from the demonstration scale facility it could be reasonably expected that, regardless of the chosen site, the assessments and approvals for a commercial scale facility would require a series of technical studies. These studies would most likely need to be completed in greater detail and volume to inform and support the primary and secondary approvals – including, but not limited to, vegetation, flora and fauna assessment, noise and fugitive air emission modelling, stormwater and drainage management, water sourcing and waste disposal options and associated environmental impacts. Technical reports/information would also be required to consider indirect environmental impacts, which would similarly support a planning approval application, including traffic impact assessment and visual impacts.

5.6.3 Planning

Planning and development requirements in Western Australia are outlined in Section 4.4.4.

Should the commercial plant be located in Geraldton, a commercial scale plant is consistent with the objectives for the zone and would fall within the land use class ‘Renewable Energy Facility’. As such, under the local planning scheme, the proposed project is a use which may be considered within the General Industrial zone, subject to public advertising.

Oakajee has been identified for many years by the state government as a deep-water port and industrial estate. It is anticipated that the approval process would be similar to the Geraldton site.

The *Planning and Development (Local Planning Schemes) Regulations 2015* identifies the list of matters that the local government is required to have regard to when considering development applications. Those matters which are relevant to the development of a commercial scale project on the proposed sites have been analysed. This analysis suggests that the development approval considerations would be focused on impacts directly arising from the development and use of the land – for example, building and works, traffic, amenity etc.

[41] DevelopmentWA website, Oakajee SIA, accessed 22 September 2020 from: https://developmentwa.com.au/projects/industrial-and-commercial/oakajee-sia/overview

[42] Primary WA Approvals, administered under Part IV of the EP Act, enable the Environmental Protection Authority (EPA) to carry out an Environmental Impact Assessment (EIA) – this is triggered if a development proposal may have a significant impact on the environment.

5.6.4 Social Impacts

A commercial scale renewable hydrogen and ammonia facility would generate considerable local and regional employment opportunities and greatly assist with expansion of a burgeoning energy sector. Greater Geraldton and the Mid-West Region would be positioned as a hub for new energy technology and for new energy production and export.

Based on the discussions held to date with key stakeholders, risks assessed by the social impact evaluation could be mitigated through effective communication and appropriate development of the project.

5.6.4.1 Key social impacts

Construction of a commercial scale project would generate many local and regional employment opportunities through the required construction workforce. The associated benefits, as outlined in Section 4.4.5, include opportunities for the local workforce and for local and Indigenous businesses to provide goods and services to the project construction. In addition, operation of the project would be expected to include multiple skilled roles associated with the plant operation and maintenance, and this would provide opportunities to develop skilled workforce in the LGA. Given the skills required and the scale of the project, it is highly likely that some of the workforce would relocate to the Mid-West region from elsewhere.

Crucially, the project would assist with expansion of the new energy sector and position the Mid-West Region as a centre for new energy technology and a hub for new energy production and export. This positioning would drive economic development and employment for the region, supporting local and regional community values and aspirations.

Increased demand for accommodation could benefit the local housing market, accommodation providers and private rental landlords.

Overall, the commercial scale project could provide considerable employment, skills development and business opportunities to the Mid-West region. It is considered that identified risks regarding land use, amenity and public health and safety could be sufficiently mitigated.

5.7 External Affairs, Stakeholder and Community Engagement Plan

5.7.1 Key findings and implications for project GERI

- There is significant bipartisan support for developing an export-scale hydrogen industry in Australia. This is expected to generate support for projects like GERI at both the state and local level.
- Clear communication of the long-term Western Australian economic benefits that Project GERI could generate may assist in gaining support and funding for enabling infrastructure requirements.
- Early engagement with local industry that could be early adopters of hydrogen could be key in ensuring that distribution channels are optimised.
- Given the scale of the project and the emerging nature of renewable hydrogen technology, sustained involvement of the local community through the project would be important.

