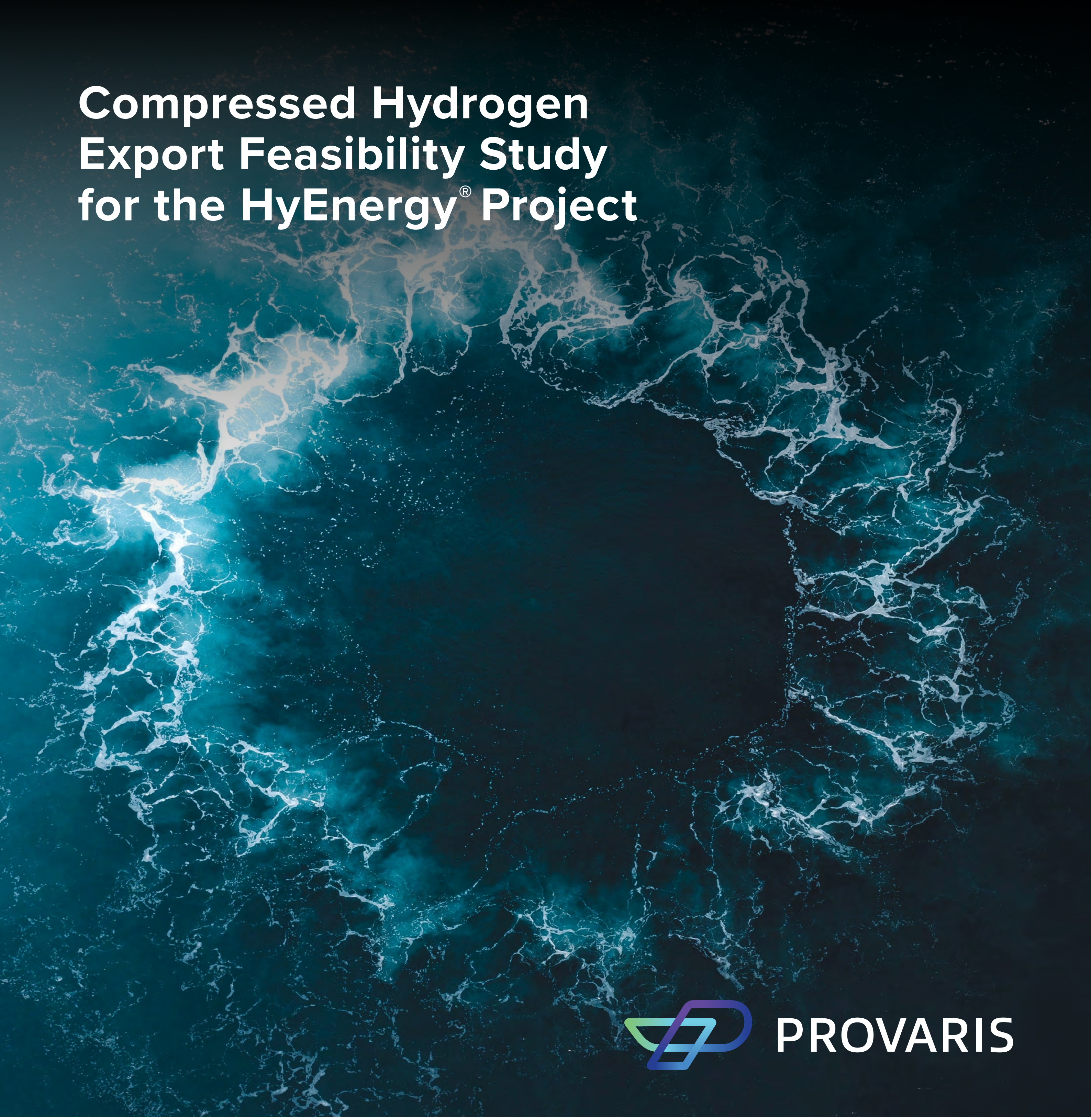
# Compressed Hydrogen Export Feasibility Study for the HyEnergy® Project



PROVARIS

# Knowledge Sharing Report

December 2022

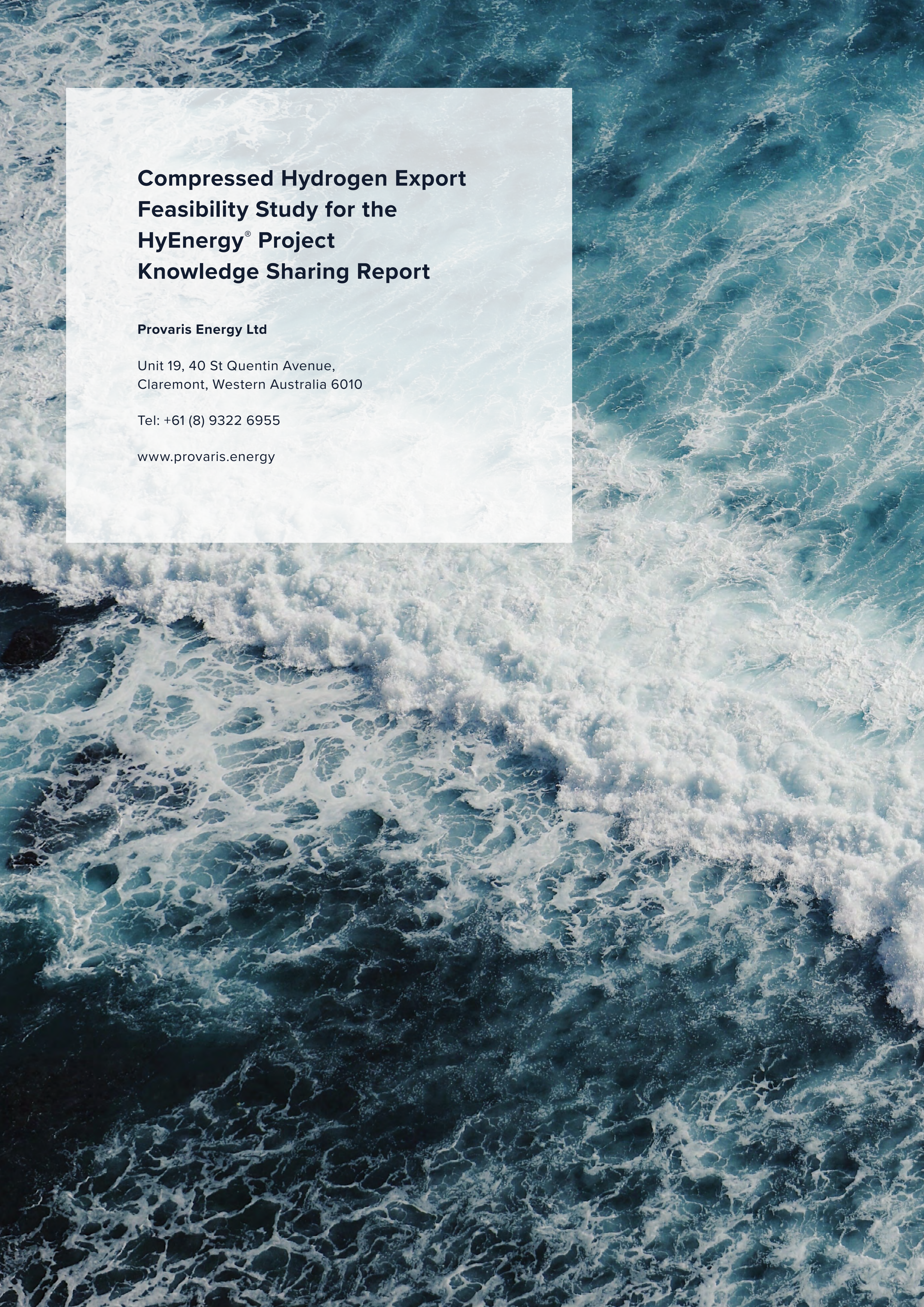
# Compressed Hydrogen Export Feasibility Study for the HyEnergy® Project Knowledge Sharing Report

**Provaris Energy Ltd**

Unit 19, 40 St Quentin Avenue,
Claremont, Western Australia 6010

Tel: +61 (8) 9322 6955

www.provaris.energy



# Contents

# Acknowledgement of Grant Funding

The feasibility study (Study) received grant funding from the Western Australian Government's Renewable Hydrogen Fund, which is administered by the Department of Jobs, Tourism, Science and Innovation (the Department).

Department of Jobs, Tourism, Science and Innovation
GOVERNMENT OF WESTERN AUSTRALIA

## Disclaimer

This study may contain forward looking statements concerning projected costs, approval timelines, construction timelines, earnings, revenue, growth, outlook or other matters ("Projections"). You should not place undue reliance on any Projections, which are based only on current expectations and the information available to Provaris. The expectations reflected in such Projections are currently considered by Provaris to be reasonable, but they may be affected by a range of variables that could cause actual results or trends to differ materially, including but not limited to: price and currency fluctuations, the ability to obtain reliable hydrogen supply, the ability to locate markets for hydrogen, fluctuations in energy and hydrogen prices, project site latent conditions, approvals and cost estimates, development progress, operating results, legislative, fiscal and regulatory developments, and economic and financial markets conditions, including availability of financing. Provaris undertakes no obligation to update any Projections for events or circumstances that occur subsequent to the date of this announcement or to keep current any of the information provided, except to the extent required by law. You should consult your own advisors as to legal, tax, financial and related matters and conduct your own investigations, enquiries and analysis concerning any transaction or investment or other decision in relation to Provaris. $ refers to Australian Dollars unless otherwise indicated.

## Study Participants

This Study has been delivered by a consortium of specialist consultants selected by Provaris including:

WSP as study lead responsible for coordinating the work packages and the overarching technical and commercial assessment. Work packages delivered by WSP include the concept design of the onshore compression facilities, shore crossing and subsea pipeline, receiving port market study, cycle time analysis and commercial modelling.

Oropesa to perform a study of the marine site conditions and review of legislative and regulatory requirements to enable the concept design of the offshore loading terminal, shipping route and GH2 carrier loading operations plan.

APL NOV for developing the SAL and BLS technology (interface with the GH2 carrier and subsea pipeline).

Environmental Resources Management (ERM) for environmental management with a focus on defining Project risks, constraints, and approvals pathways.

Turner & Townsend for the job creation assessment for the onshore compression facilities.

Paaras Marine Solutions to develop and cost the unloading marine jetty facilities at the receiving port of Singapore.

GHD for investigating onshore storage options for hydrogen.


PROVARIS
Connecting
the future
of energy

# Executive Summary

The outcomes of this feasibility study (Study) undertaken by Provaris Energy Ltd (Provaris) indicate that a compressed hydrogen export supply chain is a technically and commercially feasible method for exporting green hydrogen from the HyEnergy® Project (HyEnergy) to nominated Asia Pacific markets. HyEnergy is a proposed green hydrogen production project codeveloped by Province Resources and Total Eren (together the 'Project Proponents'), located in Western Australia's Gascoyne Region, near the town of Carnarvon and is proposing to develop a wind and solar farm with a renewable energy capacity of 8 GW over a land area in excess of 350,000 ha.

Provaris is the leading developer of integrated compressed hydrogen projects for export to regional markets, leveraging its innovative and proprietary compressed hydrogen shipping solution that allows for a marine supply chain that is simple, efficient, and cost competititive with alternative carriers of hydrogen converted to a liquid or chemical state for transport. Compression is already proven as a safe and reliable method of storing and transporting hydrogen upstream and downstream of marine shipping and can accelerate the development of greenfield hydrogen export projects with minimal technical barriers, smaller environmental footprints, and the only flexible, marine shipping vector able to cater for variable renewable energy production profiles.

The Study analysed the compression and export of 200,000 tonnes per annum of green hydrogen from HyEnergy's hydrogen production facility to Singapore, and includes: compression facilities, an outgoing pipeline to an offshore loading terminal, a fleet of Provaris' proprietary compressed gaseous hydrogen 26,000 m3 GH2 Carriers (H2Neo) and an import terminal in Singapore. The scope of the Study excludes the renewable generation, transmission, electrolysis and production of green hydrogen.

The Study incorporates engineering solutions provided by world leading energy technology developers. Hydrogen produced by the HyEnergy facility will flow into a series of reciprocating compressors. The compressor plant is laid out to be highly flexible in order to allow for a variable rate of compression. The selection of an offshore loading terminal was predicated on the water levels within Shark Bay being relatively shallow and variable up to 10 km off the coastline, presenting construction and environmental challenges for nearshore terminal alternatives.

The offshore loading terminal will utilise a Single Anchor Loading (SAL) system designed by APL NOV, who has delivered and commissioned similar technologies to the offshore oil and gas industry for over 30 years. The proprietary system provides high operability limits, allowing connection and loading to take place at a significant wave height of 3.5 m. Coupled with the inclusion of the dependable bow loading system, the GH2 carrier loading operations are efficient and suitable for the Study area in Shark Bay (Note: Study area is at the north end of Shark Bay and not within the UNESCO site). The mooring and riser assembly and pipeline end manifold is located subsea, reducing the risk of collision with vessels and has low visual and environmental impact.

Discrete event simulation modelling has been undertaken to identify potential risks and opportunities to the compressed hydrogen supply chain. The modelling tested a number of scenarios integral to the compressed hydrogen supply chain including equipment failure probabilities, planned and unexpected maintenance and variability in H2Neo carrier transit speed due to metocean conditions.

Analysis of Singapore's existing receiving port facilities indicates Jurong Island as a suitable location to unload hydrogen. Jurong Island is the largest energy precinct in Singapore with a number of potential offtakers. The unloading terminal is envisaged to consist of two island berths in a linear arrangement with supporting unloading terminal equipment and infrastructure to enable compressed hydrogen transfer to the end customers and future grid infrastructure.

An early job creation assessment indicates the construction of the onshore compression facilities alone will create a peak 615 direct full time equivalent (FTE) jobs over a 34-month execution plan, while the operation of the onshore compression facilities is expected to support 14 FTE jobs, excluding any additional indirect and induced employment opportunities developed. The construction and operation of pipelines, offshore loading terminal and supporting facilities will further add to the job creation, and will be more closely analysed in future studies.

A high-level analysis has indicated the green hydrogen delivered into Singapore from the Project can lead to a net reduction in carbon emissions of 1,022,047 tCO2/year, assuming a 50-50% use to displace grey hydrogen used for industry and fossil fuels used for power generation of data centres.

Modelling concluded that a fleet of Provaris' H2Neo carriers with storage capacity of 430 tonnes resulted in 98% of the target annual hydrogen throughput delivered (with some losses due to cyclonic events), and reinforces the reliability of an integrated compressed hydrogen export supply chain solution.

The CAPEX of the onshore compression facilities, pipeline, loading terminal and fleet of H2Neo carriers is circa USD 2.5 Billion. Cost estimates developed from the technical workstreams were fed into a commercial model to evaluate the levelised cost of hydrogen (LCOH). **The modelling indicates the LCOH for compression, pipeline, loading and unloading terminal and fleet of carriers delivered to Singapore is USD 2.48 per kg.** Compressed hydrogen export operations are assumed to last 25 years and be extended to suit the design life of the Study or the growing demand for green hydrogen imports.

Further design, development and optimisations are expected to reduce the CAPEX and LCOH as the Study is further integrated with the upstream feasibility of the HyEnergy project, including utilising a fleet of Provaris' larger capacity H2Max carriers at 120,000 m3 tonnes capacity (or 2,000 tonnes) which can deliver scale benefits at this annualised volume of export and shipping distance.

An initial hazard identification and environmental impact identification assessment was undertaken and indicates there are no significant constraints that should prevent the use of an offshore terminal with compressed hydrogen from progressing into further stages of design and development. One outcome of the Study was the design of a safe and effective solution for loading compressed hydrogen at two loading berths; ensuring upstream production of hydrogen can be continuous and according to availability of renewable energy, except during cyclonic events. Further works to progress this Study generally include stakeholder engagement, approvals, pre-FEED/FEED studies, investigations and hydrogen technology development.

# 1. Introduction

## 1.1 HyEnergy Project

The HyEnergy® Project (HyEnergy) is a proposed green hydrogen production project codeveloped by Province Resources and Total Eren (together the Project Proponents), and is located in Western Australia's Gascoyne Region, Carnarvon. HyEnergy involves installing a wind and solar farm with a proposed renewable energy capacity of at least 8 GW over a land area in excess of 350,000 ha.

Carnarvon presents as a strong opportunity due to the abundant supply of renewable energy resources and its proximity to key infrastructure including natural gas pipelines and highways to enable the supply of hydrogen to domestic and international markets.

HyEnergy is envisaged to be developed as a 5.2 GW electrolyser facility, producing up to 550,000 tpa of green hydrogen in total, with the project to contribute significantly on a domestic and global scale by:

- Developing renewable energy sources to meet the growing global demand and to achieve decarbonisation goals
- Unlocking new domestic and international export markets
- Attracting investment opportunities
- Creating new jobs
- Helping to achieve the Western Australian Government's goal of 10% green hydrogen in the Dampier Bunbury Natural Gas Pipeline (DBNGP) by 2030

## 1.2 HyEnergy Project Status

HyEnergy is currently in a detailed planning phase and is due to submit an environmental impact statement (EIS) and application for development planning approval.

Engineering design of the renewable power generation and electrolyser facilities has not been completed at the time of completing this Study.

The Project proponents are also yet to select the ultimate hydrogen end product(s) or carrier mediums for HyEnergy and anticipate this decision will be made later in the development process.

In August 2021, the Project Proponents entered into a Memorandum of Understanding with Provaris Energy Ltd (Provaris, at the time known as Global Energy Ventures) to undertake a Study to evaluate the technical and commercial feasibility of exporting hydrogen from HyEnergy, utilising a fleet of Provaris' compressed gaseous hydrogen export solution, which includes a fleet of proprietary H2Neo carriers (refer to Figure 1.2 for context). In September 2021, the Western Australian Renewable Hydrogen Fund provided funding to Provaris to support this compressed hydrogen export Study.

Compression is a simple and efficient method for the marine transport of hydrogen and does not require energy intensive or complex processes to convert hydrogen into a liquid or chemical state. Compression is already proven as a safe and reliable method of storing and transporting hydrogen upstream and downstream of marine shipping and can accelerate the development of greenfield hydrogen export projects with minimal technical barriers, limited environmental footprint, and ability to be flexible to cater for variable renewable energy production profiles.

Provaris is an early mover in the future of energy, developing integrated green hydrogen projects for export to regional markets through the simplicity and efficiency of compressed hydrogen. In 2020, Provaris developed the world's first large scale GH2 carrier and is now positioned to fast track the marine transport of hydrogen.

In 2021, Provaris received Approval in Principle (AiP) from the American Bureau of Shipping (ABS) for the H2Neo 26,000 m3 (430 tonnes) and H2Max 120,000 m3 (2,000 tonnes) carriers. The mature level of the GH2 carrier design has allowed Provaris to effectively engage with shipbuilders, regulatory authorities (Class and Flag), technical partners and industry stakeholders seeking solutions to ship hydrogen.

The Study broadly includes integration of the HyEnergy's green hydrogen production plant with an onshore compression facility, an offshore loading terminal and the operation of a fleet of H2Neo carriers for marine transport to nominated markets in the Asia Pacific region.

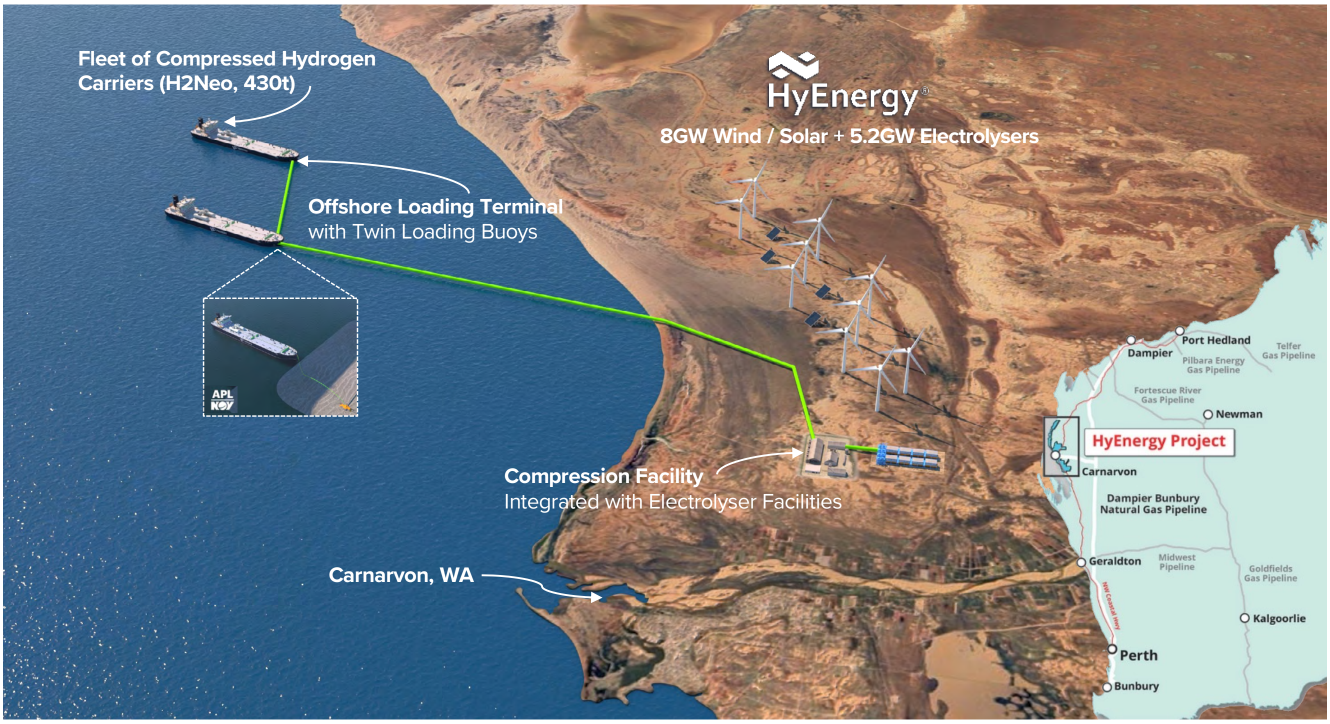



**Figure 1.2**
Project Overview with Compressed Hydrogen Export (Provaris, 2022)
*Illustration of all compression, shore-crossing and loading facilities are generic representations only.*

## 1.3 Study Scope

The Study will explore the export of green hydrogen from HyEnergy utilising Provaris' compressed hydrogen export supply chain. The green hydrogen supply chain utilising a compressed hydrogen export solution is illustrated in Figure 1.3. In summary, it includes compression, offshore loading, a fleet of H2Neo carriers, scavaging compression and onshore unloading jetty.