5.7.2 External affairs

As discussed in Section 4.5.2, hydrogen has been recognised as a low-emissions energy commodity of the future and has received significant bipartisan support. In addition, Australia's National Hydrogen Strategy – informed through extensive consultation - sets a positive tone and a clear path for the development of Australia's hydrogen industry.

The Western Australian Government has indicated strong commitment and support to enable the growth of a renewable hydrogen industry. Through the Western Australian Renewable Hydrogen Strategy, the state government has acknowledged the important role that hydrogen plays in the state's future energy mix. Project GERI offers advantages to the Western Australian Government in its pursuit of developing an export-scale hydrogen industry, including a key goal in developing the Oakajee region into an industrial hub.

5.7.3 Stakeholder Engagement

Project GERI would need to work productively with stakeholders to successfully develop a local hydrogen industry, by maintaining close collaboration with government, industry, and communities. An extensive stakeholder engagement program would need to be developed and implemented that builds on the engagement program developed from the demonstration scale facility. The stakeholder mapping and analysis would determine the level of interest, influence and priority of all stakeholders.

Regular and transparent engagement with stakeholders in the demonstration phase, in particular, with authorities such as the state government, Mid-West Development Commission, DevelopmentWA, Mid-West Ports, EPA and local councils, is essential and would help reduce the risk of roadblocks to the commercial phase of the project.

5.8 Pathway Forward and Major Challenges

The key considerations identified in the sections above in realising the commercial plant are summarised below:

Table 7: Commercial scale - major challenges

Section	Key challenges

Commercial and economic	• Enabling infrastructure costs remain a key challenge for the development of the project and should be a priority in stakeholder engagement activities. Keeping infrastructure costs outside project economics is vital and could require significant support from government bodies.
	• The key drivers from a production perspective that would determine profitability are:
	  ○ Funding
	  ○ Power costs
	  ○ Electrolyser Capex and execution
	  ○ Synergies between hydrogen and ammonia production

Technical and logistics	• Technical and logistics assessments demonstrate the feasibility of the project, subject to large scale enabling infrastructure upgrades taking place. Pathway to scale requires significant step changes across the supply chain, especially in regard to capacity of electrolysers by vendors available in the market. Based on current developments, this is deemed to be feasible by the time of commissioning of the commercial scale project.

Section	Key challenges
	• Options have been identified that would provide relatively low-cost solutions for port developments at either location option. • Options for all elements of the supply chain (renewable power, water, process, logistics) have been assessed and optimum solutions have been identified for each at either location.
Regulatory, risk and compliance	• Australian industry currently manufactures, stores and transports ammonia in accordance with national and international safety standards, including large scale facilities in WA and Queensland. At the proposed commercial scale location options, it is reasonably assumed that risks can be appropriately managed in a similar manner to existing industry methods. • Compliance with existing regulatory requirements for the hazardous industrial products should be manageable with vigilance in risk control design and in ongoing risk management. All of the risk/regulatory analysis suggests the project is viable.
Environment, planning and social	• Technical studies focusing on different environmental aspects, specific to the constraints of each site option would be required, however, no major challenges have been identified for the feasibility of the project from an environmental and planning perspective. • The social impacts are a net positive, as the project would create a significant number of jobs and support growth in the local economy.
External affairs, stakeholder and community engagement	• Stakeholders are supportive and there is political will at the Federal and State levels to facilitate the creation of an export-scale hydrogen industry. • The major challenge would be clear and early communication of the potential long-term benefits that the project would bring to the local economy. The scale of the project and emerging nature of renewable hydrogen necessitates ongoing involvement of local community groups

5.8.1 The path forward

Table 8 details key assumptions that need to be revisited for the commercial scale facility prior to commencing the project that would be informed by outcomes from the demonstration scale project and market developments.