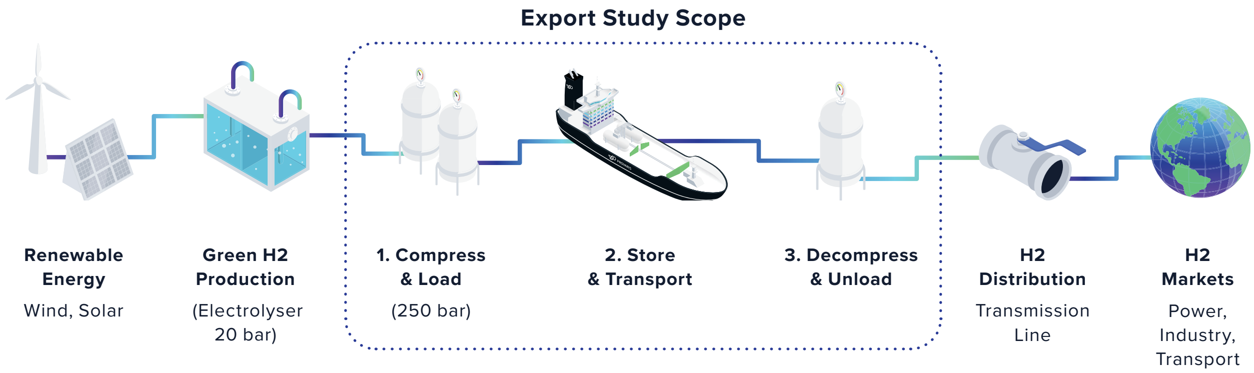



**Figure 1.3**
Compressed Hydrogen Supply Chain

**The scope of the study generally entails the following:**

- Process engineering concept design of the onshore compression facilities (refer to Section 3)
- Market study for onshore storage of hydrogen (refer to Section 3.8)
- Pipeline shore crossing location and subsea pipeline alignment to the offshore loading terminal (refer to Section 5.5)
- Pipeline shore crossing methodology and subsea pipeline concept design (refer to Section 4)
- Offshore loading terminal concept design and shipping route alignment (refer to Section 5)
- Identification of applicable legislative and regulatory requirements (refer to Section 5.6)
- GH2 carrier mooring and loading operations plan (refer to Section 6)
- Single anchor loading (SAL) system and bow loading system (BLS) design (refer to Section 6.1)
- Market and terminal study for high opportunity receiving ports (refer to Section 7)
- Cycle time analysis for hydrogen throughput determination (refer to Section 8)
- Project risk and hazard identification (HAZID) (refer to Section 9)
- Environmental impact identification (ENVID) and constraints assessment (refer to Section 10)
- Job creation assessment for the onshore compression facilities (refer to Section 11)
- CAPEX and OPEX estimation and levelised cost of hydrogen (LCOH) determination (refer to Section 12)

## 1.4 Study Battery Limits

The Study scope commences from the hydrogen outflow from the electrolysers and terminates at the unloading terminal at the receiving port, and is therefore an assessment of hydrogen transportation costs only. This is represented diagrammatically in Figure 1.4.

The Study scope excludes the renewable power generation, electrolyser, seawater intake, desalination, water treatment, brine discharge, electrical switchyard/substations and onward transportation to the end consumer at the receiving port.

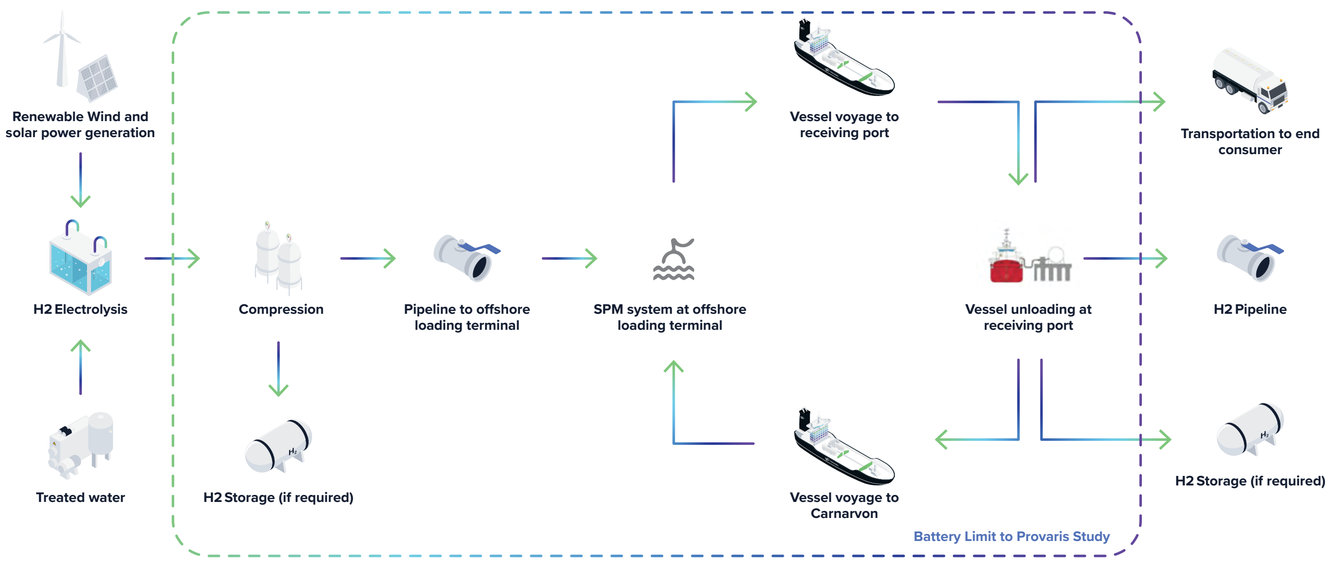



**Figure 1.4**
Study Battery Limits

# 2. Study Basis

## 2.1 Hydrogen Production

At the time of commencing the Study, it was agreed with the Project Proponents to consider a constant rate of hydrogen production. During the next Study phase an optimisation study will be undertaken to consider the impact of the variability (daily and seasonal) in the renewable energy profile in order to optimise the hydrodgen production and exports.

The Study assumes 200,000 tpa of hydrogen will be utilised for GH2 export, out of 550,000 tpa when the Project is at full scale. It is assumed the remaining 350,000 tpa will support another energy export stream. Optimisation of the Study outcomes will be explored in the next phase of the HyEnergy Pre-Feasiblity, including a variable hydrogen production profile to determine the annualised export volume, along with the inclusion of the H2Max carrier in the techno-economic modelling in order to define the economies of scale benefits available with the significantly larger GH2 carrier (approximately 4 times the cargo carrying capacity of H2Neo).

## 2.2 Project Staging

For the purposes of the Study, it is assumed the compressed hydrogen export supply chain will be delivered in a single stage and is assumed to support hydrogen export from the first stage of the HyEnergy Project. This is expected to commence 2029 but is subject to change based on the date of the final investment decision (FID). Provaris has not identified any major risks of an earlier Project start date.

## 2.3 Design Vessel and Class Approvals

Provaris is developing two proprietary gaseous hydrogen carriers, being the H2Neo (430 tonnes / 26,000 m3) and H2Max (2,000 tonnes / 120,000 m3) (refer to Figure 2.2 for key highlights). Both carriers have obtained Approval in Principle (AiP) from the American Bureau of Shipping (ABS).

The Study is based on using a fleet of the H2Neo carriers given it is the most advanced in development, with a target for Approval for Construction before the end of 2022 and first operations in 2026.

The International Maritime Organisation (IMO) addresses gas carriers under the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). This Code only addresses liquefied gases and it does not cover hydrogen as a product, nor does it cover the transport of gaseous hydrogen under pressure. Accordingly, the approval of the ship design and construction must follow the IMO route for Novel Concept approval, and American Bureau of Shipping (ABS) has been selected to support Provaris in this definition.

The novel concept review process applied is summarised through Figure 2.1 below, a review processes that involves increasingly detailed information as the project matures. It provides a general overview showing that as more engineering, testing, and/or risk assessments are conducted, the level of confidence increases as the concept performance approaches the required performance limits.

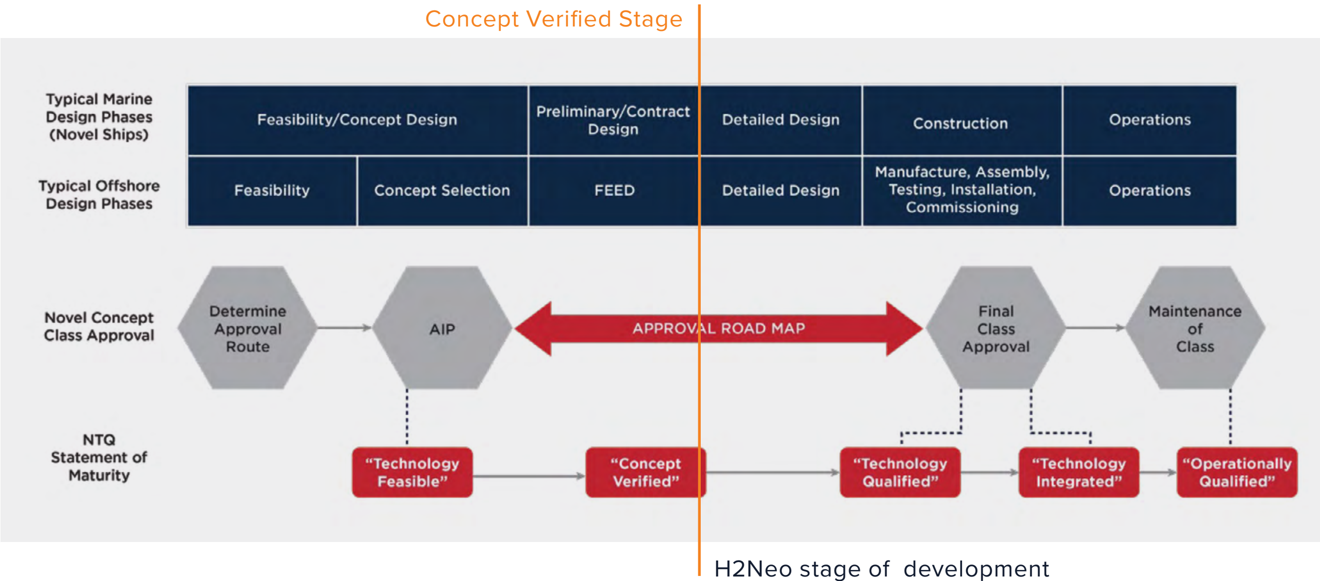
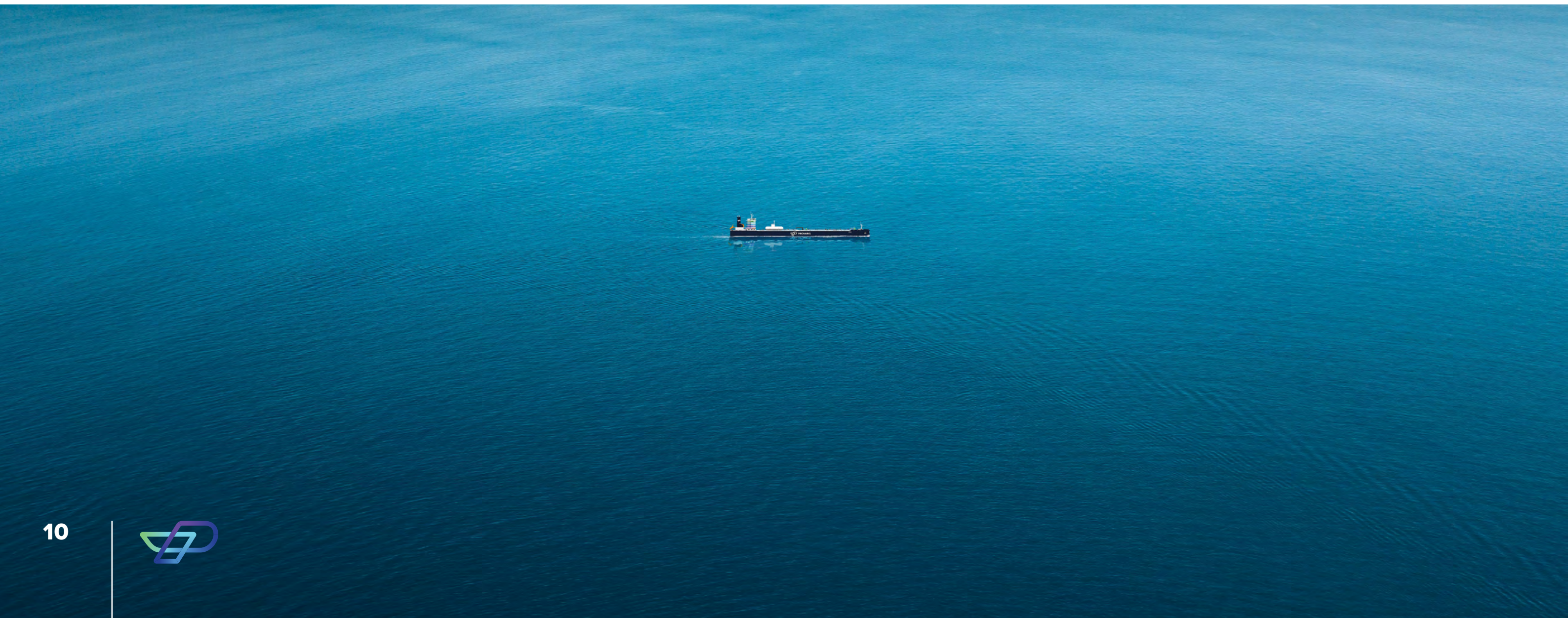



**Figure 2.1**
Novel Concept Review Process

An Approval in Principle (AIP) status was obtained for the H2Max and H2Neo carrier in 2021, providing the project management and external stakeholders the project with confidence that the concept can proceed successfully through the classification process. Subsequent to the AIP submission, Provaris and ABS have continued through the Approval Road Map for the H2Neo GH2 Carrier design, including the development and assessment of an extensive Contract Design Package.

In parallel to the design works, specialist risk studies (HAZID) have been performed and the resultant risk register from the AIP stage has been updated. By year end (2022) Provaris is confident that the H2Neo design will fall within the "Concept Verified" stage. Extensive testing of materials and welds intended for the cargo containment system (the novel technology) is also being performed, including testing in a Special Environments Laboratory (SEL) that allows for custom testing in a pressurized hydrogen environment.



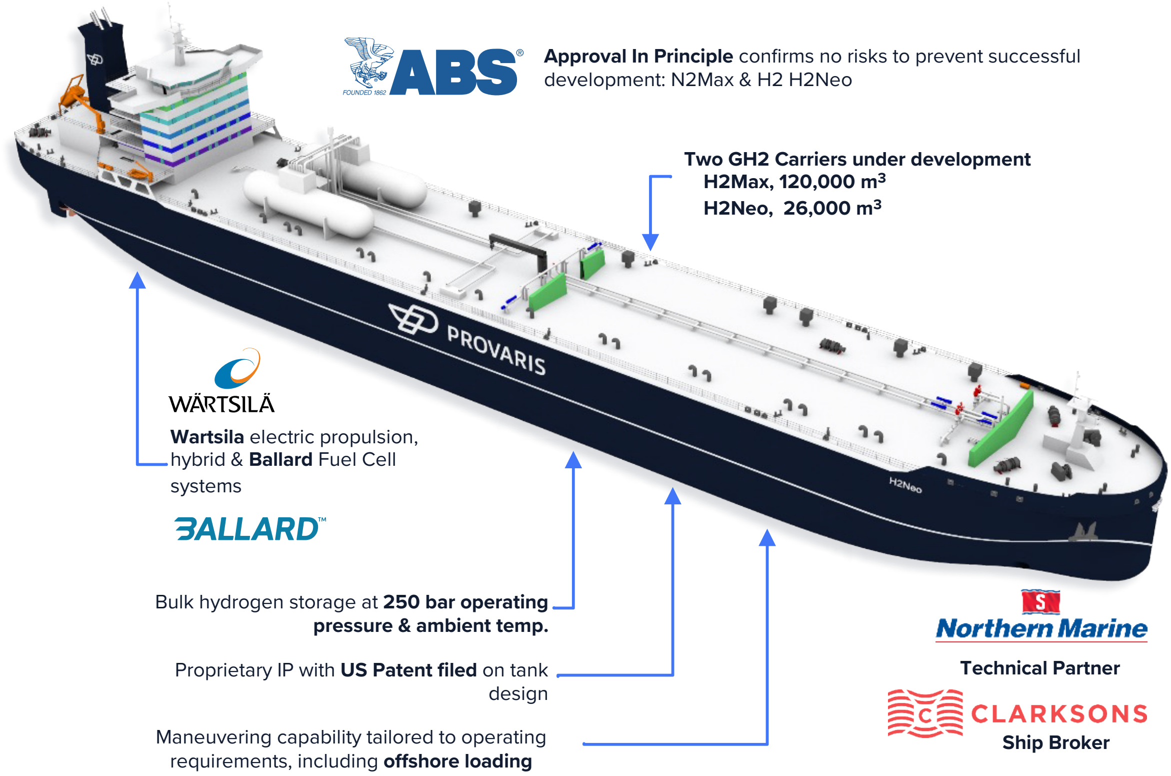



**Figure 2.2**
Provaris GH2 Carrier - H2Neo represented in the illustration.

The basic design for the GH2 Carrier is dual fuel LNG (including biogas and e-methane), however it has been designed with hybrid-electric drive propulsion so that the most favourable prime movers and fuel (subject to speed, power, availability of fuels/bunkers and commercial considerations) can be adopted at the time of signing ship building contracts. In addition to bunkering tanks on deck, the engine room arrangement allows for integrated tanks for liquid fuels such as methanol and bio-fuels. The arrangement of electric propulsion motors and batteries further allows for the installation of fuel cells that can be scaled up to meet the power demands onboard.

This Study assumes hydrogen shipments from the Project will be undertaken using H2Neo. The current principal vessel particulars as of July 2022 are provided in Table 2.1.

| Particular | Units | Value |
|---|---|---|
| Length | m | 213 |
| Breadth | m | 31 |
| Moulded depth | m | 17 |
| Laden draught | m | 8.3 |
| Speed | knots | 15.5 |
| Cargo capacity | tonnes | 430 |

**Table 2.1**
H2Neo Principal Particulars

# 3. Onshore Compression Facilities

**A concept design for the onshore compression facilities has been developed to support loading of compressed hydrogen onto the H2Neo carriers. This encompassed the design of compressors, balance of plant (BOP) and ancillary facilities. Simulations, process flow diagrams (PFD) and electrical load lists were prepared, and vendor quotations were obtained to facilitate the development of the concept design and cost estimate.**

## 3.1 Site Location

The location of the HyEnergy onshore facilities has been proposed in a 12,311 ha lease area known as Town Common (where the Project Proponents hold a Section 91 lease and MoU with the Shire of Carnarvon), a rural location within Carnarvon, Western Australia. The onshore facilities location is shown in Figure 3.1.

The onshore hydrogen production facilities for HyEnergy are expected to consist of the following:

- Electrolyser plant
- Desalination plant
- Water treatment plant
- Switchyard / substations


**Figure 3.1**
Onshore Facilities Location (Google Earth, 2022)

Seawater will be supplied to the onshore facilities via an intake pipeline and be treated (e.g. reverse osmosis, demineralisation, dosing) before pumping into the electrolysers. The electrolysers will use renewable energy to split the water into hydrogen and oxygen.

The onshore compression facilities (designed for this Study) will be collocated and integrated with the electrolyser plant. The onshore facilities will be powered by renewable power, supplied from the upstream renewable power generation facilities via overhead transmission lines.

A 3D concept of the onshore facilities is shown in Figure 3.2.

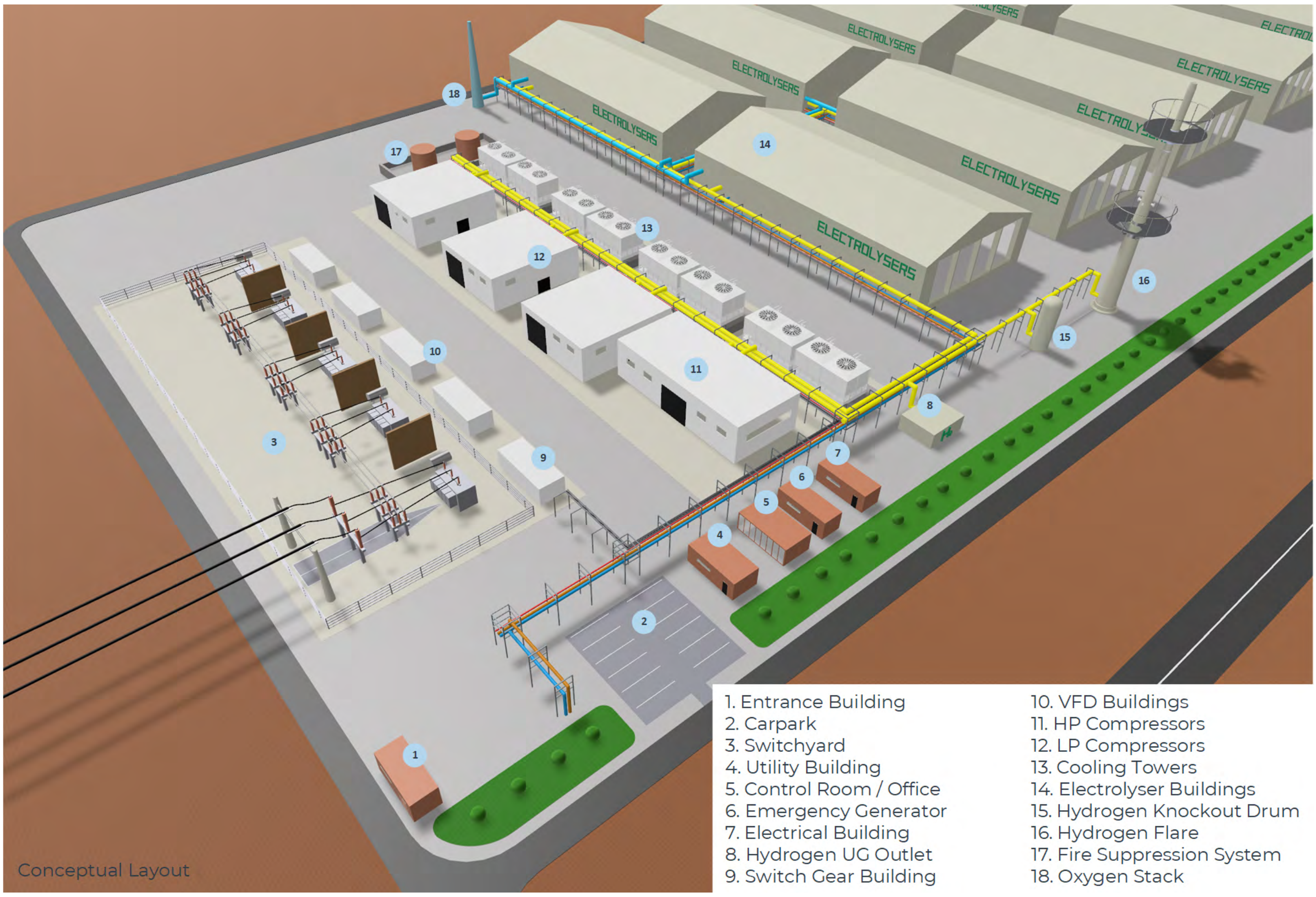



**Figure 3.2**
Simplified representation of the hydrogen production facilities, highlighting the co-location of compression, and not representative of all buildings and infrastructure required (WSP, 2022)

## 3.2 Design Basis

Hydrogen produced from the electrolysers will flow into the compressors on the onshore compression facilities. The onshore compression facilities have been designed to accommodate a nominal hydrogen flow rate of 22.83 tonnes per hour (equivalent to 200,000 tonnes per annum) and can support hydrogen production peaking of 32.65 tph (equivalent to 286,000 tpa). The compressors will raise the hydrogen pressure to 250 bar to load the H2Neo carriers.

The hydrogen supplied from the electrolysers will be a water saturated stream at 20 bar and 50°C. It is assumed that the hydrogen will be treated to remove residual oxygen, nitrogen and argon prior to feeding into the compressors.