Table 8: Key decisions required prior to commencing

Area	Key considerations
Plant location	The plant location needs to be finalised to allow land acquisition. This would be influenced by stakeholder engagement activities as well as political support for the location options considered and associated enabling infrastructure developments. Renewable power generation and associated transmission infrastructure upgrades required could also be influenced by the plant location.
Renewable power	Power costs are the major cost component for the renewable ammonia/hydrogen plant. Contract terms and project duration would have a significant impact on commercial outcomes.
Procurement	Outcomes from the demonstration scale project would impact the procurement process for the commercial scale plant in various ways.

Area	Key considerations
Product mix	The proportion of ammonia and hydrogen produced for commercial scale would be influenced by market developments in the years leading up to commencement of the commercial scale project.
Domestic distribution	Distribution options need to be optimised based on outcomes from the demonstration study and market developments, prioritising the options that provide highest economic benefit.

5.9 Procurement Options and Project Timelines

The procurement options for a commercial scale facility would build upon the process that has been undertaken for the demonstration scale facility, as outlined in Section 4.7. However, given the size and scale of a commercial scale facility, additional delivery model options should be considered. As with the demonstration scale facility, the intent would be to identify an approach that appropriately balances the project risks and costs to meet the window of opportunity for the emerging hydrogen industry. The delivery model selection criteria would therefore continue to align with this intent while using bp's project objectives as a framework.

6. Context and learnings from bp's international hydrogen and ammonia production portfolio

6.1 Overview of bp's international experience

bp is a large global energy provider with deep experience in delivery of complex, integrated energy projects. This includes significant oil and gas production and refining portfolios as well as a growing low carbon energy portfolio.

As an integrated energy company, bp also has significant experience in managing value and risk in complex energy value chains, with a world class trading organisation and strong relationships with buyers around the globe, including a long history of providing LNG to Asian markets.

Hydrogen has been used as a feedstock in various refining and petrochemical processes within bp's Downstream portfolio for decades, including bp's Kwinana refinery in Australia. Consequently, bp has significant experience in generating and handling hydrogen at industrial scales, both from production within our operations and from third-party supply.

In the early 2000s, bp had a small hydrogen mobility business and built several hydrogen refuelling stations in Europe, North America and China. bp also developed low carbon power from hydrogen opportunities, including establishing a joint venture with Rio Tinto (called Hydrogen Energy). bp was also involved in the Perth hydrogen fuel cell bus trial - providing in-kind support for the hydrogen supply chain and refuelling infrastructure.[43]

bp, with its partner SSE, developed the DF1 project at Peterhead, UK, which completed pre-FEED and FEED and received planning permission from the Scottish Executive for a nominal 475MW facility in 2007. The proposed project design was to convert natural gas into hydrogen and carbon dioxide, the hydrogen was to fuel a new combined cycle gas turbine plant and the captured 1.8 million tonnes of carbon dioxide to be utilised for EOR (enhanced oil recovery) in an offshore oil field.

Other similar projects were developed by Hydrogen Energy, notably the HECA (Hydrogen Energy California) project and HPAD project in Abu Dhabi. HPAD (Hydrogen Power Abu Dhabi) was developed by Hydrogen Energy and Masdar (Abu Dhabi Future Energy Company) and involved pre-combustion capture technology converting natural gas to hydrogen to fuel a new CCGT and utilise the 1.7million tonnes of captured carbon dioxide for EOR. FEED was completed in 2009 for the nominal 400MW plant. The project did not proceed beyond this point due to changing business priorities. HECA was originally developed by Hydrogen Energy as a petcoke and coal fuelled integrated gasification combined cycle project (IGCC) producing hydrogen for fuelling a CCGT and capturing carbon dioxide for EOR. Pre-FEED was completed by Hydrogen Energy, but due to changing business priorities it was sold to SCS Energy in 2011.

More recently, bp has announced activity in several new clean hydrogen projects:

[43] Eltis, Perth Hydrogen Fuel Cell Bus Trial, Accessed 4 December 2020 from: https://www.eltis.org/discover/case-studies/perth-hydrogen-fuel-cell-bus-trial

- Lingen Green Hydrogen – bp is working with Orsted to develop a renewable hydrogen production facility at the Lingen Refinery in NW Germany.
- H2Fifty – bp is working with Nouryon on a feasibility study for a 250 MW electrolyser in Rotterdam, Netherlands.
- H-vision – a partnership to assess feasibility of developing blue hydrogen production from fuel gas supplied by local refineries in the Rotterdam area, including bp Rotterdam Refinery, with CO_2 captured and stored as part of the Porthos carbon sequestration scheme.
- Get H2 Nukleus – a partnership to develop a 130 km hydrogen pipeline in northwest Germany linking two bp refineries (Lingen and Gelsenkirchen) and other industrial producers and users.

bp also has some previous experience of handling and producing ammonia, including operating an ammonia production facility at the Saltend petrochemical site (UK) on behalf of Yara (transferred to new ownership in late 2020), and a nitriles production facility at Lima, Ohio (US) (sold in 2004).

In addition to direct experience of production and handling of hydrogen and ammonia, bp has experience of working with partners to develop and operate carbon capture, utilisation and storage (CCUS) projects, including CO_2 injection at the In Salah gas production facility in Algeria (operational between 2004 and 2011, storing 3.8Mt of CO_2) and, more recently, through the development of the Net Zero Teesside carbon capture and storage project in the UK. CCUS will be a critical technology for the development of blue hydrogen production.

6.2 Outline of public information regarding bp's views on hydrogen sector

As a zero-carbon energy carrier, bp views hydrogen as key to deep decarbonisation of the global energy system, particularly for so-called 'hard-to-abate' sectors which cannot easily be electrified (e.g. heavy transport, industrial heat, and thermal power generation).

bp expects significant growth in the clean hydrogen market and, according to the bp 2020 Energy Outlook, hydrogen could account for as much as 16% of total final energy demand by 2050 (in the 'Net Zero' scenario). Hydrogen has a particular advantage in industry as a source of energy for high-temperature processes, such as those used in the steel, cement, refining and petrochemicals sectors. Use in transport is likely to be concentrated in long-distance transportation, particularly heavy-duty trucks. Hydrogen or hydrogen-derived fuels (e.g. ammonia, syn-fuels) are also strong candidates to decarbonise marine and aviation transport sectors.

bp expects growth in hydrogen supply to be dominated by green and blue hydrogen, with the precise mix in a given region dependent on local conditions. Under the Net Zero scenario in the bp 2020 Energy Outlook, blue and green hydrogen account for all hydrogen production in 2050 in broadly equal amounts.

6.3 Analysis of the competitive advantages in key jurisdictions

As part of bp's new strategy it aims to grow its hydrogen business to a 10% share of core markets by 2030, with an aim to build positions in both green and blue hydrogen in the US, UK, Europe, China and Australia.

In Europe there has been strong growth in political support for hydrogen and the role it can play in European decarbonisation. This has been evidenced by the launch of the EU hydrogen strategy as well as several other national hydrogen strategies (e.g. Germany, France, Portugal, Spain), with several billion Euros of support announced. Many parts of Europe are well placed to produce hydrogen. In Northwest Europe, the North Sea basin provides access to large-scale CO_2 storage for blue hydrogen production and large, high-quality offshore wind resource for green hydrogen production. Similarly, Southern Europe benefits from strong solar resource for green hydrogen production.

In the US, access to low-cost natural gas and the availability of CO_2 storage, supported by strong policy at the federal level for CCS technologies (e.g. 45Q), should enable blue hydrogen production. In addition, certain states have strong policy incentives, particularly around transport, such as the Low Carbon Fuels Standard in California, which provide support for use of hydrogen as a transport fuel.