## 3.3 Compression Facilities Equipment

### 3.3.1 Hydrogen Compressors

Based on initial compressor simulations it was determined multiple stages of compression would be required to increase the hydrogen pressure to 250 bar. This is required to ensure the discharge temperature is within an acceptable limit. The final discharge pressure is set slightly higher than 250 bar (~258 bar) to account for pressure drop along the outgoing pipeline to the offshore loading terminal where the H2Neo carriers are loaded.

To support the concept design and cost estimation of the onshore compression facilities vendors were engaged to obtain OEM information for compressor designs. A specification detailing the requirements of the compressors was prepared to support the request for information. Vendors were asked to provide compressor designs that would provide operational flexibility required for GH2 carrier loading. Parallel multi-stage units and single stage units in series were potential configuration options to consider.

Baker Hughes, Neuman & Esser, Siemens Energy and NEXT Compression were able to supply quotes for this Study. All vendors supplied reciprocating compressors with varying sized units and configurations to meet the design requirements.

### 3.3.2 Hydrogen Compression Process

The selected compression train consists of 3 × 3 stage LP units in series followed by 3 × 1 stage HP units. To achieve the nominal compression rate of 22.83 tph (200,000 tpa) only two compression trains are required to be operating at a time while the third provides redundancy for maintenance, repairs and production peaking.

The hydrogen discharged after each compression stage will be hot (~140°C) and will be air cooled to 50°C before entering into the next stage of compression. Any water produced from cooling the hydrogen stream is removed by suction scrubbers and is recycled to the water treatment plant for reuse.

Due to the high operating pressure, the HP units at the final stage of compression consists of lubricated cylinders. An oil coalescing filter is provided after the final stage of discharge to remove lube oil from the hydrogen before it is pumped to the outgoing pipeline into the GH2 carrier. The lube oil collected from the oil coalescing filter is sent to the flare system which consist of a flare knockout drum (FKOD) and a flare stack.

The full hydrogen compression process is diagrammatically shown in Figure 3.3.

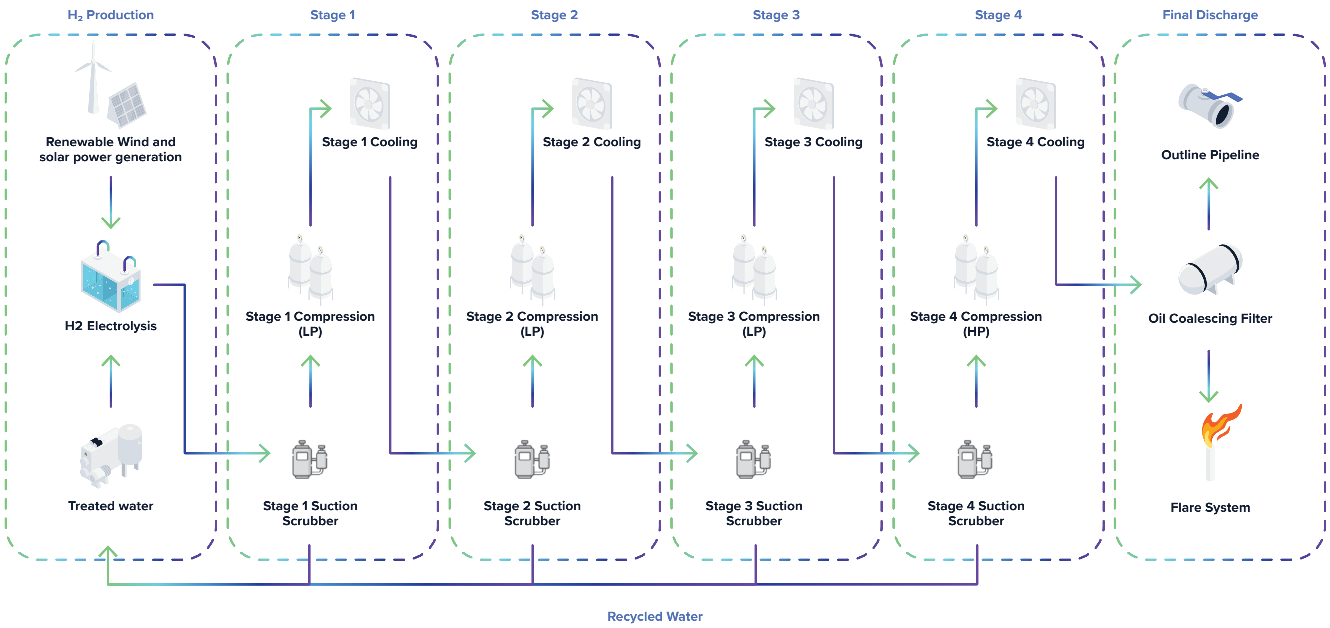



**Figure 3.3**
Hydrogen Compression Process

## 3.4 Electrical Infrastructure

A preliminary electrical load list for the compressor packages and BOP is provided in Table 3.1.

| Item | Combined Motor Load (kW) | Total High Voltage (kW) | Total Medium Voltage (kW) |
|---|---|---|---|
| LP Compressor Package A | 13,598 | 12,900 | 698 |
| LP Compressor Package B | 13,598 | 12,900 | 698 |
| LP Compressor Package C | 13,598 | 12,900 | 698 |
| HP Compressor Package A | 4,108 | 3,650 | 458 |
| HP Compressor Package B | 4,108 | 3,650 | 458 |
| HP Compressor Package C | 4,108 | 3,650 | 458 |
| Instrument Air Compressor Package | 150 | – | 150 |
| Lighting | 250 | – | 250 |
| Electrical Heat Trace / Building Heat | 2,500 | – | 2,500 |
| Miscellaneous | 100 | – | 100 |
| **Total** | | **49,650** | **6,468** |

**Table 3.1**
Electrical Load List Summary

An electrical switchyard is to be provided with power transformers, variable frequency drive (VFD) isolation transformers, station transformers etc. The design assumes a VFD building with a motor control centre (MCC) will be provided for each of the three LP compressors and one for the three HP compressors. The VFDs allow for additional capacity control of the motors to improve operational flexibility of the compressors.

A separate switch gear building and electrical building will be provided for other electrical components at the plant including motors, programable logic controllers (PLC), distributed control systems (DCS), lighting, heat tracing etc.

The installed capacity of the compression facilities is 49,650 kW, plus 6,468 kW of ancillaries (~13% of compressors and BOP). With the compression facilities capable of a design peak flow rate of 32.65 tph, this represents an installed compression factor of 1,719 kW per tph of hydrogen (including ancillaries).

**Installed Compression Capacity:** 1,719 kW per tph of hydrogen

## 3.5 Power Consumption for GH2 Carrier Loading

Under normal operating conditions where the hydrogen feed flow rate is 22.83 tph, only two compressors will be operating. This equates to a peak power consumption of 38,412 kWh.

The power consumption during a typical GH2 carrier loading is 687,279 kW (~18 hours, for 95% capacity of the GH2 carrier, H2Neo). This represents a power consumption of 1.68 kWh per kg of hydrogen loaded.

**Power Consumption:** 1.68 kWh per kg of hydrogen loaded

By comparison, power consumption to liquefy hydrogen is approximately 10-15 kWh per kg of H2.
Source: UNSW, 2021, Carrier Conversion Energy Requirement, pg 75

## 3.6 Ancillary Facilities

A control room/office and general utilities building has been nominally sized for the onshore compression facilities. Instrument air (IA) is required for the onshore compression facilities. An IA package has been nominally provided consisting of 2 × 100 hp compressors. Drain systems will be provided throughout the onshore compression facilities including a drain drum to each compressor building and general-purpose drain tanks for spills and washing operations. A back up generator package has been provided for critical systems including IA and plant lighting.

## 3.7 Site Layout

A plot plan of the overall onshore compression facilities is provided in Figure 3.4. The total footprint of the compressor buildings, discharge coolers, VFD and switchgear buildings, ancillary buildings, piperack and flare system is ~2.6 ha. Note the electrolyser facilities are not drawn to scale and may be in the order of 10 ha (excluding BOP and ancillaries). The purpose of showing the electrolyser facilities is to illustrate it will be located adjacent to the compression facilities.

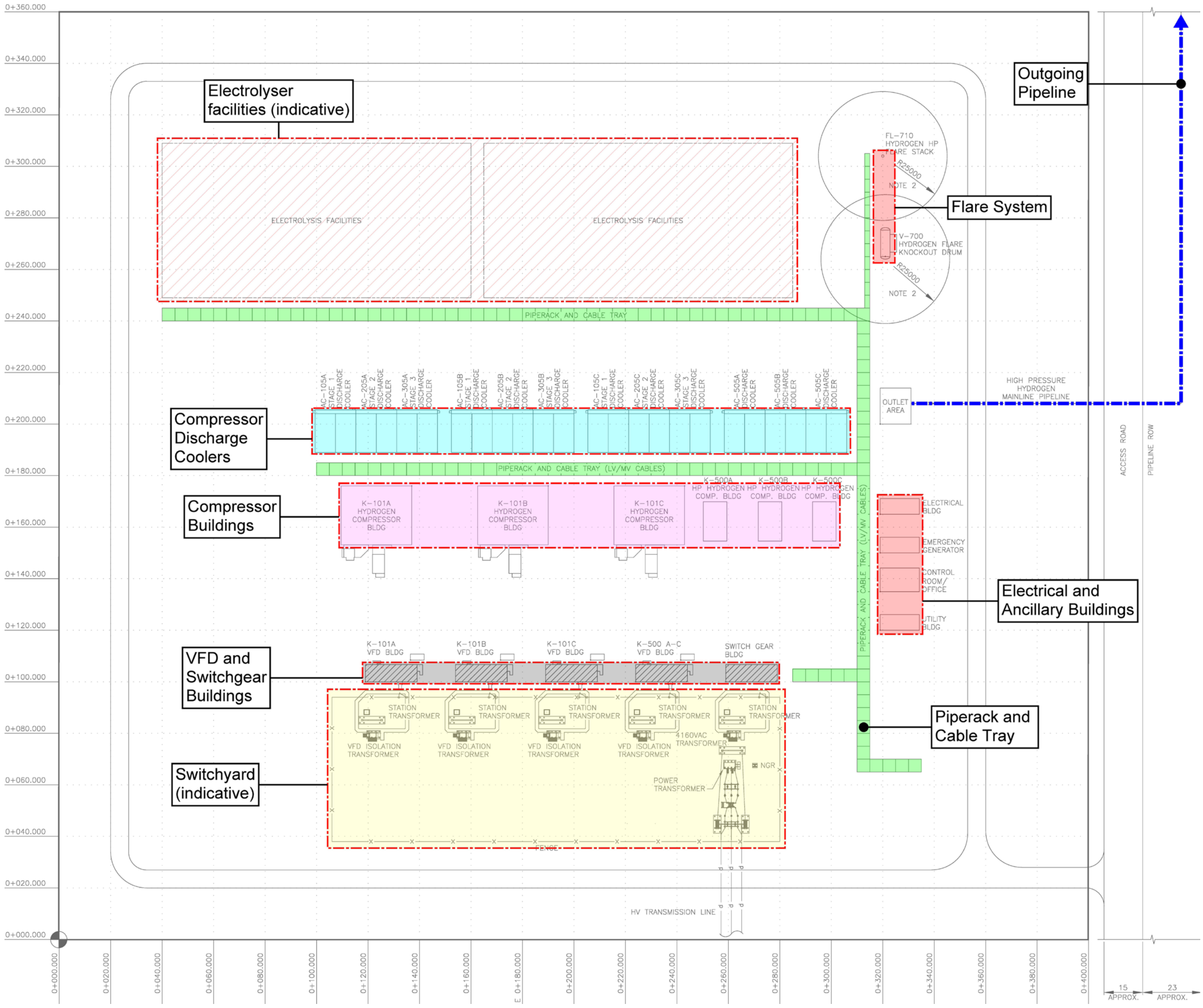



**Figure 3.4**
Plot Plan of Onshore Compression Facilities, illustrative only for the Study and not representative of the HyEnergy project design (WSP, 2022)

## 3.8 Hydrogen Storage

A desktop study has been undertaken to review various onshore hydrogen storage options including containerised tube matrices with carbon steel pressure vessels and large-scale static storage vessels. A nominal hydrogen storage capacity of 5 tonnes was used for a cost benchmarking exercise.

Hydrogen storage could be used intermittently if there is no loading of GH2 carriers while hydrogen is being produced and compressed. This may be due to factors including adverse weather conditions or repairs to infrastructure downstream of the compressors e.g. outgoing pipeline, equipment at the offshore loading terminal. The stored hydrogen would eventually be loaded onto the GH2 carriers.

Due to the cost and scale of available storage solutions, the Study concluded that onshore storage could only optimise the cycle time and throughput when installed at significant scale (i.e. hundreds of tonnes). Therefore for this application it was deemed to be cost prohibitive, based on the cycle time analysis found in Section 8. For this reason, the use of onshore storage has been excluded from the Study, however this proposition is to be reviewed by the Project Proponents during the HyEnergy feasibility.

### 3.8.1 Containerised Cylinders

Vendors were engaged to provide quotes for containerised cylinders. A summary of the quotes on an equivalent 5 tonne storage basis is provided in Table 3.2.

| Option | Price (AUD) |
|---|---|
| 20’ ISO storage, 450 barg, 330 kg | $12.6M (3-year lease term) |
| 40’ ISO storage, 300 barg, 835 kg | $7.3M |
| 20’ ISO storage, 300 barg, 395 kg | $7.15M |
| 10’ ISO storage, 300 barg, 175 kg | $7.25M |

**Table 3.2**
Containerised Cylinders for Hydrogen Storage

### 3.8.2 Large Scale Pressure Vessels

An Australian pressure vessel fabricator was engaged for high-level feasibility review of a type 1 full metal hydrogen storage vessel. The size of a hydrogen pressure vessel with a storage capacity of circa 5 tonnes would be in the order of 5 m ID × 26 m s/s. A hydrogen pressure vessel of this size would involve overcoming engineering, construction and transportation challenges. Key design considerations include:

- Hydrogen embrittlement
- Material selection
- Welding procedures
- Stress concentration

Their proposal included three options, all which include a single layered carbon steel (JIS G3115 SPV 490) vessel. JIS G3115 SPV 490 steel plates are not widely used in Australia and is not included in American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code (BPVC). Therefore, design pressures and storage capacities cannot be accurately calculated. A summary of the options is provided in Table 3.3, noting the costs provided are for material only and does not consider fabrication or delivery.

| Option | Key dimensions | Price (AUD) | Commentary |
|---|---|---|---|
| **One (1) vessel** | 5.2 m ID × 24 m s/s<br>Weight ~726 t | $5M | Very few fabricators would be able to produce this vessel and is not recommended due to the expense of fabrication. This sized vessel is expected to only store circa 3.5 tonnes of hydrogen. |
| **Two (2) vessels** | 3.5 m ID × 28 m s/s<br>Weight ~385 tonnes per unit | $5.4M | Shells may require rolling overseas as equipment is not available locally. Forging of the shells is an alternative. Total cost would be cheaper than a single vessel option when accounting for fabrication and delivery. |
| **Four (4) vessels** | 2.5 m ID × 28 m s/s<br>Weight ~202 tonnes per unit | $5.6M | Option would have the cheapest cost out of all options when accounting for fabrication and delivery. |

**Table 3.3**
Thornton Engineering Proposal Summary

An alternative benchmark that has been deployed in Europe was also assessed. Details are provided in Table 3.4.

| Option | Key dimensions | Price (AUD) | Commentary |
|---|---|---|---|
| **Ten (10) vessels** | 2.8 m ID × 23 m s/s<br>Weight ~94.7 tonnes per unit | $6.6M | Utilises a more commonly available lower grade steel, A517 Gr E. Hydrogen storage ~540 kg per unit. |

**Table 3.4**
Low Pressure (60 bar) Vessel Cost Benchmark

### 3.8.3 Hydrogen Floating Storage Barge

Based on the review of the current onshore hydrogen storage options, Provaris is developing a floating compressed hydrogen storage barge solution which can be utilised at either the loading or unloading site in order to optimise the fleet configuration and provide 'buffer storage' to the overall supply chain. The design concept utilises Provaris' proprietary pressurised cargo containment used to transport hydrogen on the GH2 carriers. The capex of barge storage is expected to be cheaper than a H2Neo carrier and significantly cheaper than current market onshore storage offerings on a capex per tonne basis, as described above. A concept of a 430 tonne hydrogen floating storage barge (H2Leo) is presented in Figure 3.5.

The floating storage barge could be utilised in the event that a GH2 carrier is either unavailable or unable to be loaded. The barge could be situated along the subsea pipeline route and with a shallow draught it could be closer to the shoreline and in more sheltered waters than the offshore loading terminal. Given the barge would rarely disconnect from its mooring, a semi-permanent anchoring solution could be used. The compressed hydrogen cargo could either return to the onshore facilities for compression onto a GH2 carrier, or compressors could be installed on the barge for direct transfer. The operational benefits and economics of incorporating floating storage will be explored in future studies by the HyEnergy project and will need to consider the capital costs of an additional pipeline and mooring.

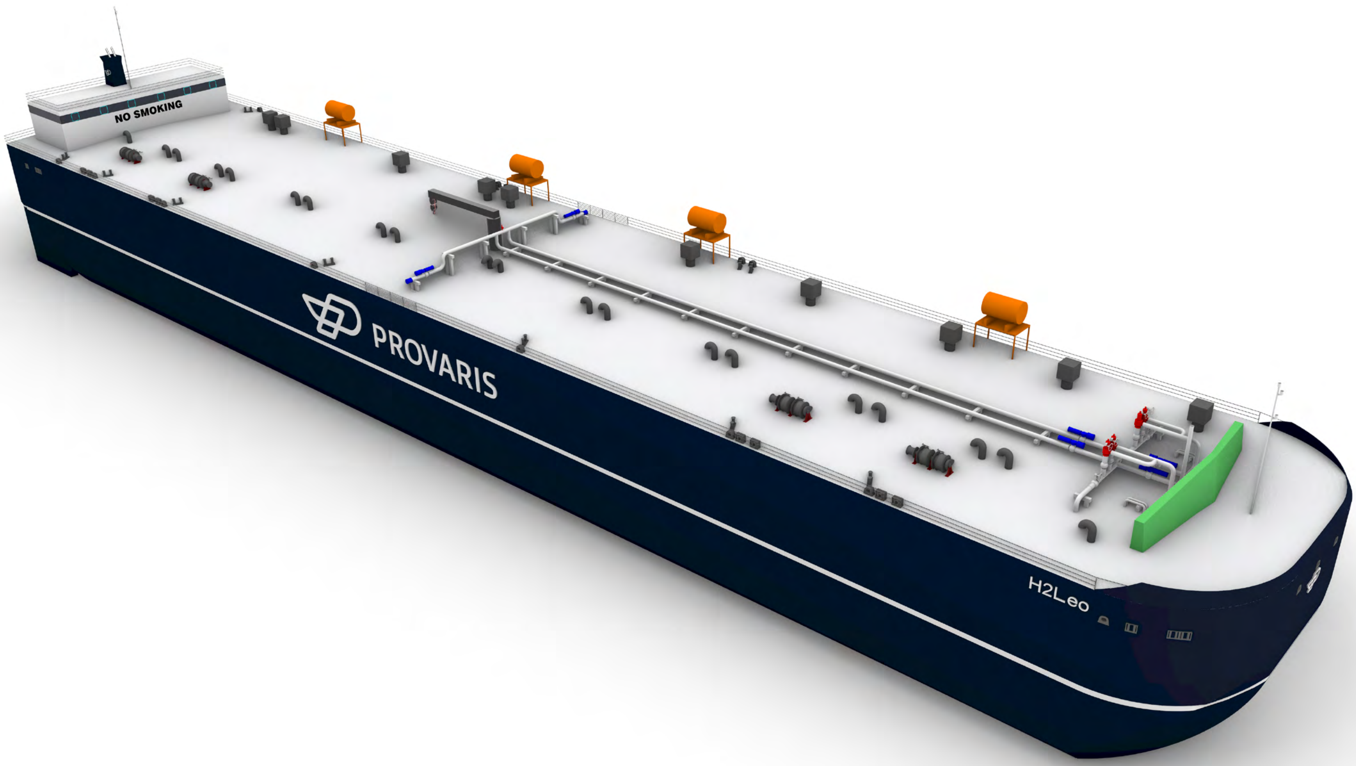



**Figure 3.5**
H2Leo Concept for Floating Compressed Hydrogen Storage

# 4. Shore Crossing and Subsea Pipeline

**A desktop study of the ground conditions was undertaken at the proposed shore crossing location and along the subsea pipeline to the single point moorings (SPM).**

The area of interest is based on Oropesa's assessment and design of the offshore loading terminal summarised in Section 5.5. Various locations for the pipeline shore crossing have been investigated in this Study, in the proximity of:

- South Bejaling (Boolathana)
- North side of Town Common

A previous study carried out by AECOM for the Gascoyne Development Commission (Bejaling Deepwater Port Study, 15 October 2010) had indicated potential sites for a multi-purpose deep water port at South Bejaling. It is understood these sites were studied as they presented favourable characteristics for vessel navigation, compared to options further south towards Carnarvon.

Currently, the onshore facilities for HyEnergy are located at the northern end of Town Common, which is also a potential location for the downstream facilities including the pipeline shore crossing to the offshore loading terminal. The Project Proponents currently hold a Section 91 lease at Town Common and a MoU with the Shire of Carnarvon.

Substantial field investigation involving met-ocean monitoring, environmental, geotechnical, and surveys would all be needed to confirm the feasibility of final locations.

All figures contained in this report are conceptual and the final location of the pipelines and shore crossing is to be confirmed in future studies undertaken by the Project Proponents.

## 4.1 Ground Conditions Assessment

The shore crossing and subsea pipeline study area is located in the Gascoyne sub-basin of the Carnarvon geologic basin, the nearshore area of which is formed from a Cainozoic wedge of carbonate material and is characterised by a sea floor with very shallow seaward gradients. Over the length of the pipeline, the depth to seabed increases westerly from approximately 0-15 m (~1:1000).

The Geoscience Australia Marine Sediments (MARS) database contains two seabed sediment samples recorded in the general vicinity, approximately 30-35 km south of the pipeline (refer to Figure 4.1). These samples include bioclastic sand and calcarenite, with the latter taken to be consolidated (cemented). A detailed study undertaken in 2008, some 90-100 km north of the pipeline included 24 sediment samples ranging from 5-18 km offshore, all of which were predominantly sand or sand/gravel mixtures and generally had little to no mud fraction. Clasts were generally bioclastic (shells, corals and the like) and all carbonate contents exceeded 88%.