Australia has large and advantaged renewable energy resources (with particularly high-capacity factors enabled by the combination of wind and solar) providing strong potential for large-scale green hydrogen production. In addition, strong government support for hydrogen has been demonstrated through a national hydrogen strategy and funding support for early studies, e.g. through ARENA. Historical ties to Asian economies which are now looking to import hydrogen at large scale present a unique opportunity to develop the hydrogen industry for the large-scale export of hydrogen, or hydrogen-derived products (e.g. ammonia).

6.4 Comparison of key price drivers and differentiators between key jurisdictions

The cost of green hydrogen production is particularly sensitive to the cost of electricity. The long-term success of green hydrogen will, in large part, be driven by falling costs of renewable power. The capital cost of electrolysers and costly distribution channels are other barriers to cost-competitive green hydrogen production, but this is forecast to fall rapidly as production capacity is scaled through automation, supply chain optimisation and economies of scale. Consequently, the share of the overall levelized cost of green hydrogen (LCOH) attributed to the cost of electrolysers is expected to reduce.

There are certain risks associated with the development of large-scale hydrogen plants, particularly related to verifying and testing the technology at a scale that has not been built before (more than 100ktpa of hydrogen), and the operational safety and risks associated with transportation and storage.

For green hydrogen, certain geographies (e.g. Western Australia, North Africa, Middle East) have access to advantaged renewables, with complementary wind and solar generation providing very high-capacity factors, driving down the levelized cost of hydrogen production.

Gas price and availability and cost of CO_2 transport and storage will drive the economics of blue hydrogen production, with the US and Middle East well placed. Gas reforming and syngas CO_2 technology are mature and so the initial market development will largely be driven by timely access to CO_2 transport and storage infrastructure.

6.5 The end use of hydrogen and ammonia in key jurisdictions

As well as existing feedstock markets, demand for hydrogen as an energy carrier is expected to rise in heavy duty transport, high-temperature industrial heat, domestic space heating in buildings, and thermal power generation. Similarly, demand for ammonia as a chemical feedstock may be supplemented by additional demand for ammonia as a fuel, e.g. for long-distance deep-sea shipping, or in power generation in some regions.

Strong decarbonisation policies in Europe are promoting hydrogen use across the energy system, although it is expected that large-scale demand for clean hydrogen will also come from feedstock uses promoted by national implementations of the EU's Renewable Energy Directive II (RED2), e.g. to lower the carbon intensity of refined products. Likewise, clean hydrogen use as a transport fuel has strong policy support in some European nations and it is expected that this will drive development of hydrogen-fuelled heavy-duty trucking over the next decade. There are also a number of early-stage projects investigating the use of hydrogen (or blends with natural gas) in industrial and domestic heating and power generation, although strong governmental support will be required.

In the US, policy measures such as the Low Carbon Fuels Standard in California are promoting hydrogen use in transport, and it is expected that this will continue with a shift towards heavy-duty trucking. Other potential clean hydrogen demand sectors are less advanced than Europe, but in time it is expected that demand in heating (industrial and domestic), as well as power and feedstock, will follow.

In East Asia, hydrogen demand is largely focused on transport, including fuel cell passenger cars, buses and commercial vehicles, with a growing interest in power generation. Demand for ammonia as a fuel is also expected to grow in this region, particularly in Japan where initial demand for blending with coal for power generation is expected to grow, and in time may develop into ammonia-fuelled combined cycle gas turbine power generation. East Asian markets are also likely to be amongst the first to demonstrate use of ammonia as a marine fuel.

6.6 International observations in safety considerations

One of bp's core values is safety, so this is a key consideration in the production, distribution and use of both hydrogen and ammonia.

Hydrogen has a wide flammable range in air which can lead to risk of fire and explosion. Ammonia is highly toxic and corrosive, and so both require careful handling. Nevertheless, hydrogen and ammonia production are mature industries – ammonia having been commercially manufactured for over 100 years. Within bp's own refining and petrochemical portfolio, hydrogen, and to a lesser extent ammonia, have been managed safely for decades.