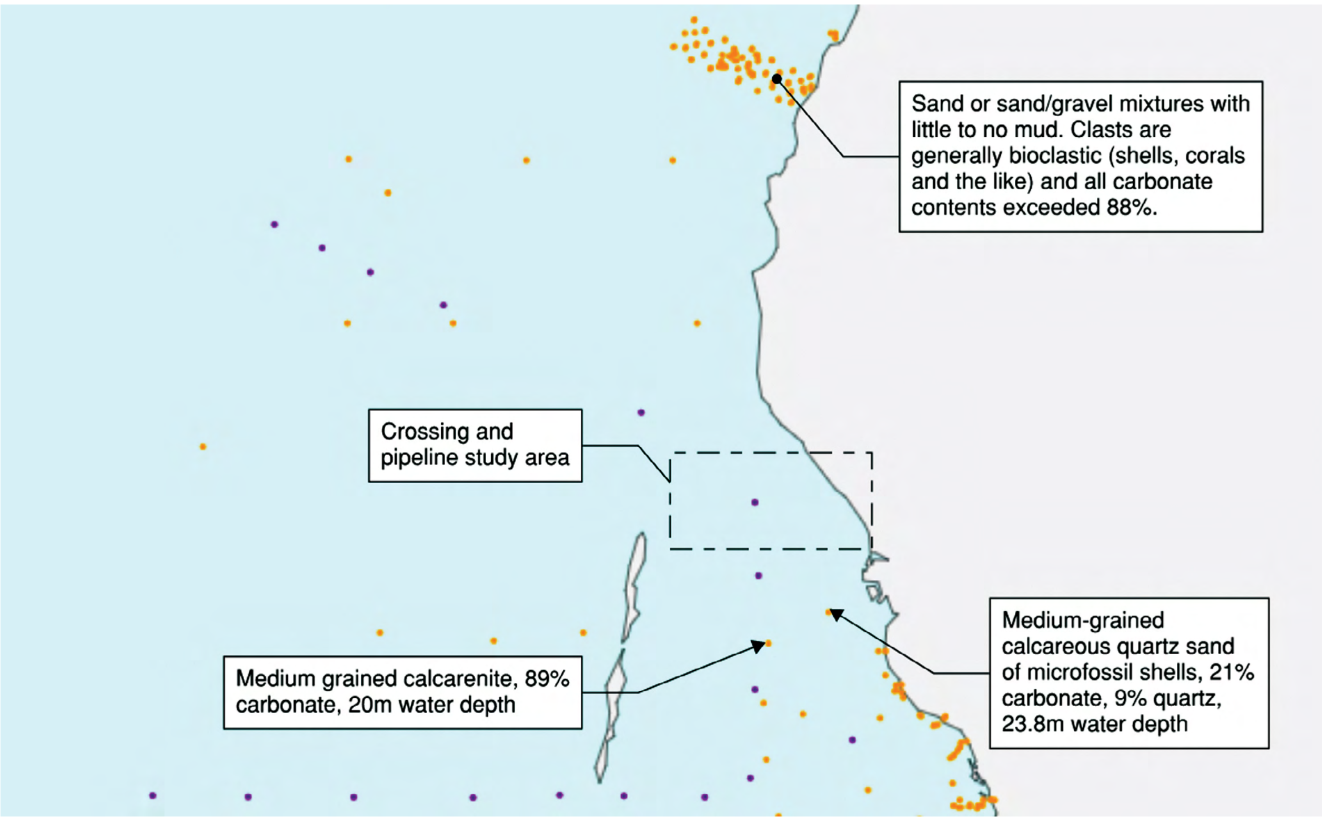



**Figure 4.1**
Seabed Sediment Samples (MARS, 2022)

Limited data on the shallow subsea geology was available in the immediate vicinity of the pipeline study area. It is possible there is presence of complex quaternary carbonate sediments including interbedded and cross cutting sands, muds and varying degrees of cementation including the presence of carbonate rock outcrops. Such variable conditions may pose a risk to the Project.

## 4.2 Crossing Methodology and Pipeline Configuration

### 4.2.1 General Arrangement

Based on the understanding of site conditions and environmental sensitivities (refer to Section 10 for a summary), the shore crossing is proposed as a horizontal directional drill (HDD). The proposed HDD length is 2.5 km which places the pipeline exit point at approximately -6 mCD. The remainder of the pipeline will be trenched. The HDD exit point is likely to be sufficiently distant from the shoreline environmental sensitivities but may be within the wave energy zone. To reduce the risk of scour, rock armour will be provided in the trench until -8 mCD. This segment is assumed to be 2.5 km in length. The remainder of the trenched segment is assumed to be in sufficiently deep water and considered outside the wave energy zone and will be backfilled with the excavated material.

It is proposed that each SPM will have its own individual pipeline from the shore crossing. The two pipelines will join at the end of the trench to form a ring line. This configuration allows a single pipeline to supply both SPMs which builds redundancy in the system and is advantageous if maintenance or repair is required on the other. Further discussion on hydrogen loading to the GH2 carrier is provided in Section 6.

### 4.2.2 Pipeline

For design and costing purposes the nominated pipe size was assumed to be 12 inches, made from grade X-70 carbon steel with a wall thickness (WT) of 0.688 inch. A concrete armour coating will be provided to the pipeline in trenched segments. Based on the distances between the proposed onshore facilities and offshore loading terminal, up to 34km of pipeline has been included in the commercial analysis. The pipeline route will be assessed in conjunction with other pipelines required for HyEnergy (e.g. seawater intake / saline discharge) to avoid environmental disturbance and reduce cost.

### 4.2.3 Horizontal Directional Drill

The HDD will use one intersect drill to achieve the target 2.5 km length. One bore is assumed for each pipe. Two working areas will be provided which are as follows:

- Onshore location which would serve as the entry point for the HDD
- Offshore location, 2.5 km from the shoreline which would serve as the exit point for the HDD

### 4.2.4 Trenched Segments

The two pipelines will be placed in a single trench using a barge with S-Laying equipment, suitable for installation of concrete coated pipes in shallow water. The two pipelines will be laid as a bundle, held together with a mechanical pipe spacer to allow installation in a single pass.

Based on the available information, it is assumed the trench will be 1.8 m wide at the bottom and 1 m deep with a 1:4 slope. Concept sections of the pipeline along the rock armoured and buried segments are provided in Figure 4.2.

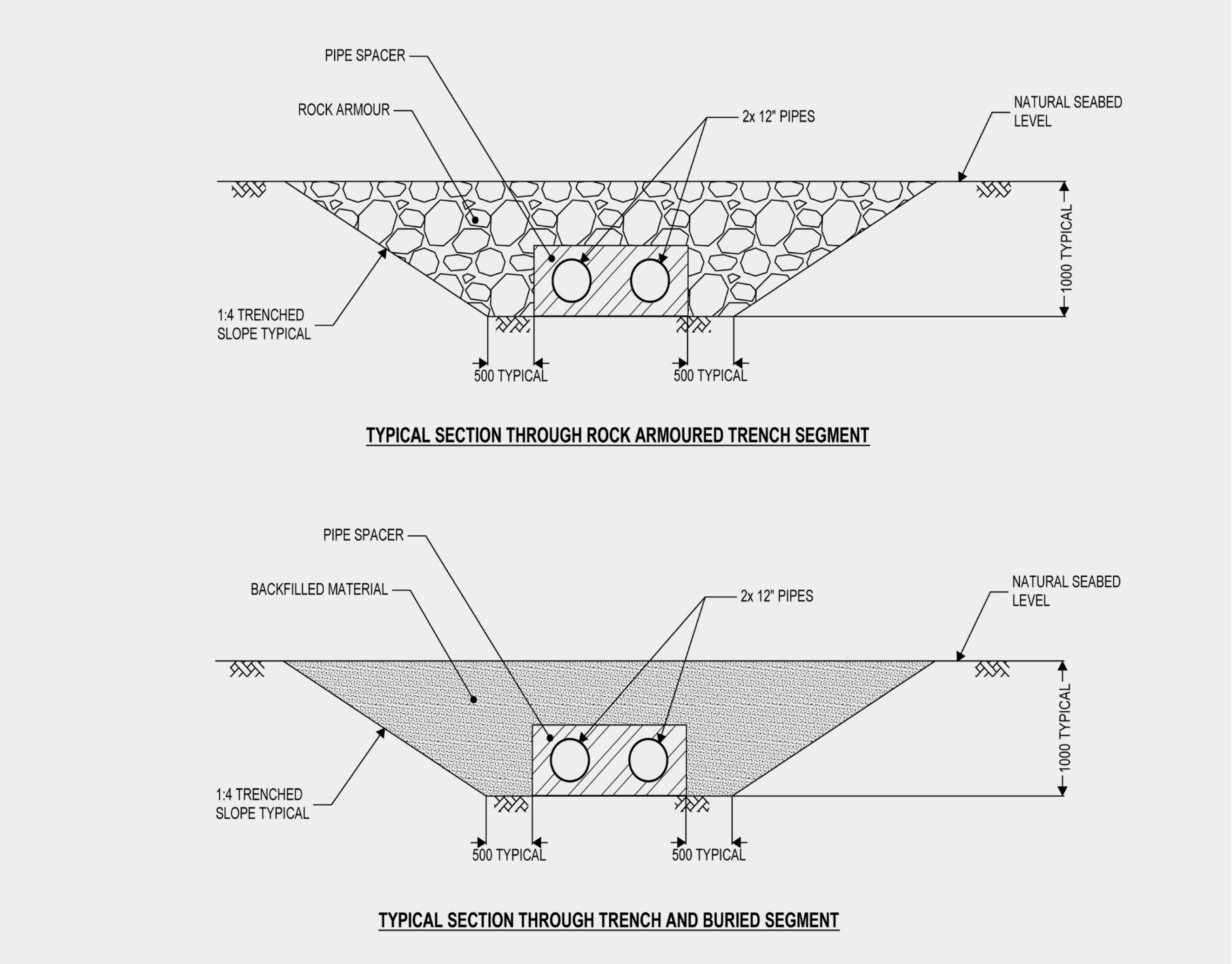



**Figure 4.2**
Concept Sections of Trenched Pipeline (WSP, 2022)

# 5. Offshore Loading Terminal

## 5.1 Offshore Loading Terminal Context

The HyEnergy site is primarily surrounded by Shark Bay an ~2,300,000 ha world heritage site, with the remainder as the Indian Ocean (adjacent to Lake Macleod). The water level within Shark Bay varies but is relatively shallow (less than 10 m deep) for approximately 8-10 km off the coastline. This presents challenges for nearshore terminal designs as extensive dredging would be required and likely be cost and environmentally prohibitive, therefore an offshore loading terminal has been considered for this Study.

While the offshore loading terminal may be a significant distance away from the coastline, if positioned within Shark Bay it would benefit from the protection of Bernier Island (refer to Figure 5.1). Options outside of Shark Bay have not been considered for this Study due to exposure to extreme swells which will severely limit operability without a protection structure (e.g. breakwater).

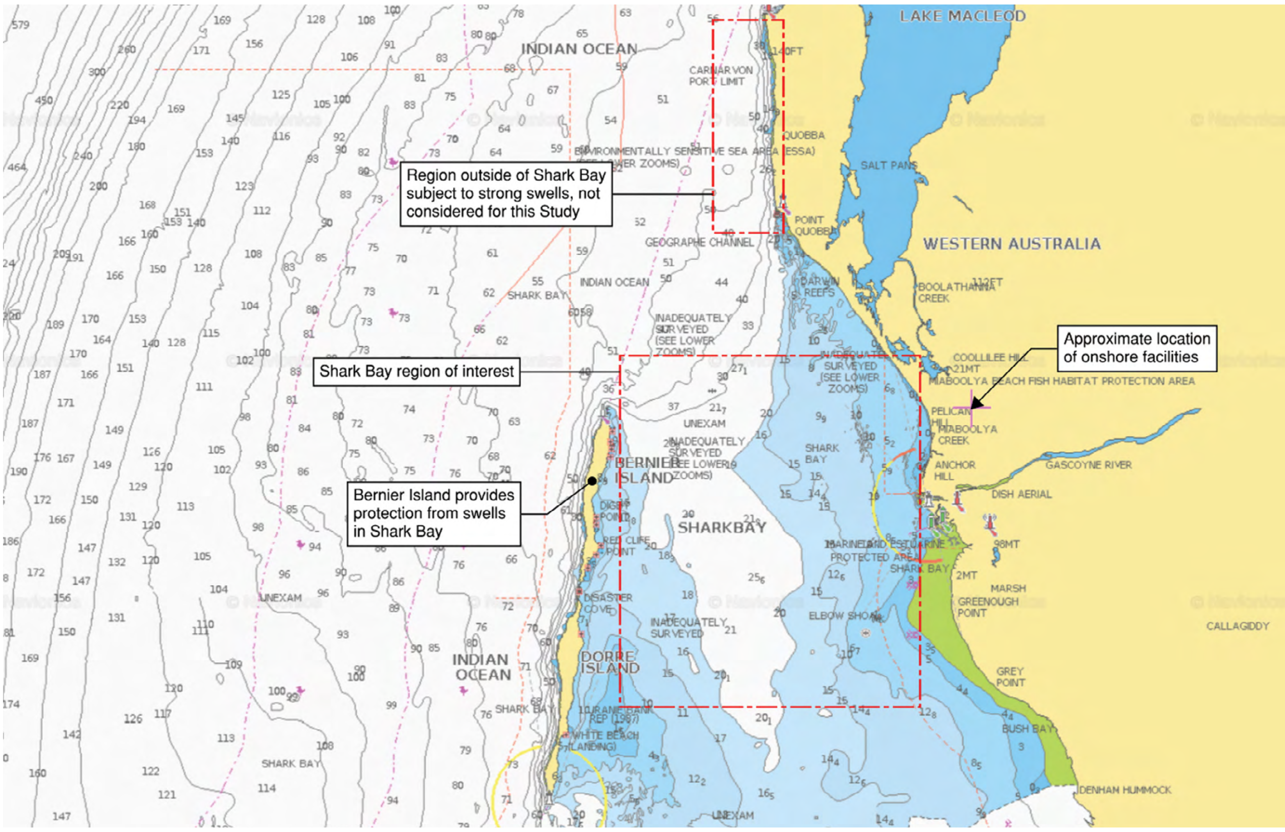



**Figure 5.1**
Onshore Facilities Location (Navionics, 2022)

The loading terminal berth infrastructure would typically consist of a fixed loading platform and mooring and berthing dolphins when nearshore, or when offshore a specialised offshore loading system such as a single point mooring (SPM) connected to the shoreline via a subsea pipeline. A SPM was selected for this Study as it:

- Typically offers greater operability limits compared to marine loading arms on a fixed loading platform
- Can have various components on the seabed which will have a lesser visual impact than a fixed loading platform

## 5.2 Design Philosophy

The offshore loading terminal will consist of a twin SAL, allowing up to two H2Neo carriers to be connected at any one time. Hydrogen will be loaded to one carrier at a time, with the second mooring allowing the second carrier to connect while the first is loading. Once the first H2Neo carrier has finished loading, the hydrogen supply can be switched to the second. This terminal arrangement is intended to ensure loading operations are continuous and avoid hydrogen storage requirements due to the continuous supply from the onshore compression facilities. The twin SPM arrangement is also desirable as it allows loading operations to continue if maintenance or repair is required at the other SPM.

## 5.3 Site Selection Factors

The following factors have been considered in the site selection process:

- **Bathymetry** – Sufficient depth for the H2Neo carrier to safely access, load and depart. **Dredging is not intended in the design.** Seabed is to be capable of providing adequate holding ground for the planned mooring systems.
- **Metocean** – Weather, current and sea conditions to sustain mooring and export operations all year (except for cyclonic events).
- **Established industries** – Pipeline and mooring locations to minimise impact on current marine operations.
- **Environment** – SPM and pipeline location to be clear of environmentally sensitive or protected areas.
- **Community** – Mooring location to be clear of areas of local recreational focus.

## 5.4 Mandatory Requirements

Based on the review of factors the following requirements have been established for the site selection of the offshore loading terminal:

- The initial mooring locations must be at a minimum depth of 15 m (at lowest astronomical tide (LAT)) which is based on:
- GH2 carrier laden draught of 8.3 m
- Nominal under-keel clearance (UKC) of 1 m
- Height of mooring system sitting 3 m proud of the seabed (details of mooring system provided in Section 6.1.1)
- Inaccuracy in existing bathymetry data of ± 2 m
- The mooring locations will be clear of declared sensitive marine areas (Marine Parks, Environmentally Sensitive Sea Area etc.)
- The mooring locations will be clear of known commercial trawling areas
- Access to and from the mooring areas will be by a planned, declared navigation route
- The proposed locations are not proximal to any known historic site

Further engineering and design development of the SPM system will be undertaken at the next phase of the Project. The shallow seafloor gradient in the Study area means the water depth will require consideration of the pipeline cost, environmental and social impacts, as well as the deeper draught of Provaris' larger GH2 carrier H2Max (a potential optimisation to the compressed hydrogen shipping cycle, refer to Section 8).

# 5.5 Proposed Location and Access Route

The SPM and shore crossing locations are shown indicatively in Figure 5.2. as well as the proposed GH2 carrier access route. As the GH2 carrier will be arriving from Asia Pacific it will enter Port of Carnarvon waters via the Geographe Channel from the northwest. Once in the Port of Carnarvon the GH2 carrier will approach the queuing point and wait until a SPM is free.

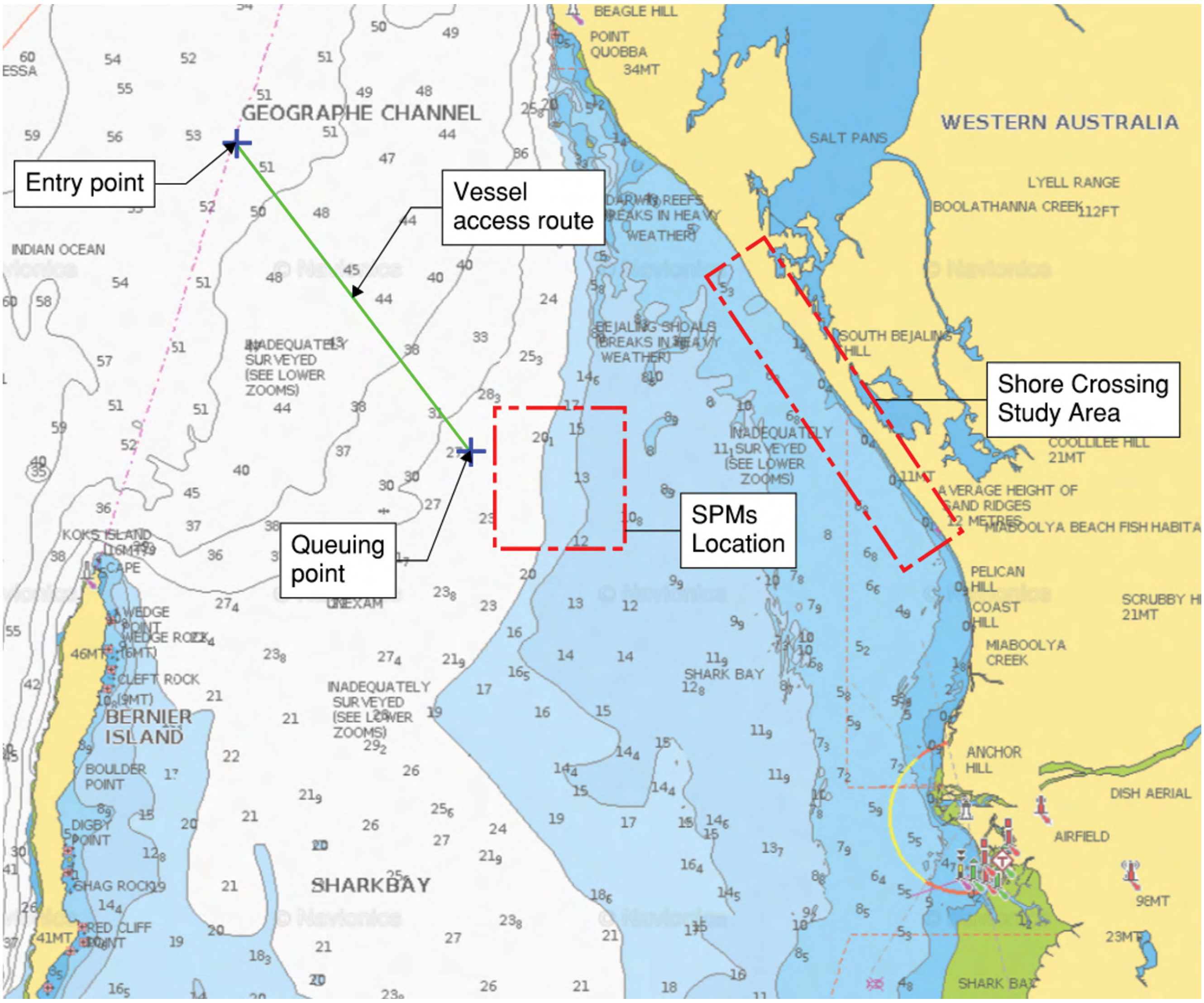



**Figure 5.2**

SPM and Shore Crossing Location and GH2 Carrier Access Route (Navionics, 2022)

Licencing of the SPMs will be governed by the legislation affecting Shark Bay at the time of application. Current regulation is under the Port of Carnarvon and may transfer to the MidWest Ports Authority, however the WA Department of Transport (DoT) has advised there is no known date this will occur and any operations in the foreseeable future should be planned with existing legislation extant.

To this end the SPMs will be within the port limits of the Port of Carnarvon and subject to the regulations pertaining to the Shipping and Pilotage Act 1967.

## 5.6 Stakeholder Engagement

A stakeholder engagement plan is currently being developed. Key decision-making authorities to be engaged early include:

- Department of Water and Environmental Regulation (DWER) (WA Govt)
- Environmental Protection Authority (EPA WA) (WA Govt)
- Department of Agriculture, Water and Environment (DAWE) (WA Govt)
- Department of Biosecurity, Conservation and Attractions (DBCA) (Cth)
- Shark Bay World Heritage Advisory Committee
- Department of Jobs, Tourism, Science, and Innovation (DJTSI) (WA Govt)
- Department of Primary Industries and Regional Development (DPIRD) (WA Govt)
- Department of Planning, Lands and Heritage (DPLH) (WA Govt)
- Yamatji Marlpa Aboriginal Corporation (YMAC)
- Department of Transport (DoT) (WA Govt)
- Mid-West Ports Authority (MWPA)

Other relevant legislation and guidance material include:

- Environmental Protection Act 1986 (EP Act)
- Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act)
- Environment Protection (Sea Dumping) Act 1981 (EPSD Act)
- Biodiversity Conservation Act 2016 (BC Act)
- Aboriginal Heritage Act 1972
- Historic Shipwrecks Act 1976
- Maritime Archaeology Act 1973
- Biosecurity Act 2015
- Shipping and Pilotage Act 1967 (SPA)
- Port Authorities Act 1999 (PAA)
- Maritime Transport and Offshore Facilities Security Act 2003 (MTOFSA)

# 6. GH2 Carrier Loading Operations

## 6.1 GH2 Carrier Loading Equipment

The single point mooring (SPM) is being designed by APL NOV who have proposed a twin single anchor loading (SAL) system. A SAL is a mooring assisted loading system which consists of a turret that provides weathervaning capability. Operability limits are also high, allowing connection and loading to take place at significant wave height (Hs) of 3.5 m. APL NOV has assessed the metocean data from Oropesa and no weather events are likely to interrupt connection to the GH2 carrier except for cyclonic events. The mooring and riser assembly is clear of the GH2 carrier and lies on the seabed well protected during idle condition. The SAL system is both safe and environmentally friendly. The SAL pipeline end manifold (PLEM) is located subsea, reducing the risk of collision with the GH2 carrier. The SAL has low visual and environmental impact with a small footprint, ~8 × 8 × 3 m high.

To compliment the SAL system, the GH2 carrier requires an additional loading manifold forward, and a bow loading system (BLS) is proposed which provides an efficient means of offshore loading. The BLS incorporates a cardan at the loading manifold, which provides a moment free connection between the flexible riser and the GH2 carrier and enhances the durability and service life of the SAL and BLS components.

### 6.1.1 Single Anchor Loading

The SAL system connected to a vessel is shown in Figure 6.1. Each of the main components are described in Table 6.1.

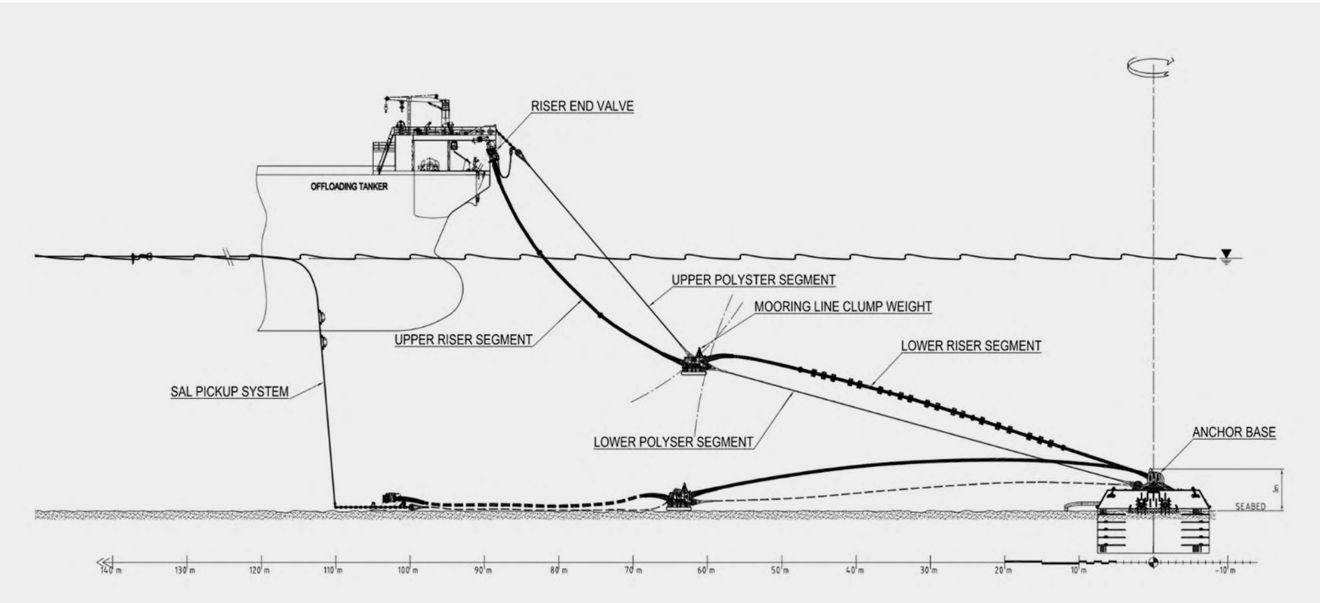



**Figure 6.1**
SAL System Connected to Vessel (APL, 2022)

| Component | Description |
|---|---|
| Anchor base | The main steel structure of the system which is secured to the ground by a pile. The anchor base transfers the forces from the riser and mooring system via a bearing swivel arrangement in the turret to the pile. The anchor base also consists of the PLEM, a series of valves and control systems. |
| Lower polyester segment (LPS) | Consists of buoyancy modules and connects to the SAL anchor and the MLCW. The LPS is shorter than LRS to ensure no mooring loads are subject to the LRS. |
| Upper polyester segment (UPS) | Connects to the MLCW and chafing chain (upper end of UPS that connects to vessel mooring system). The UPS is shorter than URS to ensure no mooring loads are subject to the URS. |
| Lower riser segment (LRS) | Connects to the anchor and the MLCW and transfers product to the vessel. |
| Upper riser segment (URS) | Connects to the MLCW and REV and transfers product to the vessel. |
| Mooring line clump weight (MLCW) | Located between the upper and lower segments of the mooring line and riser. It stablishes the system on the sea floor when disconnected from the vessel and also acts as a spring to reduce peak loads on the mooring system. |
| Riser end valve (REV) | Located at the upper end of the URS and connects to the BLS coupler. |
| SAL pickup system | Enables the riser and mooring line to be picked up when the vessel arrives at the SAL. Consists of a messenger line, bridle for REV connection and buoys for identification. |

**Table 6.1**
SAL System Key Components

The SAL system will utilise a high precision acoustic positioning (HiPAP) system to enable communication subsea. The key components and arrangement to the system are shown in Figure 6.2. The HiPAP system can be used for vessel positioning, data traffic and control of valves. The HiPAP system will send a digital acoustic signal, which is read by a transponder or acoustic control system (ACS) transducer and returns with a signal with the required information.

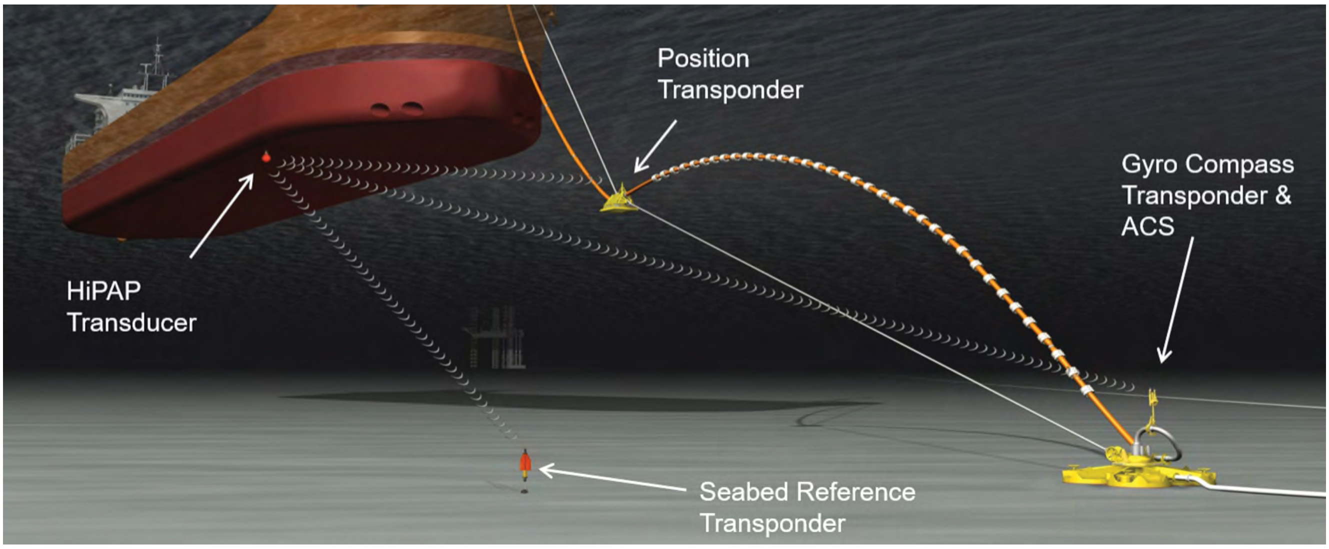



**Figure 6.2**
SAL HiPAP System (APL, 2022)

### 6.1.2 Bow Loading System

The BLS main component is the bow loading manifold which is shown in Figure 6.3. The bow loading manifold consists of the following components:

- Hydraulically operated coupler to allow connection to the REV
- Ball valve with hydraulic actuator
- Cardan with load cell to measure tension in the riser
- Pitch and roll swivel
- Trim cylinders to allow manoeuvring of the cardan
- Coupler claws with guide pins

The BLS also consists of the following:

- Riser pressure transmitter and gauge – To monitor pressure in the riser.
- Bleed valve – To allow bleed down of hydrogen outboard of the coupler before disconnecting the REV.
- Pressure test flange – For pressure testing the riser and coupler.
- Line valve – Fitted with limit switches that feed open and close positions to the vessel's control system.

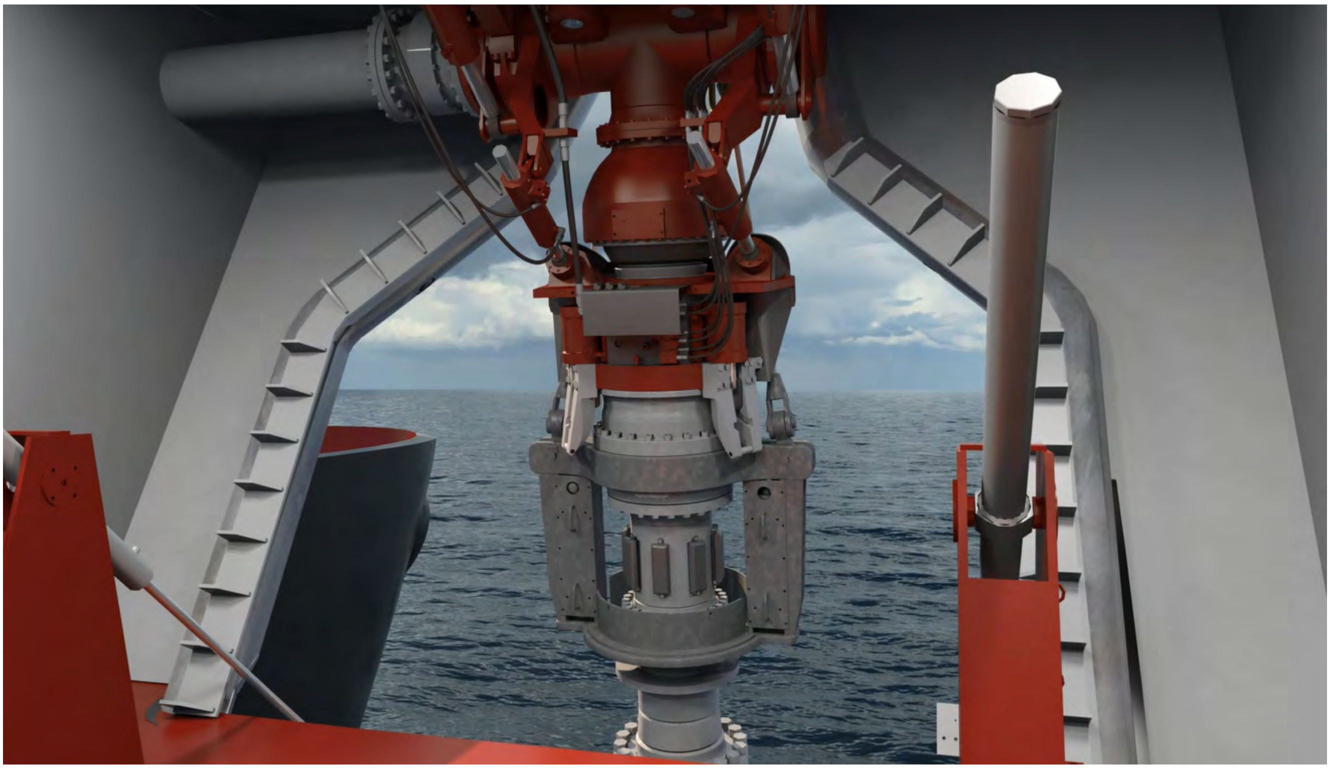


**Figure 6.3**
Bow Loading Manifold (APL, 2022)

### 6.1.3 Hydrogen Ready

The SAL system is traditionally designed for oil and gas operations, however most of the components are ready and proven for hydrogen, such as the mooring, anchor, turret, subsea piping, ACS and valves. Components which are considered new and/or require further development are mainly limited to material selections and sealing philosophy being a requirement by Class. Typically, APL NOV will engage Det Norske Veritas (DNV) as third party to verify the Class and qualification requirements.

### 6.1.4 Analogue

An example of a twin system that demonstrates the reliability, availability and maintainability of APL NOV's offshore systems is the Heidrun Project. Installed in 1994, in the North Sea, the Heidrun system was the first application to use twin Submerged Turret Loading buoys. With no storage, the operation was dependent on continuous connection and mooring of oil tankers to the buoys. In November and December 2001, the Heidrun oil field experienced a 100 year storm with reported maximum wave heights over 25 m and significant wave height over 16 m. During that time two DP shuttle tankers, were connected to two buoys and remained connected through the storm.

In excess of 1 billion barrels of oil were delivered from the Heidrun field to DP shuttle tankers via the twin system. More than 1,600 connections were made (as frequently as three days) with overall offtake regularity recorded as 99.9% over the life of the project.

## 6.2 GH2 Carrier Loading System

The process flow diagram (PFD) for GH2 carrier loading operations is provided in Figure 6.4.

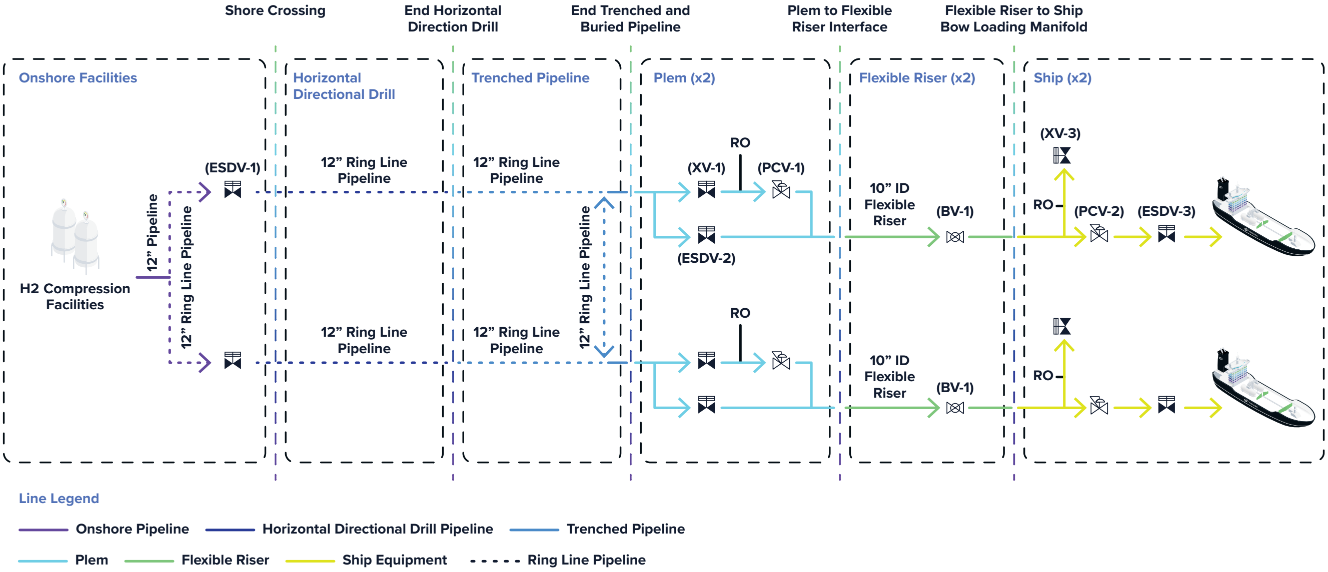



**Figure 6.4**
GH2 Carrier Loading PFD

The PFD illustrates the key components to the GH2 carrier loading system from the onshore compression facilities to the GH2 carriers. **Importantly it demonstrates a safety focussed solution to transfer compressed hydrogen to the offshore loading terminal and between the individual H2Neo carriers.** The following is included in the PFD:

- Pipeline from the onshore compression facilities, branching into two lines and forms a ring line at the end of the trench. The pipeline will maintain pressurisation at 250 bar all way up to the two PLEMs (anchor base of the SAL system).
- Two PLEMs with an arrangement of valves and pressure regulator
- Flexible riser for connection to the GH2 carrier BLS
- GH2 carrier BLS and an arrangement of valves, pressure regulator and venting system

## 6.3 GH2 Carrier Approach to SPM

### 6.3.1 Entry and Access Point

Entry and departure from Shark Bay will need to be managed to mitigate interaction with fishing vessel activities and seasonal migration of Humpback Whales. An Operational Management Plan with specific instructions for whale interaction is recommended.

The GH2 carriers will be unladen on the approach and are expected to operate unaided by towage.

### 6.3.2 Manoeuvring to SPM and Connection

As the Captains for the GH2 carriers will be repeating the voyage continuously, they are (over time) expected to obtain pilotage exemptions to avoid the need to embark a licensed Pilot to support the GH2 carrier's manoeuvre to the SPM. For the approach to the SPM, the GH2 carrier will be escorted by a support vessel.

The support vessel will provide a means of transfer if a Pilot is required and will also fulfil other duties. In regular operations to and from Shark Bay there may be a requirement to have access to shore transfers for stores, equipment, and personnel (pilot, agent, loadmaster, or other shore representatives). The support vessel can fulfil the roles of a pilot boat, line boat, stores transfer vessel and as required undertake Maritime Transport and Offshore Facilities Security Act (MTOFSA) roles and functions in accordance with the Facility Maritime Security Plan and Port Security Plan. The support vessel will also be required to be ready to respond to contingency and resilience demands such as spill response, emergency towing, mooring maintenance, etc.

The propulsion arrangement of the GH2 carrier is expected to remove the requirement for a tug to support this operation, although the support vessel may assist with passing connecting lines between the SPM and GH2 carrier. The HiPAP system will also assist on the approach and is generally activated from a 500 m distance.

Preparation for GH2 carrier loading is also expected to take place on the approach to the SPM. This includes testing of all GH2 carrier BLS equipment to streamline GH2 carrier loading operations.

The GH2 carrier will then connect to the SAL mooring equipment and the hydrogen transfer line at the BLS coupler.

## 6.4 GH2 Carrier Loading Methodology

Once the GH2 carrier is secured to the SAL mooring system and transfer line, a small subsea XV valve will be opened to allow hydrogen flow to pressurise the flexible riser. A pressure regulator in series with the pressurising XV will ensure that the ring line pipeline remains at 250 bar.

Once the flexible riser reaches 250 bar the pressure regulator on the GH2 carrier will be activated and the Emergency Shut Down Valve (ESDV) on the GH2 carrier will be opened slowly. The main subsea ESDV can be opened to increase the hydrogen flow rate into the GH2 carrier and the small subsea XV valve can be closed.When the GH2 carrier reaches 250 bar the ESDV on the GH2 carrier will be closed and the subsea ESDV will also be closed to isolate the flexible riser.

The flexible riser can be depressurised by activating the on-board depressurising (bleed) system. The flexible riser can be disconnected safely from the GH2 carrier BLS and the GH2 carrier can detach from the SAL mooring system.

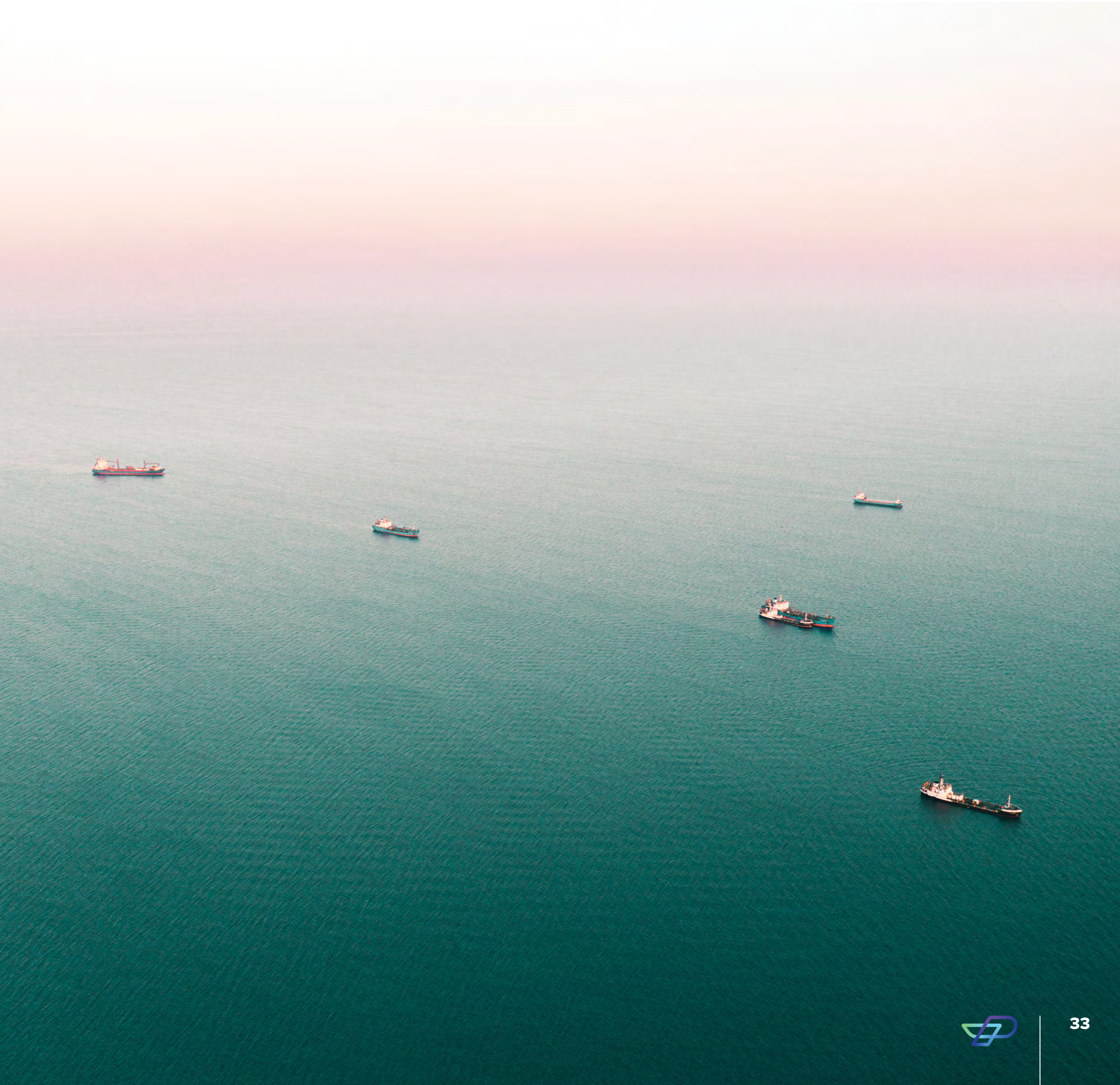
## 6.5 GH2 Carrier Departure

Once the GH2 carrier is fully disconnected from the SAL system, the support vessel will escort the GH2 carrier away from the SPM to the queuing point. If required for the manoeuvring operations, the Pilot will board the support vessel before the GH2 carrier departs to the receiving port via the proposed access route.

## 6.7 Exclusion Zone

An exclusion zone surrounding the SPMs is necessary for maritime security reasons imposed by MTOFSA and for safety relating to the hazardous nature of hydrogen handling. An exclusion zone for safety reasons will be a factor determined by the industry regulator. At this stage these matters remain under consideration and such a body has not been formed at the time of this Study.

The Australian Hydrogen Council has adopted 8 ISO standards (Hydrogen Mobility Australia 2019) relating to hydrogen trade however these do not consider safety distances when loading hydrogen onto GH2 carriers. In the absence of regulatory or peak body direction an exclusion zone of 1 km surrounding the SPMs is recommended for security and safety purposes. This estimate will be reviewed once a quantitative risk assessment (QRA) has been undertaken with supporting dispersion and consequence modelling (e.g. hazardous areas, overpressure and heat radiance contours).



# 7. Unloading Terminal at Receiving Port

**A desktop market study was undertaken to identify potential opportunities to position a hydrogen import terminal in Singapore. The review has considered repurposing existing and developing new facilities.**

**The opportunity scan for repurposing facilities has been limited to existing ports only. Planned greenfield ports, recreational ports and those that appear to have been established for a sole non-related trade (e.g. ferry ports) have not been considered. The opportunity scan is not intended to discount any options from further consideration. It is expected that consultation with relevant port authorities and government agencies in each location will be required to validate the results of this desktop study.**

## 7.1 Unloading Terminal Requirements

The assessment concluded that two berths would be required based on the estimated throughput and operational parameters. Floating storage may reduce this to a single berth.