When moving to production of clean hydrogen, additional safety considerations must be taken into account. Blue hydrogen requires the addition of carbon capture and storage technology which, although the technology is not new, has not been deployed widely at scale for these applications. Specific considerations must be made for CO_2 handling (drying, compression and transmission), including the handling of supercritical fluid and the potential for asphyxiation if released at high concentrations into the environment.

While the technology for green hydrogen production has existed in some cases for many decades (e.g. alkaline electrolysis), the level of deployment is comparatively low, with relatively small electrolyser production capacities. Many of the companies now seeking to install electrolysers, including engineering contractors and potential operators, have limited experience of the technology. The original equipment manufacturers, while in some cases benefiting from decades of small-scale manufacturing experience, tend to have limited experience of engineering, procurement and construction (EPC), particularly for large-scale installations. Their experience to date tends to have focused on small scale, containerised or skid-mounted solutions. In addition, these companies typically do not have experience of the safety practices and culture of the oil and gas industry. These observations combine to make safety a key concern for the design and execution of early projects.

Significant work is already underway through industry, standards bodies and regulators to assess risks and set standards for green hydrogen production. bp is participating in a range of forums including the Hydrogen Council, Hydrogen Europe and the Australian Hydrogen Council. Key areas which bp believes need attention are:

- Ensuring strong industry process safety capability across the green hydrogen industry.
- Development of standard tools and assumptions for consequence modelling of compressed and liquid hydrogen.
- Staying current with international standards – the Australian approach of mirroring ISO standards should lead to greater consistency between regions.

6.7 International observations on community and stakeholder management

bp is an active member of a number of associations promoting hydrogen around the world including the Hydrogen Council (90+ member companies), Hydrogen Europe and the UK Hydrogen Taskforce. Through these organisations, bp has supported the publication of recent studies to help raise the profile of hydrogen among industry, governments, investors and the general public, including the recent Hydrogen Council *'Path to Hydrogen Competitiveness'* study and the Hydrogen Taskforce's *'The Role of Hydrogen in Delivering Net Zero'* report.

Recent studies suggest public awareness of hydrogen and ammonia is low, which raises the importance of public relations activities such as the Hydrogen Council's CLIMATE CH_2AMPION campaign, seeking to highlight the need for a global energy transition with hydrogen at the core. It is anticipated that public acceptance will be maintained as the industries scale further, so long as a strong safety record continues to be achieved.

6.8 Other key international observations and learnings

The IEA's recent 2020 Hydrogen Tracking report highlights that, while deployment of hydrogen technologies maintained strong momentum in 2019, deployment is still off-track for the Sustainable Development Scenario (the IEA's reference scenario aligned with the Paris Agreement). This highlights the challenging nature of the required scale-up for hydrogen and ammonia technologies to meet climate goals.

Growing global support for hydrogen as a key pillar for the energy transition and, notably, the policy settings recently announced by some governments, particularly in Europe, give reason for optimism that hydrogen's potential can be realised. Governments will continue to have a central role to play in developing the right policies and regulations to allow hydrogen technologies to reach full potential. The timely development of such measures will unlock private sector investment to build both supply and demand, and as the industry scales, costs will reduce, making clean hydrogen (and ammonia) increasingly competitive.

bp believes partnerships will be a vital ingredient for the successful scale-up of the hydrogen economy and stands ready to partner with industry, government and investors to realise hydrogen's role in helping the world reach net zero.

7. Major challenges & key learnings gained from undertaking the Feasibility Study

7.1 Major challenges

This feasibility study has unearthed a few clear and critical challenges in producing a successful large-scale, green hydrogen investment.

7.1.1 Obtaining off-take agreements

The key challenge is to obtain anchor customer contracts at an acceptable price point. Further firming the pricing assumptions with off-takers is the next step to refine the economic case of a large-scale green hydrogen investment. For the purposes of this feasibility study, we ran multiple pricing scenarios.