As a preliminary estimate recommended by BS 6349-1-1 an under-keel clearance (UKC) of 1 m should be provided. Therefore, the minimum depth for the berths and approach channels should be 9.3 m. Dredged depths of existing ports are based on publicly available information.

The Study assumed demand for hydrogen at the receiving port is assumed to be relatively constant, such that the requirement for terminal storage should be minimal. Terminal storage would be dependent on the GH2 carrier size, import rate and expected delays with offtakes to the end consumer. Engagement with ports and customers is required to confirm this assumption.

Processing of hydrogen by means of blending or other methods may be required depending on the end consumer requirements. Further engagement of stakeholders at the target markets is required to understand the desired mix and may require a processing facility at the terminal.

Spatial requirements for the import terminal are to be confirmed at a later phase of the Project. For the opportunity scan a nominal area typical to natural gas terminals has been assumed for the maritime infrastructure.

## 7.2 Opportunity Scan

### 7.2.1 Opportunity Characterisation

Each opportunity investigated focused on the key characteristics defined in Table 7.1.

| Characteristic | Significance |
|---|---|
| **Hydrogen vision in place** | Ports/operators with a defined vision would be easier to work and approach. |
| **Projects and industry partners** | Existing projects and partners are a strong indicator of commitment to use of hydrogen. |
| **Customers** | Direct established links to downstream users will be valuable to drive import demand. |
| **Import ambition** | An appetite for hydrogen imports increases the attractiveness of the opportunity. |
| **Existing infrastructure** | Situating the terminal in an existing energy precinct with similar products would be preferred. |
| **Onward transportation** | Accessibility and availability of other transportation modes to allow distribution of hydrogen is favourable. |
| **Land availability** | Available greenfield or brownfield land adjacent to existing ports and terminals is deemed attractive. |
| **GH2 carrier access** | The ability to accommodate the GH2 carrier based on draught. |

**Table 7.1**
Opportunity Characteristics

A traffic light system was adopted to rate each opportunity against each characteristic as per Table 7.2.

| Characteristic | Green (2 Points) | Amber (1 Point) | Red (0 Points) |
|---|---|---|---|
| **Hydrogen vision in place** | Port/operators with mature hydrogen vision | Port/operators with a developing hydrogen vision | Port/operators with no clear hydrogen vision |
| **Projects and industry partners** | Engaged by Provaris and hydrogen projects labelled on the map | Hydrogen projects labelled on the map | No details of existing projects or industry partners |
| **Customers** | Clear demand for hydrogen in various sectors | Some initiatives for hydrogen | No clear demand for hydrogen |
| **Import ambition** | Plans to import hydrogen | Unclear but potential based on hydrogen vision | No clear plans to import hydrogen |
| **Existing infrastructure** | Natural gas terminal | Bulk liquids terminal | No existing energy infrastructure |
| **Onward transportation** | Links to roadways, rail or pipelines | Potential or developing links for onward transportation | No direct onward transportation systems |
| **Land availability** | Generous amount of land unoccupied | Some land assumed available | Limited land available |
| **GH2 carrier access** | Channel depth > 11 m | Channel depth > 10 m | Channel depth < 10 m |

**Table 7.2**
Characteristic Rating System

### 7.2.2 Singapore

Singapore has been selected as the primary market for compressed hydrogen imports in this Study, with further markets to be assessed with the project proponents. The shipping distance to Singapore lends favourably to compressed hydrogen on a levelised cost of hydrogen (LCOH) delivered basis. Singapore is also actively engaged in hydrogen market and has entered into various memorandums of understanding (MoU) exploring hydrogen technologies and applications.

The options that have been considered in the Singapore opportunity scan are listed below:

- Tanjong Pagar Precinct / Brani Island (PSA Singapore operated)
- Pasir Panjang Precinct (PSA Singapore operated)
- Sembawang Wharves (PSA Singapore operated)
- Jurong East (Jurong Port operated)
- Jurong Island (various operators)
- Bukom Island (various operators)

An overview of Singapore and the above opportunities are provided in Figure 7.2.

Based on the characterisation ratings assignment to each opportunity, Jurong Island was viewed as the most favourable to position a hydrogen import terminal. Jurong Island is the largest energy precinct in Singapore with a number of potential offtakers. Various operators have engaged in MoUs to explore the use of hydrogen. The conditions lend favourable to imports of hydrogen and it is therefore the apparent choice.

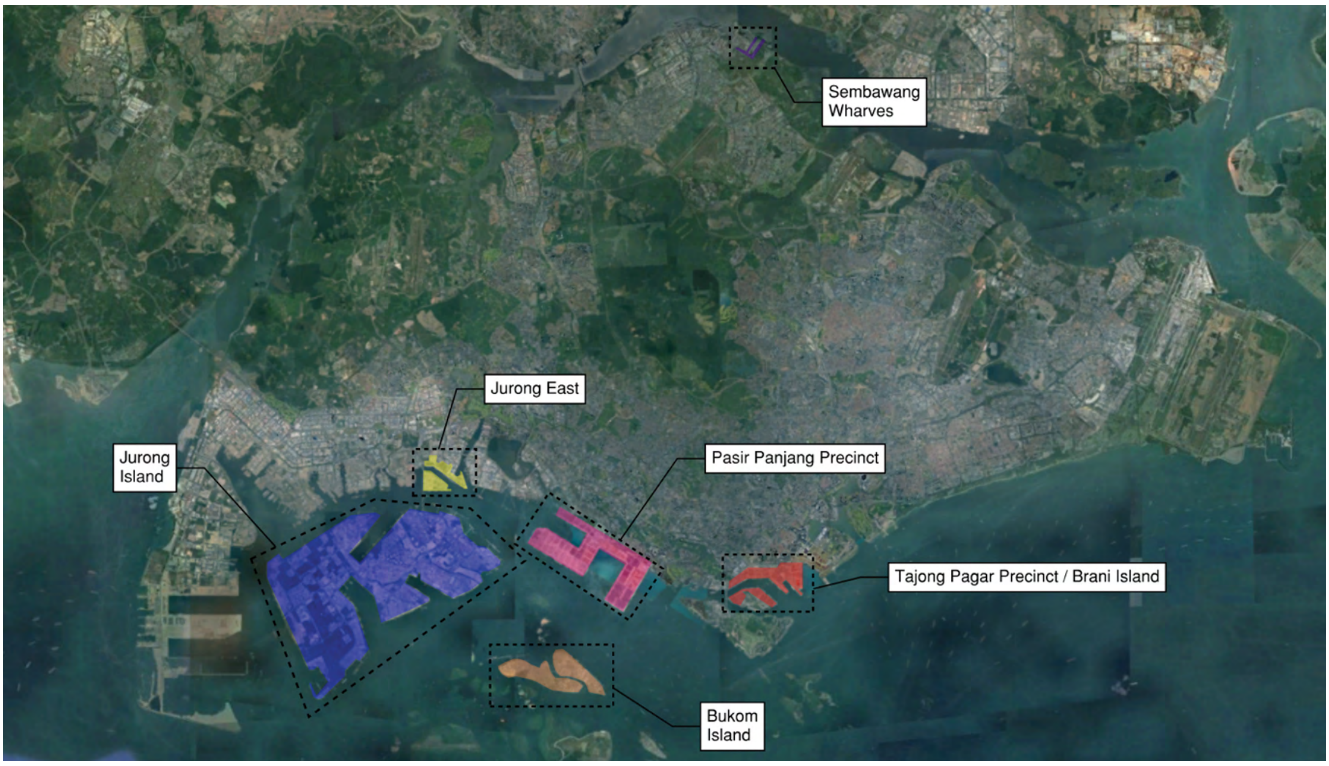



**Figure 7.1**
Singapore Opportunities (Google Earth, 2022)

Carnarvon Town, south of the Study area

## 7.3 Unloading Terminal Concepts

Paaras Marine Solutions was engaged to develop concepts for a new unloading terminal in Singapore. The selected concept developed for this Study is an island berth facility consisting of:

- Two berths in a linear arrangement to support unloading from two GH2 carriers (H2Neo)
- Approach trestle connecting the jetty to shore, supporting a compressed hydrogen pipeline and walkway
- Loading platform with one MLA and fire monitor
- Breasting and mooring dolphins
- Catwalks

The admin/office and compression facilities would be located at the onshore terminal. A concept plan of the unloading terminal is provided in Figure 7.2 and 3D render is shown in Figure 7.3. **The developed concept is not intended to confirm the layout of the facility.**

No hazard or risk assessment has been undertaken to confirm spatial requirements of the facility. These tasks are expected to be undertaken at the next stage of the Study.

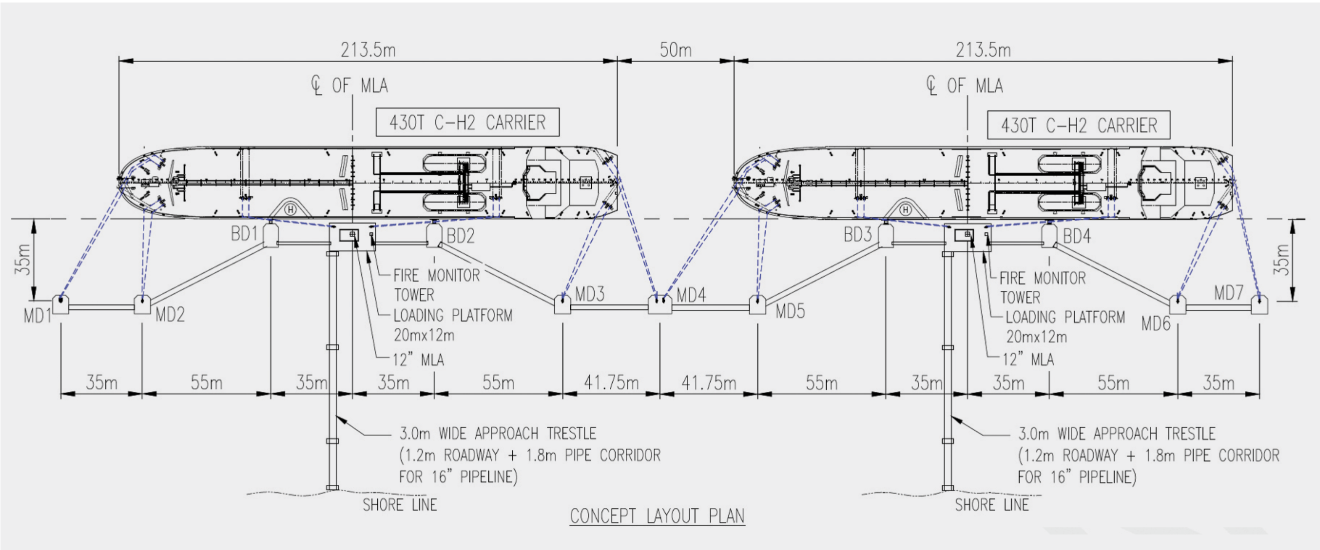



**Figure 7.2**
Unloading Terminal Concept Plan (Paaras Marine Solutions, 2022)


**Figure 7.3**
Unloading Terminal 3D Render (Paaras Marine Solutions, 2022)

### 7.3.1 Structural Concept

The loading platform will consist of reinforced concrete decking and beams supported on steel tubular piles. Precast construction will be adopted as much as possible to minimise work on site. Provision of mooring hooks and access ladders is envisaged to be required. The structure will be designed to take topside loads, mooring loads, berthing loads and environmental loads.

The breasting dolphins will be reinforced concrete caps supported on steel tubular piles. Rubber fenders will be provided to the berthing face. Access ladders are envisaged to be required while Quick release hooks (QRH) may not be necessary.

The mooring dolphins will be reinforced concrete caps supported on steel tubular piles. QRH will be provided to support mooring of GH2 carriers. Access ladders are envisaged to be required.

The approach trestle will consist of steel trusses that will accommodate a compressed hydrogen pipeline and a 1200 mm wide walkway. Reinforced concrete headstocks on steel tubular piles will be provided along the length of the approach trestle to support the steel trusses.

Steel trusses will be provided to accommodate access between the loading platform, breasting dolphins and mooring dolphins.

## 7.4 Singapore Stakeholder Engagement

In addition to the import location characterisations provided in Table 7.2, Provaris management attended meetings with several of the key Singapore Government agencies and stakeholders. The scope of the meetings was to provide an understanding of a compressed hydrogen supply chain for Singapore's future hydrogen import requirements, and to ascertain what additional technical and regulatory requirements the agencies will require for the import of compressed hydrogen using the Provaris H2Neo carrier.

The list of agencies and stakeholders included:

**Energy Market Authority (EMA):** The EMA is a statutory board under the Ministry of Trade and Industry, with the goals to ensure a reliable and secure energy supply, promote effective competition in the energy market and develop a dynamic energy sector in Singapore. EMA seeks to forge a progressive energy landscape for sustained growth. EMA is setting policy and strategy direction for the use of hydrogen in the decarbonisation goals of Singapore's energy market. The three key roles for EMA are to:

- Operate the critical delivery infrastructure used in the supply of electricity to homes, offices and industries
- Regulate Singapore's electricity and gas industries as well as district cooling services to promote fair competition
- Developing the industry by advancing manpower capabilities, catalysing innovations and establishing thought leadership.

**Economic Development Board (EDB):** The EDB is a government agency under the Ministry of Trade and Industry, is responsible for strategies that enhance Singapore's position as a global centre for business, innovation, and talent. EDB will play an influencing role in the establishment of new industries around hydrogen and the impact it can have on existing industries.

**Ministry of Trade and Industry (MTI):** The MTI's role is to promote economic growth and create jobs, to enable Singaporeans to improve their lives. Together with a number of statutory boards, MTI ensure that Singapore's economy continues to be competitive, is able to attract investments, and nurture a deeper base of global Singapore enterprises. MTI is currently reviewing the country's hydrogen strategy and is working closely with the Australia Government to collaborate on hydrogen and other green energy solutions. An example is the sustainable future for both nations through a bilateral Green Economy Agreement currently being drafted for execution in late 2022. It is a comprehensive strategic partnership for environmental goods and services.

**Maritime and Port Authority (MPA):** The MPA's role is to develop Singapore as a premier global hub port and international maritime centre. Roles include port authority and regulator, to ensure safety, security and environmental protection. The MPA is tasked with the mandate to replicate the port's success as the dominate LNG trading hub in Asia, with new green shipping fuels including ammonia, hydrogen, methanol, etc.

Provaris has also now initiated a technical and economic review of the compressed hydrogen supply chain, with MTI and the agencies listed above to be involved in the review and future approvals required for the import of compressed hydrogen to Singapore. It is expected that ongoing consultation will be made with the relevant agencies as further details on the Project are defined, including the timing and requirements of a port unloading facility.

## 7.5 Carbon Emissions Reduction Analysis

For the purposes of calculating an emissions reduction, the green hydrogen delivered into Singapore was assumed to be used for industry and power generation of data centres. This high-level analysis has assumed 50-50% use split, to displace grey hydrogen used for industry and diesel used for power generation of data centres. This early assessment is based on the HyEnergy project information available at the time of completing this Study and information available on the public domain.

Most hydrogen produced is 'grey' by a process known as steam methane reforming (SMR) and on average emits 8.90 kgCO2/kgH2 (IEA, 2019). Burning diesel oil emits approximately 2.70 kgCO2/L (of diesel) (NTC, 2019), and on an equivalent hydrogen energy basis 9.07 kgCO2/kgH2 (RMI, 2019). Carbon emissions produced from refining diesel oil can be highly variable but on average can be assumed to be ~0.32 kgCO2/L (of diesel) (Madugula, 2021), or on an equivalent hydrogen energy basis 1.08 kgCO2/kgH2. Therefore, the total carbon emissions emitted from producing and burning diesel oil on an equivalent hydrogen energy basis is ~10.15 kgCO2/kgH2.

Based on the average throughput determined by the cycle time analysis, 196,181 tpa will be delivered to Singapore with a fleet of 19 GH2 carriers. The carbon emissions reduction by using green hydrogen is presented in Table 7.3.

| Sector | Energy Source | Carbon emissions emitted (kgCO2/kgH2) | Supplied green hydrogen (tpa) | Carbon emissions reduction (tCO2/year) |
|---|---|---|---|---|
| **Industry** | Grey Hydrogen | 8.90 | 98,091 | 873,005 |
| **Data Centres** | Diesel | 10.15 | 98,091 | 995,304 |
| **Total** | – | – | **196,181** | **1,868,310** |

Note: Data centres assumed to powered by diesel generation. Carbon emissions emitted is on an equivalent hydrogen energy basis.

**Table 7.3**
Carbon Emissions Reduction Analysis

In order to deliver the green hydrogen to Singapore, the Study assumed the GH2 carrier will consume liquified natural gas (LNG) and marine diesel oil (MDO). While the basic design is dual fuel LNG (including biogas and e-methane), the GH2 Carrier has been designed with hybrid-electric drive propulsion so that the most favourable prime movers and fuel (subject to speed, power, availability and commercial considerations) can be adopted at the time of construction. In addition to bunkering tanks on deck, the engine room arrangement allows for integrated tanks for liquid fuels such as methanol and bio-fuels. The arrangement of electric propulsion motors and batteries further allows for the installation of fuel cells that can be scaled up to meet the power demands onboard.

LNG production and combustion emits approximately 3.64 kgCO2/kg (of LNG) (Columbia SIPA, 2021), while MDO production and combustion emits approximately 3.85 kgCO2/kg (of MDO).

Note other components to the compressed hydrogen supply chain which are highly uncertain at this stage of the Study have not been included in this carbon emissions reduction analysis. Various elements including the construction of facilities, operation at the onshore facilities at Carnarvon (expected to be minimal due to running on renewable power) and other supporting and indirectly associated components to the compressed hydrogen supply chain are all excluded.

Based on the fuel consumption for a typical GH2 carrier cycle, and the number of cycles per GH2 carrier per annum, the carbon emissions produced by transporting the green hydrogen to Singapore can be estimated as shown in Table 7.4, which results in a net reduction in carbon emissions of 1,022,047 tCO2/year.

| Fuel | Fuel Consumption (tpa) | Carbon emissions emitted (tCO2/year) |
|---|---|---|
| **LNG** | 223,259 | 812,587 |
| **MDO** | 8,753 | 33,676 |
| **Total** | – | **846,263** |

**Table 7.4**
Carbon Emissions Emitted for Transportation

**Net Reduction in Carbon Emissions for Delivering Green Hydrogen to Singapore:** 1,022,047 tCO2/year

# 8. Cycle Time Analysis

**Discrete event simulation modelling has been undertaken to evaluate risks and identify opportunities in the compressed hydrogen supply chain. The modelling has adopted the Monte Carlo method to perform a very large number of simulations over the period of the Project to collect statistics on the expected performance.**

The modelling performed has been used to determine the following as a probability distribution:

- Hydrogen shipment cycle time to the receiving port
- The number of GH2 carriers required to achieve continuous loading of GH2 carriers to minimise hydrogen storage
- Throughput of compressed hydrogen

## 8.1 Discrete Event Simulation Model

The discrete event simulation model has considered inputs and cycle components as described in the following sections. It is noted the simulations have made simplifications of real-world activities based on available information. This cycle is also shown diagrammatically in Figure 8.1.

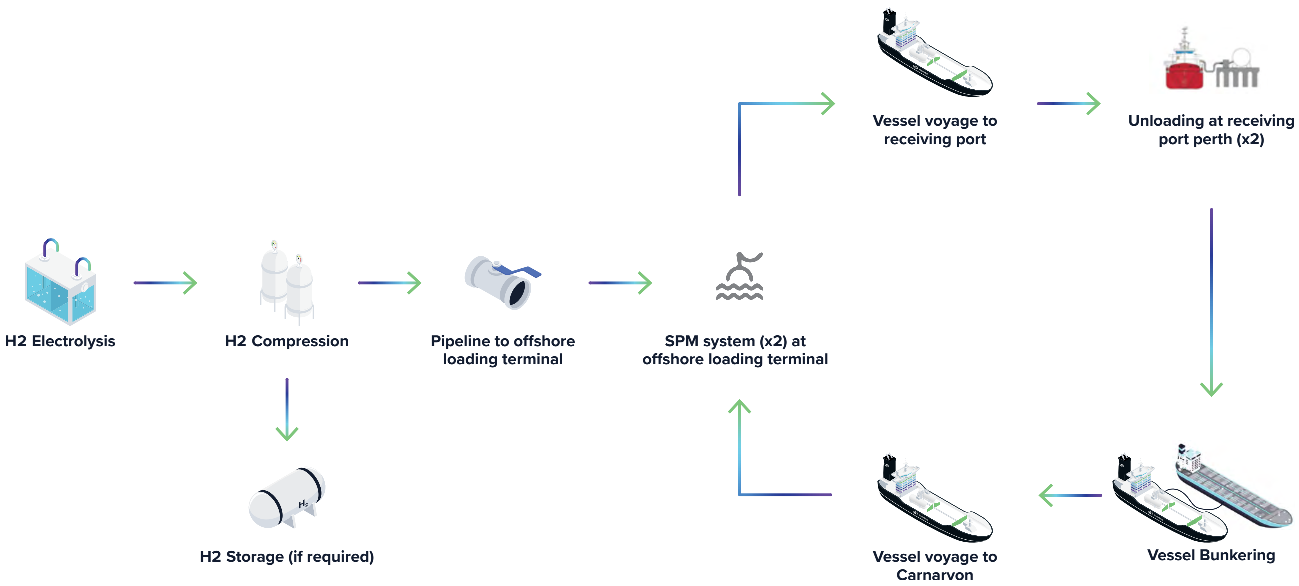



**Figure 8.1**
Key Components of Discrete Event Simulation Model

Hydrogen is assumed to be produced 24/7 at a rate of ~28.83 tph (200,000 tpa) for compression.

The H2Neo carrier approach is based on a fixed time to slow down and approach along the proposed access route. Carriers will manoeuvre and connect to one of the two SPM systems based on a fixed time and will queue if a SPM is unavailable. Connection to the SPM can only be made within the SPM operability limits.

The H2Neo loading rate is equal to the hydrogen production rate (i.e. 22.83 tph) and loading will occur one carrier at a time. Once completed loading the carrier will be disconnected based on a fixed time and the supply of hydrogen will switch to the other connected carrier. It was assumed GH2 carriers will be loaded to 95% of the total cargo capacity (i.e. 408.5 tonnes) as there will be remaining heel pressure from previous shipments.

After a GH2 carrier disconnects it will depart for the receiving port (Singapore) based on a fixed slow departure speed along the proposed access route.

The GH2 carrier approach to the unloading terminal is based on a fixed time to slow down, approach and connect to the unloading system at one of the two berths. GH2 carriers will queue if a berth is unavailable. Given the receiving ports are relatively well protected, adverse wind and wave conditions aren't expected to affect operability.

Unloading rate is assumed as 33.64 tph (~2000 m3/h or 7.8% of the GH2 carrier capacity per hour) to limit GH2 carrier time at the berth. Hydrogen can be unloaded from two GH2 carriers simultaneously. GH2 carriers will be unloaded till 5% of the total cargo capacity is remaining (i.e. 21.5 tonnes). Unloading beyond 5% requires additional power requirements as the GH2 carrier cargo pressure depletes. Future studies will explore unloading to lower volumes. GH2 carriers will then disconnect and slowly depart based on a fixed time.

After hydrogen unloading, GH2 carriers will be bunkered for refuelling and replenishment of supplies. The complete bunkering operation will take 12-18 hours drawn randomly from a uniform distribution. An additional 2 hours are added for replenishment of supplies every 3 calls.

The GH2 carriers will return to the offshore loading terminal at Carnarvon to repeat the cycle.

GH2 carrier voyage speeds are subject to disruption from adverse weather, wave climate and equipment failures.

The nominal GH2 carrier speed was assumed to be 15.5 knots however the speed reduces based on the significant wave height. NOAA WAVEWATCH data was used to develop probability distributions of significant wave heights along the route of the GH2 carrier voyage.

Cyclones will result in a shutdown of loading and unloading operations. Cyclone data was used to synthesise daily cyclone warnings based on the historic rate of occurrence. GH2 carriers that encounter a cyclone at sea are held out in the simulations. Cyclone warnings are issued for a particular location if the track of the cyclone centre enters a 10° square. Cyclone data for Carnarvon has been obtained from the Bureau of Meteorology while for regions outside Australia records from International Best Track Archive for Climate Stewardship were used.

The simulation considers no storage and 'infinite storage' scenarios. The difference in throughput for no storage and infinite storage for a set number of GH2 carriers are compared.

Mechanical failure and downtime probabilities have been considered for the following equipment. Data has been obtained from the original equipment manufacturer (OEM) and similar systems from previous projects where more accurate information was not available.

- Hydrogen compressors
- Pressure seal of loading and unloading discharge systems
- SAL systems
- GH2 carrier engine
- GH2 carrier propulsion thruster
- GH2 carrier periodic (scheduled) dry docking maitenance
- GH2 carrier in-water survey

## 8.2 Fleet Determination and Sensitivity

An initial GH2 carrier sensitivity test has been conducted to determine the optimal number of H2Neo carriers that should be adopted in the compressed hydrogen shipping cycle. For each GH2 carrier number scenario, the throughput has been calculated for no storage and infinite storage conditions.

Continuous loading occurs when there is no significant change in throughput when increasing the number of GH2 carriers in the cycle. Continuous loading of GH2 carriers occurs at 17 GH2 carriers for Singapore under infinite storage conditions and at 19 GH2 carriers under no storage conditions  As discussed in Section 3.8, the cost of onshore hydrogen storage is quite substantial with CAPEX exceeding AUD 1M per tonne. As the increase in throughput under the infinite storage condition is not considered material for the amount of onshore storage required it was concluded to disregard hydrogen storage for this Study.

Continuous loading is preferred as it provides redundancy to the compressed hydrogen shipping cycle, as throughput will not be as adversely affected from events such as dry docking and mechanical failures which would interrupt the cycle.

## 8.3 Simulation Outcomes

Results from Monte Carlo simulations in this Section are based on 20 years of operation. On average, two out of three compressors may be down for 22.7 hours per year which results in GH2 carrier loading at 50% capacity (i.e 11.42 tph). It is also highly unlikely that all three compressors will be down which results in no loading of GH2 carriers. Such event results in an average annual downtime of 0.08 hours per year.

If both SPMs at the offshore loading terminal in Carnarvon are occupied, GH2 carriers must queue before connection can be made. The average GH2 carrier queue time at Carnarvon is approximately 14-15 hours greater in cycles with continuous loading.

The modelling results indicate the GH2 carriers could generally queue for extended periods, however communication can be made between the GH2 carrier and port to reduce voyage speed and subsequently optimise fuel consumption and minimise operational costs. This will be explored as an optimisation at the next phase of the Study.

The annual throughput over 20 years of operations from the Monte Carlo simulations is provided in Figure 8.2.

**It can therefore be concluded the compressed hydrogen supply chain is able to deliver over 98% of the target throughput, noting that a portion of the hydrogen loss is due to factors external to the compressed hydrogen supply chain e.g. extreme weather events (cyclones).**

From a commercial perspective 19 H2Neo carriers was be adopted for the Study to transport the target rate of 200ktpa to Singapore. Optimation of the simulation during the next stage of the Study will include the larger H2Max carriers and floating storage barge, optimised to consider a variable hydrogen profile.

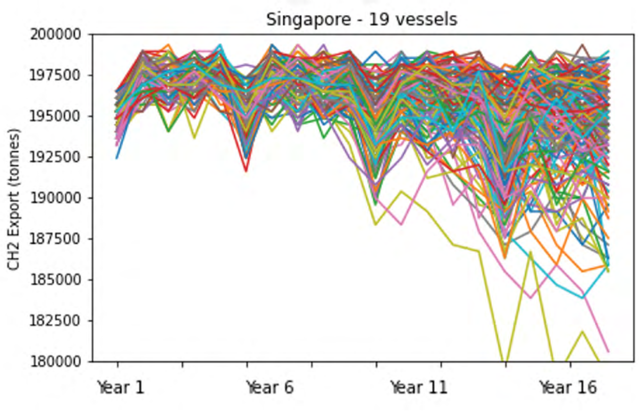



**Figure 8.2**
Annual Throughput Monte Carlo Simulation Results (WSP, 2022)

# 9. Operational Hazard Identification

**A preliminary hazard identification (HAZID) workshop has been undertaken to identify risks that may impact the overall success of the Project. The participants of the workshop include WSP, Provaris, APL NOV and Oropesa. The workshop focused on HAZID unique to compressed hydrogen and offshore loading operations.**

Hazards related to the operations of the GH2 carriers have not been included in this assessment. It is assumed these will be resolved as part of the process of achieving full Class approval with American Bureau of Shipping.

The participants of the workshop were issued a HAZID brief to outline the purpose of the workshop, scope of assessment, agenda and preparation work. Prior to the workshop participants reviewed the guidewords and prompt list provided in the HAZID brief to assist with identifying risks relevant to their area of expertise. Consideration was given to hazards related to the following topics:

- Operability and maintainability
- Constructability
- Development and implementation of design philosophies
- Extreme environmental conditions
- Emergency response

For the hazards identified, current arrangement controls and alternative arrangement controls were also identified. The work completed in advance of the workshop was compiled into a preliminary HAZID risk register which was reviewed during the HAZID workshop.

## 9.1 Scope of Assessment

The workshop addressed the construction, operation, maintenance and environmental impacts of the Project. The breakdown of the scope is provided in Table 9.1.

| Item no. | Scope description |
|---|---|
| **1.01** | Onshore facilities - Compression |
| **1.02** | Onshore facilities - Utilities |
| **1.03** | Onshore facilities - Flare |
| **1.04** | Onshore facilities - Storage |
| **2.01** | Pipeline - Shore crossing |
| **2.02** | Pipeline - Subsea pipeline |
| **3.01** | Offshore loading - GH2 carrier approach and connection |
| **3.02** | Offshore loading - Loading operations |
| **3.03** | Offshore loading - GH2 carrier disconnection and departure |

**Table 9.1**
HAZID Scope of Assessment

## 9.2 Workshop Methodology

The participants gathered in an online workshop forum. The preliminary HAZID risk register was displayed and updated based on discussions within the workshop. The assessment of each scope element commenced with the following steps:

- The designer briefly outlining the broad purpose of the component being studied and displayed on the drawing/PFD
- General questions about the scope and intent of the design were raised and answered by the designer

This process was completed for all scope elements. Additional hazards for each scope element were also identified using a brainstorming process utilising the guidewords and prompt list.

## 9.3 Hazard Identification Outcomes

Each hazard identified and assessed was inserted in the HAZID risk register using the following process:

- A description of the hazard
- Possible causes and consequences
- Alternative arrangements or control options (improvements) as required and where important
- Actions identifying ‘task’ and ‘by organisation or person’ as required and where important (post workshop activity)

A total of 63 hazards were recorded, 2 of which were construction related and 61 were operations related.

A total of 7 hazards were recorded that related to safety in design guidewords and 56 hazards related to hazard and operability (HAZOP) guidewords.

**No hazards were identified to be unmanageable and further risk mitigations / improvements will be provided at the next stage of the Project.**

# 10. Environmental Assessment

**A desktop assessment has been undertaken by Environmental Resources Management Australia (ERM) to examine the environmental sensitivities in the Study area and how they may constrain and influence the future development. The assessment focused on the marine environment and the associated infrastructure, including the pipeline from the onshore compression facilities to the offshore loading terminal, the GH2 carrier loading operations and the associated GH2 carrier movements. The assessment excludes onshore impacts of the Project which have been assessed by ERM on a separate engagement with the Project Proponents. While there are a variety of sources that could lead to environmental impacts, the identified environmental impacts potentially occurring from the Study are not considered unique but will require a robust application of appropriate and recognised mitigation and management measures to prevent unacceptable impacts from occurring. It is also noted the offshore loading facilities will interface with Commonwealth managed fisheries and will therefore likely require approvals separate to the state.**

## 10.1 Environmental Risk Assessment

The sensitivities and constraints identified within the Study area have been grouped into the following eight categories:

1. Marine fauna and avifauna
2. Benthic habitats and communities
3. Protected areas
4. Commercial fisheries
5. Defence and unexploded ordnance
6. Marine vessel traffic
7. Maritime cultural heritage
8. Other marine users and infrastructure

These sensitivities and constraints pose a risk due to heightened public and stakeholder interest, elevated level of regulator environmental assessment, potential for onerous conditions depending on the final design, additional studies ahead of submission. Each of the sensitivities and constraints have been risk assessed using a risk ranking system to identify material environmental, ecological and stakeholder issues that might impact Project development. Each risk is allocated a likelihood and consequence rating as shown in Table 10.1 and Table 10.2 respectively.

Once a risk is allocated a likelihood and consequence rating, it is inserted into the risk matrix shown in Table 10.3 which provides an overall risk rating as defined in Table 10.4. The overall environmental risk summary to the Project is provided in Table 10.5.

| Likelihood | Definition |
|---|---|
| **Certain** | It is certain that the issue will arise or impact will occur. |
| **Likely** | It is highly likely that the issue with arise or impact will occur. |
| **Possible** | It is possible that the issue with arise or impact will occur. |
| **Unlikely** | It is unlikely that the issue with arise or impact will occur. |
| **Highly Improbable** | It is highly improbable that the issue with arise or impact will occur. |

**Table 10.1**
Likelihood Definition

| Consequence | Definition |
|---|---|
| **Extreme** | If this issue arises, the Project may not or will not obtain environmental approvals. |
| **Major** | If this issue arises, considerable time delays will be incurred to resolve the issue through further investigations, stakeholder consultation, negotiations, or other factors. |
| **Moderate** | If this issue arises and the Project is approved, onerous approval conditions are set for the Project. |
| **Minor** | If this issue arises, further investigations, stakeholder consultation, negotiations, or other factors would be required but no significant time delay would be expected. |
| **Insignificant** | If this issue arises, no significant consequences are expected. |

**Table 10.2**
Consequence Definition

| | | Consequence | | | | |
|---|---|---|---|---|---|---|
| | | **Insignificant** | **Minor** | **Moderate** | **Major** | **Extreme** |
| **Likelihood** | **Certain** | Low-Medium | Medium | High | High | High |
| | **Likely** | Low-Medium | Medium | Medium | High | High |
| | **Possible** | Low | Low-Medium | Medium | High | High |
| | **Unlikely** | Low | Low | Low-Medium | Medium | High |
| | **Highly Improbable** | Low | Low | Low-Medium | Medium | Medium |

**Table 10.3**
Risk Matrix

| Consequence | Definition |
|---|---|
| **High** | Risks that need urgent and immediate attention. |
| **Medium** | Risks that require proactive management. |
| **Low-Medium** | Risks that require active monitoring. |
| **Low** | Risks that are below the risk acceptance threshold and do not require active management. |

**Table 10.4**
Risk Definition

**Table 10.5** Environmental Risk Assessment Summary

| Constraint | Comments | Consequence | Likelihood | Overall |
|---|---|---|---|---|
| Marine fauna and avifauna | Overlap with migration (late July to September) and resting (winter) biologically important areas (BIA) for the humpback whale. Whales are particularly susceptible to underwater noise which may occur during the construction phase and potentially the operational phase due to GH2 carrier noise. Humpback whales may rest in the Project area between May and November, but particularly during their southern migration from September to November, including with calves. | Moderate | Likely | Medium |
| | Overlap with a breeding BIA for roseate terns (mid-March to July). | Minor | Possible | Low-Medium |
| | Shore crossing location directly adjacent two endangered loggerhead turtle nests recorded during a recent survey. SPMs ~70 km from habitat critical to the survival of the loggerhead turtle and nesting BIAs around Dirk Hartog Island. Nesting season extends from December to March. | Minor | Possible | Low-Medium |
| | Potential for the area around Carnarvon, including the pipeline alignment to be an important foraging area for vulnerable green turtles, possibly being declared a BIA in the future. | Minor | Possible | Low-Medium |
| | SPMs ~34 km north of a breeding BIA for wedge-tailed shearwaters (mid-August to mid-May) and records of this species in the vicinity of the proposed SPM locations. Light spill is a particular concern, especially for fledglings when they first leave the nest. | Minor | Possible | Low-Medium |
| | Presence of endangered blue whales with distribution and migration BIAs in waters close to the entrance to Geographe Channel for April to August and October to December. | Insignificant | Possible | Low |
| Benthic habitats and communities | Information about benthic communities and habitats in the immediate vicinity of the pipeline alignment and SPM locations is scarce and will require future studies to be conducted to enable impact assessment. The potential for sensitive seagrass communities in the area represent a potential constraint if they include Priority Ecological Community Posidonia australis complex meadows, or if large areas of seagrass (whether Posidonia or other species) or other benthic ecological communities could be impacted by the pipeline construction or GH2 carrier spills. Seagrass was heavily impacted by the marine heatwave of 2011, with limited recovery since that time (Simone Strydom, 2020); and seagrass forms an important part of the diet of dugongs and green turtles. | Moderate | Likely | Medium |

**Table 10.5** Environmental Risk Assessment Summary (continued)

| Constraint | Comments | Consequence | Likelihood | Overall |
|---|---|---|---|---|
| Protected areas | There is no overlap with any protected areas, however the Shark Bay World Heritage Area (SBWHA) and the Commonwealth and State Shark Bay Marine Parks surround the proposed infrastructure locations at closest distances of 5 km, 13 km and 27 km respectively. The shore crossing location is nearby the Miaboolya Beach Fish Habitat Protection Area and >20 km from the Point Quobba Fish Habitat Protection Area (FHPA). | Moderate | Possible | Medium |
| Commercial fisheries | The site overlaps with the management boundaries of a number of commercial fisheries. The only Commonwealth fishery likely to be affected is the Western Tuna and Billfish Fishery. WA State Fisheries most likely to be affected are the Shark Bay Crab Managed Fishery, Shark Bay Prawn Managed Fishery, Shark Bay Scallop Managed Fishery and Gascoyne Demersal Scalefish Managed Fishery. | Minor | Possible | Low-Medium |
| Defence and unexploded ordnance | There are designated Defence Practice areas to the north of the Project off the Ningaloo coast. The potential risk from the unexploded ordnance (UXO) site is highly improbable. | Minor | Unlikely | Low |
| Marine vessel traffic | Vessel traffic crosses the pipeline alignment with elevated numbers of vessels in the vicinity of the SPM locations. Commercial fishing vessels operate out of Carnarvon. | Minor | Possible | Low-Medium |
| Maritime cultural heritage | The only shipwrecks in the vicinity of the proposed Project locations are three vessels near the proposed entry point into Shark Bay and the entrance to Geographe Channel. | Insignificant | Unlikely | Low |
| Other marine users and infrastructure | Major tourism operations in the region are focused primarily north and south of the Project area in Shark Bay and the Ningaloo coast. Recreational fishing is popular in the Carnarvon area and Project surrounds, including at Miaboolya Beach. | Minor | Possible | Low-Medium |

## 10.2 Next Steps

| Recommendations | Description and notes |
|---|---|
| **Water and sediment quality study** | Background water quality data is not readily available for the areas of interest. Only one sediment sampling study was completed to the south of Carnarvon, which is restricted in its applicability. |
| **Benthic communities and habitats surveys of Project footprint** | Collection of digital baseline data on the spatial extent of benthic communities and habitats and quantitative ground truthing of the type and extent of benthic communities and habitats (BCH) near the pipeline alignment e.g. drop camera surveys and geophysical mapping tools e.g. side scan sonar / multibeam sonar surveys. |
| **Underwater noise modelling** | To be undertaken to understand the impacts of GH2 carrier noise to humpback whales in the resting BIA, as well as impacts on whales and other noise sensitive species from pile driving activities. |
| **Bird surveys** | The Project is undertaking bird utilisation surveys of the area, while focusing on the proximity of migratory species to the proposed locations of the wind turbine infrastructure (not in Provaris' scope of Study), the scope is to include seabird surveys. |
| **Oil spill modelling and management plan preparation** | Given the proximity to protected marine areas such as the SBWHA, potential for spills from operational vehicles is likely to be a sensitive issue for stakeholders. |
| **Dredge plume and brine discharge modelling** | Dredging is currently not proposed for the offshore loading terminal, however if this were to change dredge modelling will provide invaluable information for managing impacts to seagrass beds or mangrove habitats. While outside the scope of this Study, brine discharge from desalination will be an integral component to the Project and may impact salinity levels in SBHWA. Brine discharge modelling is therefore recommended to determine the impact to the marine environment. |

**Table 10.6**
Environmental Assessment Next Steps

# 11. Job Creation Assessment

**An early assessment of job creation has been undertaken by Turner & Townsend (T&T) for the onshore compression facilitates. The scope includes the analysis and development of a Class 5 factored estimate for the number of jobs (blue and white collar) for the construction and operations phase and a Level 2 resource-based schedule.**

The scope of assessment excludes the following:

- Electrolyser facility and other supporting facilities such as the seawater intake, desalination, water treatment, brine discharge and electrical switchyard/substations.
- Works downstream of the onshore compression facilities (i.e. outgoing pipeline, shore crossing, subsea pipeline and offshore loading terminal).

All costs associated to the job creation estimate have been developed in Australian dollars (AUD) and is based on rates current for 2022.

### 11.1.1 CAPEX Job Creation

The simulation was created based on the AACE Class 5 CAPEX estimate developed for the onshore compression facilities. The labour costs needed for installation and engineering, procurement and construction management (EPCM) has been derived by Happel's method (AACE International Recommended Practice No.59R-10) which uses factors for each class of equipment.

An average hourly rate of $70 per hour for site personnel and $120 per hour for home office personnel has been assumed to convert labour costs to man-hours.

A 14/7 (14 days on, 7 off) site crew roster at 10 hours per day has been assumed, resulting in an average of 220 hours worked per month for blue collars.

A Level 2 schedule has been developed targeting project completion in 34 months and benchmarking average durations for major site works (earthworks, structural, mechanical, piping, electrical and instrumentation) from similar sized projects.

Field and office full time equivalents (FTE) resources have been derived by distributing total project hours over total project duration.

### 11.1.2 OPEX Job Creation

The simulation was created based on a yearly OPEX estimate for operations developed for the onshore compression facilities. Fixed and variable costs driven by resources have been identified and analysed.

Blue collar personnel included in the estimate are listed below:

- 6 plant operators
- 2 mechanic operators
- 2 instrumentation and electrical and control (IEC) operators
- 3 extra resources to cover for vacation/sick allowance

The blue-collar salaries have been estimated as $2.68M based on the below assumptions:

- 2 day shifts per day
- 1 night shift per day
- 8 hours per shift
- 4 FTEs per day shift (2 plant operators, 1 mechanic operator and 1 IEC operator)
- 2 FTEs per night shift
- 10 total FTEs (day and night)
- $80 per hour average hourly rate
- 15% allowance for holidays and sick days

The OPEX estimate does not include contract services for general staff (operations manager, operations superintendent, maintenance superintendent, site administration etc.) as these are part of the overall site wide facility team.

Contract services and third-party engineering service costs have been assessed on an average rate of $120 per hour.

## 11.2 Summary of Findings

As seen in Figure 11.1 the evaluation identified total project hours of circa 1.71M over a 34-month execution plan. Circa 1.41M hours are related to blue collars supporting constructing and commissioning (C&C), while circa 291,000 hours are related to EPCM activities.

Figure 11.2 shows the Onshore Compression Facilities alone can support an estimated 615 direct FTE jobs during construction, reaching a maximum of 514 FTE for construction and commissioning works and 101 FTE for EPCM activities.

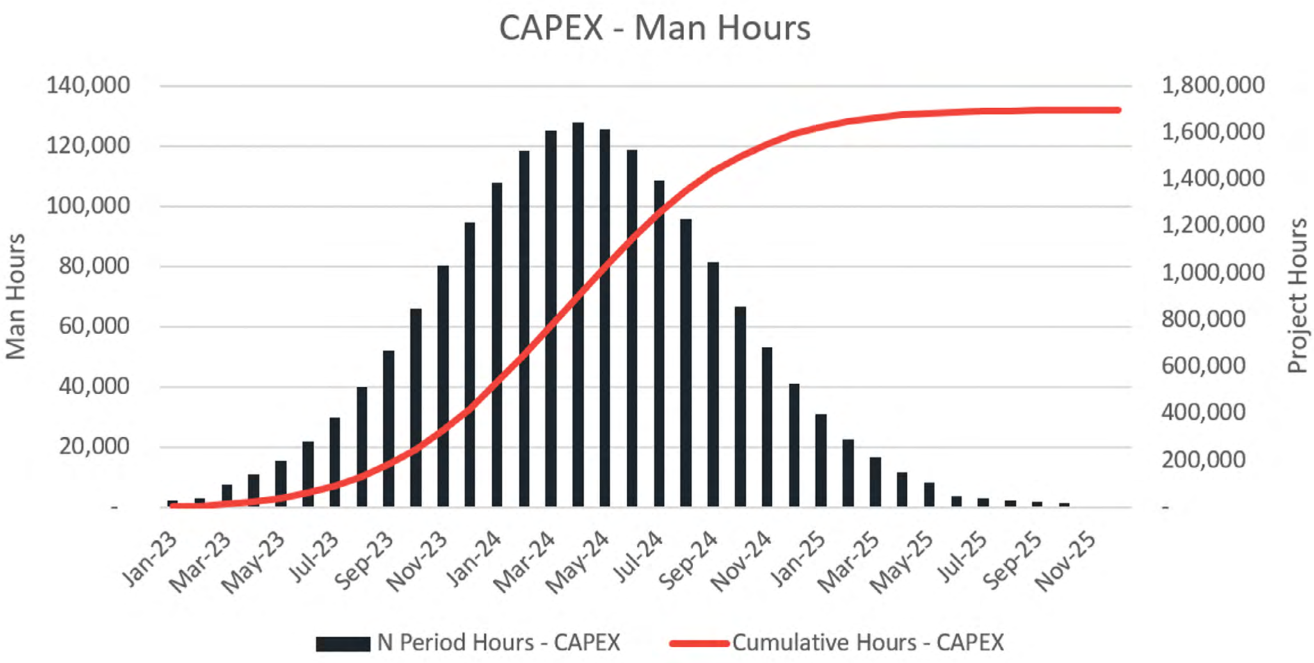



**Figure 11.1**
CAPEX Man Hours

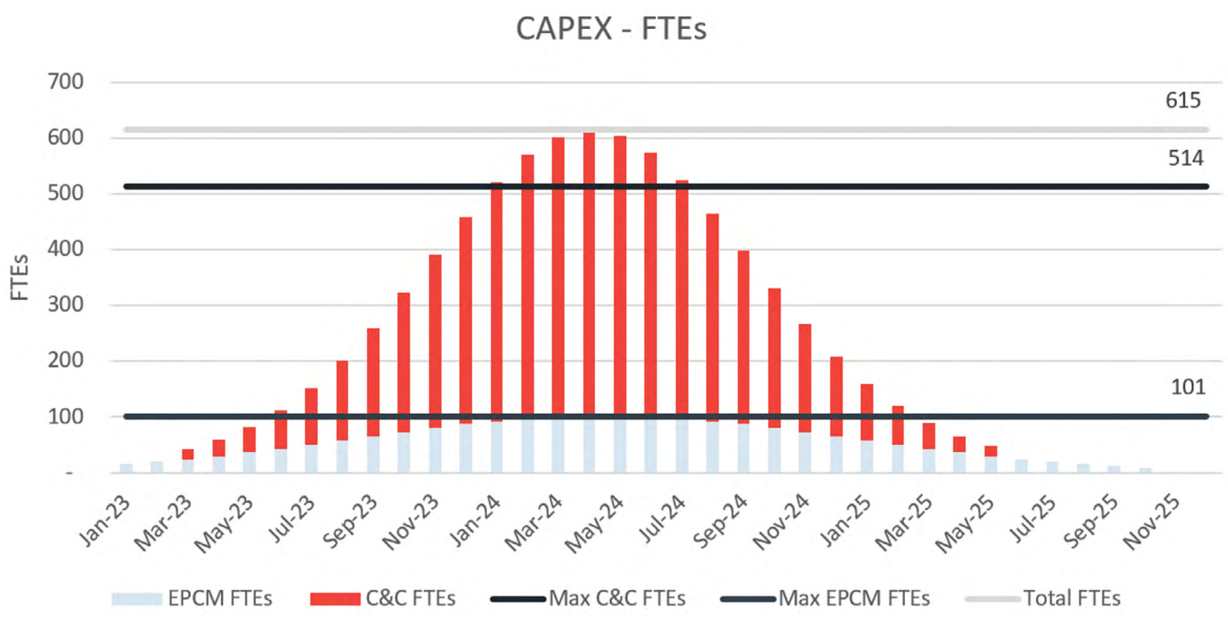



**Figure 11.1**
CAPEX Man Hours

As seen in Figure 11.3 the evaluation identified circa 35,802 hours per year are required for operations. Circa 33,488 hours are related to blue collars for ordinary supervision, whereas circa 2,314 hours are related to supporting contract services.