7.1.2 Enabling infrastructure readiness

At demonstration scale, infrastructure investment in the existing transmission network would be required, as the current system is unable to support load requirements. Grid reliability concerns also remain.

Significant transmission infrastructure upgrades would be required for the commercial scale plant. In addition, optimising renewable power generation against plant utilisation would be key in managing costs.

Export port locations considered for the commercial scale plant currently do not have facilities suitable for bulk liquid ammonia export operations and would require significant upgrades to accommodate export.

7.2 Key learnings

7.2.1 Location

Geraldton was seen as the ideal location for the project due to its proximity to the Port of Geraldton for exports, and access to key domestic markets. As detailed in Section 4.2.5.2, several factors affect the current suitability of the Port of Geraldton as an export option. As such, Fremantle Port has been determined to be the viable shipping export location for the demonstration scale study.

7.2.2 Partnerships

Tapping into the future hydrogen market requires reciprocal commitments between customers, investors and technology partners. The current barrier to entry and impediment to lower costs of production for renewable hydrogen are a “chicken and egg” problem of production capacity investment and market commitment.

7.2.3 Power Price

Depending on scale, power is either the highest or second highest contributor to costs. Optimisation of capacity factor, utilisation and PPA pricing is essential. The most important optimisation lever in a project such as Project GERI is between PPA, generation profiles and electrolyser utilisation profiles.

7.2.4 Pathway to scale

Project economics become much more favourable at large commercial scales (i.e. circa 1,000ktpa – the size of the commercial scale facility). Electrolyser vendors are just beginning to scale up production.

8. Conclusion and Recommendations

There are a multitude of positive forces that could lead to green hydrogen and ammonia becoming significant fuels within many sectors in Australia and internationally. It is clear this would be of great benefit to Australia and, with bipartisan Australian political endorsement and a set of influential industry players motivated to support this transition, there is a window of opportunity to capitalise.

The issue of how to overcome relatively high costs and the need to scale to reduce costs is arguably the largest issue for renewable hydrogen.

Government support will be key for the development of the hydrogen industry and the path forward for this project. The key areas where government support and funding are vital are:

- Ensuring reliability of power supply for the demonstration scale plant: current power network requires upgrades to take on the additional load from the demonstration scale facility.
- Transmission upgrades for the commercial scale plant: load requirements for the commercial scale would necessitate transmission upgrades including new power lines and a substation.
- Port development for the commercial scale plant: either port location considered for the facility would require substantial investment to allow for large scale export of bulk hazardous liquids.
- Supportive tax structures: Tax structures that support the development of the hydrogen industry and ensure continued investment until the industry matures will be key to unlocking Australia's hydrogen potential.
- Prioritised approval pathways: Accelerating timelines for approvals would increase confidence to invest so early movers can ensure speed to market.
- Government decarbonisation incentives: Incentives to decarbonise such as a carbon price and/or clean fuel subsidies, and requirements for hydrogen blending into gas networks, could play a pivotal role in early widespread adoption of clean fuels such as hydrogen.
- Continued investment in hydrogen R&D: Investment in R&D on emerging hydrogen technologies would hasten progress down the cost curve.

Insights gained from a demonstration scale project could inform decisions (ranging from procurement to product mix) for a commercial scale project through demonstration scale testing of different technologies and optimisation of cost/performance. In effect, maintaining a mix of technology and vendors at demonstration scale is necessary to hedge risk in moving to scale.

For the commercial scale plant, the three main levers for substantially reducing the LCOH (at gate) from the demonstration base case to the commercial scale base case are scale (increasing output from 20ktpa to 1mtpa ammonia), reduction in electrolyser capex costs due to learning factors, and reduction in electricity PPA prices.

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GHD Advisory

Level 10 999 Hay Street
Perth WA 6000 Australia

61 8 6222 8222
permail@ghd.com

Rev.No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	Various	Jason Fonti	[signature]	Andrew Dash	[signature]	26/03/2021