The onshore compression facilities are expected to support an estimated 14 direct FTE jobs on an annual basis. Daily equipment monitoring, coordination of required maintenance and communications with GH2 carriers will be carried out by 13 FTEs working on 3 shifts per day, while circa 1 FTE will provide ongoing general services (mechanical, IEC and pipefitting maintenance).

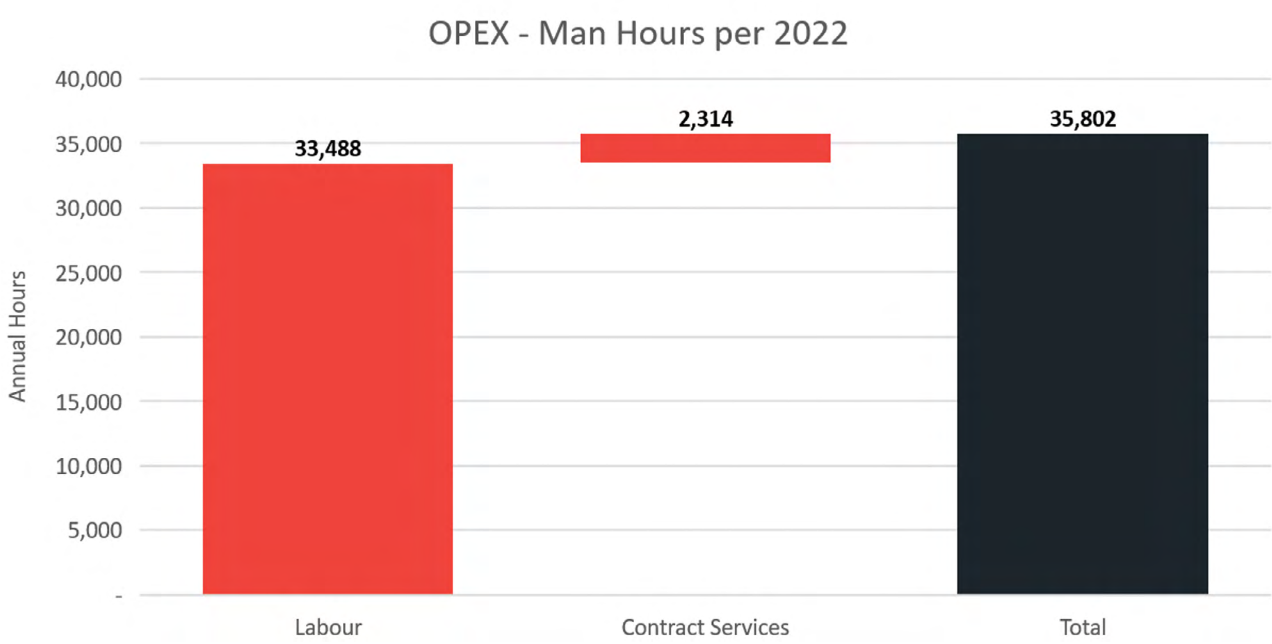



**Figure 11.1**
CAPEX Man Hours

# 12. Study Commercials

## 12.1 Cost Estimate

An AACE Class 5 estimate has been prepared for various components studied in the compressed hydrogen supply chain. Costs are presented in United States dollars (USD).

**Investigations, detailed design, taxes, duties, approvals, land/seabed acquisition are excluded unless noted otherwise. Cost of hydrogen production and hydrogen distribution from the import terminal to the end customer is also excluded.**

Changes to the scope, design basis and assumptions could have a material impact on the Project costs. Costs are applicable to the time of issuing this report. It is recommended that all costs are verified by a contractor capable of delivering the works to ensure they reflect the current understanding of market conditions.

A summary of the CAPEX and OPEX items by cost area for the primary case (Singapore shipments with 19 H2Neo carriers) is provided in Table 12.1 and Table 12.2 respectively. These costs are in USD in 2022 real terms.

| Cost Area | Cost (USD) |
|---|---|
| **CAPEX Total** | Approx. $2.5 Billion<br>Includes, compression pipeline, offshore loading, ship fleet and unloading terminal |

**Table 12.1**
CAPEX Summary

| Cost Area | Cost (USD) |
|---|---|
| **The OPEX of the full supply chain** | |
| **Annual OPEX Total** | Approx. $80 Million |

**Table 12.2**
OPEX Summary

### 12.1.1 Onshore Compression Facilities and Onshore Pipeline

#### CAPEX

Cost of equipment has been based on budgetary quotes supplied by vendors or in-house estimating tools and previous project benchmarks where information was not available.

Cost of equipment installed is based on Lang factors which have been developed from historical similar facilities and area classifications. The lang factors account of foundations, structural, instrumentation and electrical construction specific to the piece of equipment within a 10 m radius.

The total CAPEX of the onshore compression facilities includes freight, ancillaries, engineering and procurement, construction management, chemicals, start up and owner cost all as nominal percentages.

#### OPEX

The operating costs of the onshore compression facilities are divided into the following categories.

- Labour – Includes salaries, benefits, vehicle costs, travel, accommodation, meals, entertainment and training.
- Contract services – Third party services including road maintenance, turnarounds, mechanical services, lab work etc.
- Equipment rental – Rental of equipment used for maintenance including scaffolding etc.
- Purchased energy – Electricity, fuel gas and diesel are the main energy sources used. As per advice from the Project Proponents this has been assumed as AUD 0.03/kWh in real 2022 terms.
- Supplies and materials – Motor fuel, lubricants, computer, pipefitting materials, instrumentation etc.
- Regional taxes and fees – Regulatory, insurance, taxes and other government fees.
- Miscellaneous – Items that do not fit into the above categories including general field and office expenses.

The total annual OPEX of the onshore compression facilities is summarised in Table 12.4. Costs are in real 2022 terms.

| Item | Cost (USD) |
|---|---|
| **Total** | Approx. $11 million |

**Table 12.4**
Onshore Compression Facilities OPEX Summary

## 12.2 Commercial Modelling

### 12.2.1 Basis of Modelling

A commercial model was developed using discounted cash flow (DCF) methodology incorporating the following inputs:

- Modelling currency is in USD
- Capital and operating costs as presented in Section 12.1.
  - Capital costs are spread across 3 years of construction. Capital costs are spread equally over the period except for the GH2 carriers, for which 20% will be paid in year 1 and 2 and 60% in year 3.
  - Operating costs are spread over a 25 year period. At the end of the 25 year operating phase it is assumed H2Neo carriers will be sold for their residual value.
- Valuation date is 2026 (i.e. year for which real and net present value (NPV) discounted costs are expressed)
- All costs are inserted into the model in native currency they have been prepared
- Discount rate of 8% on real costs before tax
- Contingency is not included in the model

### 12.2.2 Methodology

The modelling assembles the capital and operating costs estimates, and coverts and aggregates the costs according to the global modelling requirements. The primary outputs required at the NPV of the whole of life costs (USD 2026 base), and the LCOH (USD/kg) based on the throughput analysis provided in the cycle time analysis.

The NPV calculation aggregates the costs in both 2026 real and nominal terms, and converts them to the base currency (USD), before applying the discount rate of 8% (real before tax) to the real cashflows to calculate their NPV. The LCOH is the NPV of the cost, divided by the discounted total throughput of hydrogen delivered during the operating phase.

The sensitivity of the NPV costs was calculated four factors. For each factor, a high and low case was defined as likely to extreme variations. The factors varied and include: Escalation; Foreign exchanges rates; Discount rate; and Fuel cost.

### 12.2.3 Levelised Cost of Hydrogen – Compressed and Delivered

For the primary destination Singapore and with a H2Neo carrier fleet count of 19, the base case levelised cost of compression, pipeline, loading, shipping fleet and delivery of hydrogen is USD 2.48 per kg. This figure excludes the  production cost of hydrogen for 200ktpa annualised production.

**LCOH**
**Compression, pipeline, loading, shipping and delivery:**

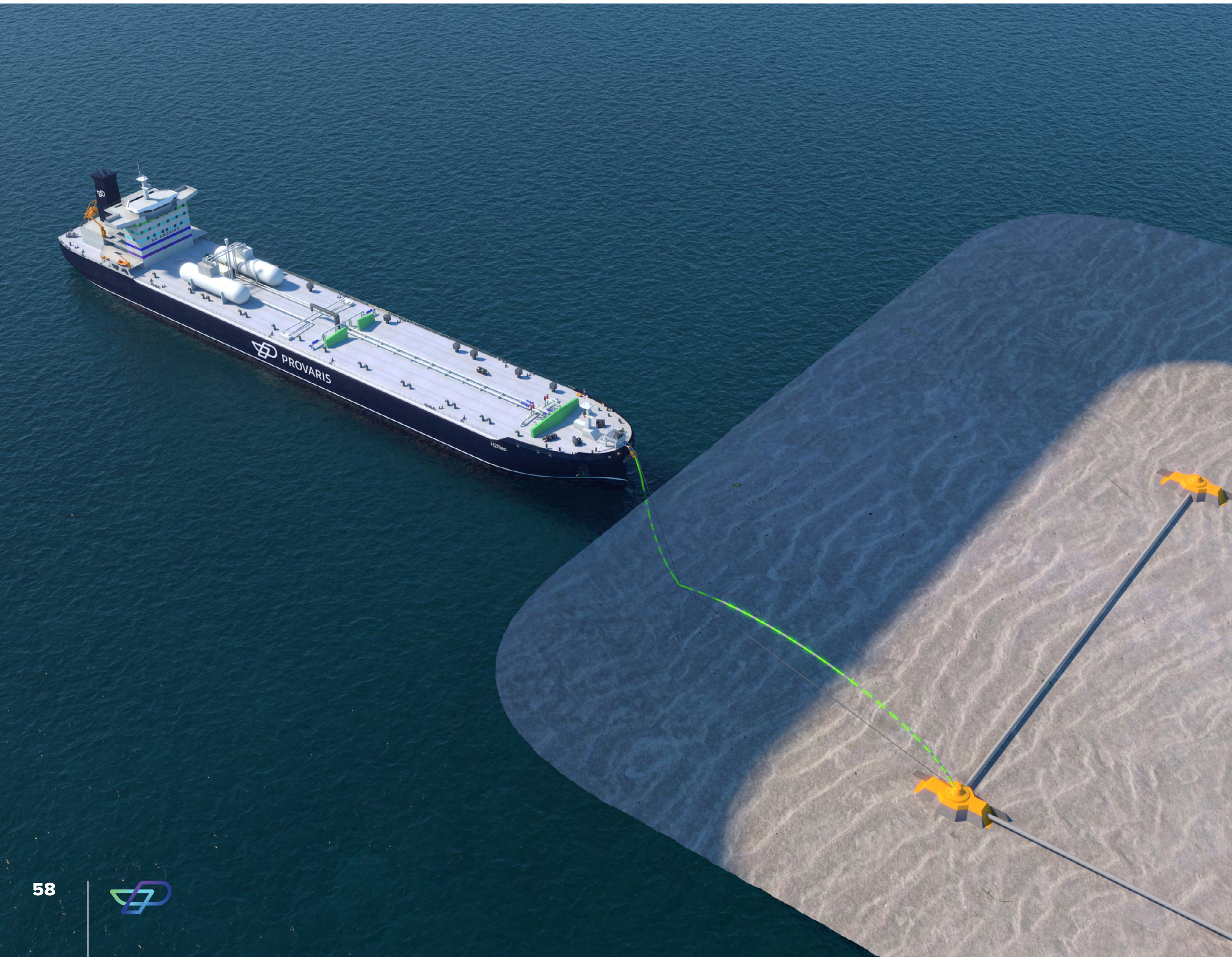
**US$2.48 per kg**

# 13. Conclusions and Recommendations

**The outcomes of this Study indicate that compressed hydrogen is a technically and commercially feasible method of exporting hydrogen from the Project to Asia Pacific. The Study has explored exporting a target 200,000 tpa of green hydrogen from the HyEnergy project to Singapore, with an average delivery rate of over 98% of the target annual throughput.**

Cost estimates developed from the technical workstreams were fed into a commercial model to evaluate the LCOH. The modelling indicates the LCOH for compression and shipping to Singapore is USD 2.48 per kg, based on a fleet of H2Neo carriers.

An initial hazard identification and environmental impact identification assessment was undertaken and indicates there are no significant constraints that should prevent the Study from progressing into the next stage of design and development



## 13.1 Next Steps

The Study has identified high priority works in Table 13.1 that can reduce the level of uncertainty and should be included in the scope of the next stage of the Study along with typical design development activities which have not been identified.

| Area of Study | Recommendations |
|---|---|
| **General** | Optimisation study for hydrogen storage and BESS (to be undertaken as part of the upstream design and wider Project) |
| | Further design and development of the GH2 Carrier by Provaris including obtaining full Class approvals and integration with the BLS |
| | Further studies related to site selection of the onshore facilities |
| | Obtain further funding to progress the Project |
| **Onshore Compression Facilities** | Onshore compression facilities Pre-FEED/FEED study |
| | Hydrogen storage alternatives study |
| **Shore Crossing and Subsea Pipeline** | Detailed literature review of site geology |
| | Geotechnical and geophysical survey, seabed sediment interpretation and sampling |
| | Shore crossing and subsea pipeline Pre-FEED/FEED study |
| **Offshore Loading Terminal** | Bathymetry survey at offshore loading terminal |
| | Local stakeholder engagement and review of legislative compliance |
| | Metocean data collection and modelling |
| | Mooring system analysis and vessel motion modelling |
| | Offshore loading terminal Pre-FEED/FEED study |
| **GH2 carrier Loading Operations** | SAL and BLS development and hydrogen qualification |
| **Unloading Terminal at Receiving Port** | Stakeholder engagement at receiving port |
| | Unloading terminal concept design |
| **Cycle Time Analysis** | Consideration of variable hydrogen production in cycle time analysis |
| | Further scenario modelling e.g. inclusion of larger carriers (H2Max) |
| **Environmental Assessment** | Water and sediment quality study |
| | Benthic communities and habitats surveys of Project footprint |
| | Underwater noise modelling |
| | Bird surveys |
| | Oil spill modelling and management plan preparation |
| | Impact assessment of the offshore loading facility’s construction and operation activities |
| **Project Execution Plan** | Project delivery model and O&M strategy study |

**Table 13.1**
Study High Priority Next Steps

# 14. Disclaimer

This study may contain forward looking statements concerning projected costs, approval timelines, construction timelines, earnings, revenue, growth, outlook or other matters (“Projections”). You should not place undue reliance on any Projections, which are based only on current expectations and the information available to Provaris. The expectations reflected in such Projections are currently considered by Provaris to be reasonable, but they may be affected by a range of variables that could cause actual results or trends to differ materially, including but not limited to: price and currency fluctuations, the ability to obtain reliable hydrogen supply, the ability to locate markets for hydrogen, fluctuations in energy and hydrogen prices, project site latent conditions, approvals and cost estimates, development progress, operating results, legislative, fiscal and regulatory developments, and economic and financial markets conditions, including availability of financing. Provaris undertakes no obligation to update any Projections for events or circumstances that occur subsequent to the date of this announcement or to keep current any of the information provided, except to the extent required by law. You should consult your own advisors as to legal, tax, financial and related matters and conduct your own investigations, enquiries and analysis concerning any transaction or investment or other decision in relation to Provaris. $ refers to Australian Dollars unless otherwise indicated.

# 15. Bibliography


**Columbia SIPA. (2021). The Carbon-Neutral LNG Market: Creating a Framework for Real Emissions Reductions.**

Retrieved from Columbia SIPA: https://www.energypolicy.columbia.edu/research/commentary/carbon-neutral-lng-market-creating-framework-real-emissions-reductions#:~:text=LNG%2DSpecific%20Emissions%20Calculations&text=For%20example%2C%20when%20combusted%2C%20natural,2.76%20metric%20tons%2

**Google Earth. (2022). Google Earth.**

Retrieved from Google Earth.

**IEA. (2019). The future of hydrogen, Data and assumptions.**

Retrieved from IEA: https://iea.blob.core.windows.net/assets/29b027e5-fefc-47df-aed0-456b1bb38844/IEA-The-Future-of-Hydrogen-Assumptions-Annex_CORR.pdf

**Madugula, S. H. (2021). Science Direct.**

Retrieved from Estimation of $CO_2$ emissions from petroleum refineries based on the total operable capacity for carbon capture applications: https://www.sciencedirect.com/science/article/pii/S2666821121000788

**MARS. (2022). Marine Sediments (MARS).**

Retrieved from Australian Government, Geoscience Australia: http://dbforms.ga.gov.au/pls/www/npm.mars.search

**Navionics. (2022). Navionics Chart Viewer.**

Retrieved from Navionics: https://webapp.navionics.com/#boating

**NTC. (2019). Carbon Dioxide Emissions Intensity for New Australian Light Vehicles 2018.**

Retrieved from National Transport Comission: https://www.ntc.gov.au/sites/default/files/assets/files/Carbon%20dioxide%20emissions%20intensity%20for%20new%20Australian%20light%20vehicles%202018.pdf

**Provaris. (2022). ASX Announcements.**

Retrieved from Provaris: https://wcsecure.weblink.com.au/pdf/PV1/02556177.pdf

**RMI. (2019). Run on Less with Hydrogen Fuel Cells.**

Retrieved from https://rmi.org/run-on-less-with-hydrogen-fuel-cells/#:~:text=By%20contrast%2C%20hydrogen%20has%20an,more%20than%20diesel%20or%20gasoline.

**Simone Strydom, K. M. (2020). Too hot to handle: Unprecedented seagrass death driven by marine heatwave in a World Heritage Area. Global change biology.**

**UNSW. (2021). HySupply Publication.**

Retrieved from GlobalH2E: https://www.globh2e.org.au/_files/ugd/8d2898_153f1369fe4742be9a95d34cb6866394.pdf

# 16. Abbreviations

| | |
|---|---|
| **AACE** | Association for the Advancement of Cost Engineering |
| **ABS** | American Bureau of Shipping |
| **ACS** | Acoustic control system |
| **ADCP** | Acoustic doppler current profiler |
| **AIP** | Approval in Principle |
| **AMPP** | Association for Materials Protection and Performance |
| **ANSI** | American National Standards Institute |
| **API** | American Petroleum Institute |
| **ASA** | Acoustical Society of America |
| **ASHRAE** | American Society of Heating and Air-Conditioning Engineers |
| **ASME** | American Society of Mechanical Engineers |
| **ASTM** | American Society for Testing and Materials |
| **AUD** | Australian dollar |
| **AWS** | American Welding Society |
| **BC Act** | Biodiversity Conservation Act |
| **BCH** | Benthic communities and habitats |
| **BESS** | Battery energy storage systems |
| **BIA** | Biologically important areas |
| **BLS** | Bow loading system |
| **BOP** | Balance of plant |
| **BPVC** | Boiler and Pressure Vessel Code |
| **BS** | British Standards |
| **C&C** | Construction and commissioning |
| **CAD** | Canadian dollar |
| **CAPEX** | Capital expenditure |
| **CSA** | Canada Standards Association |
| **D&C** | Design and construct |
| **DAWE** | Department of Agriculture, Water and Environment |
| **DBCA** | Department of Biosecurity, Conservation and Attractions |
| **DBNGP** | Dampier Bunbury Natural Gas Pipeline |
| **DCF** | Discounted cash flow |
| **DCS** | Distributed control system |
| **DJTSI** | Department of Jobs, Tourism, Science, and Innovation |
| **DNV** | Det Norske Veritas |
| **DoT** | Department of Transport |
| **DPIRD** | Department of Primary Industries and Regional Development |
| **DPLH** | Department of Planning, Lands and Heritage |
| **DWER** | Department of Water and Environmental Regulation |
| **EBITDA** | Earnings before interest, tax, depreciation and amortisation |
| **ECI** | Early contractor involvement |
| **EDB** | Economic Development Board |
| **EIS** | Environmental impact statement |
| **EMA** | Energy Market Authority |
| **EN** | Euro Norm |
| **ENVID** | Environmental impact identification |
| **EP Act** | Environmental Protection Act |
| **EPA** | Environmental Protection Authority |
| **EPBC** | Environmental Protection and Biodiversity Conservation Act |
| **EPC** | Engineering, procure and construct |
| **EPCM** | Engineering, procurement and construction management |
| **EPSD Act** | Environment Protection (Sea Dumping) Act |
| **ESD** | Emergency shutdown |
| **ESDV** | Emergency shutdown valve |
| **ERM** | Environmental Resources Management |
| **ESSA** | Environmentally Sensitive Sea Area |
| **FEED** | Front end engineering design |
| **FHPA** | Fish Habitat Protection Area |
| **FID** | Final investment decision |
| **FKOD** | Flare knockout drum |
| **FTE** | Full time equivalent |
| **FX** | Foreign exchange |
| **GEV** | Global Energy Ventures (now known as Provaris Energy) |
| **GH2** | Gaseous hydrogen |
| **H2** | Hydrogen |
| **HAZID** | Hazard identification |
| **HAZOP** | Hazard and operability |
| **HDD** | Horizontal directional drill |

| | |
|---|---|
| **HiPAP** | High precision acoustic positioning |
| **HP** | High pressure |
| **Hs** | Significant wave height |
| **IA** | Instrument air |
| **IEA** | International Energy Agency |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IEC** | Instrumentation and electrical and control |
| **IES** | International Electrotechnical Commission |
| **ID** | Inner diameter |
| **ISA** | International Society of Automation |
| **ISO** | International Organisation for Standardisation |
| **ISPS** | International Ship and Port Facility Security |
| **KPI** | Key performance indicator |
| **LAT** | Lowest astronomical tide |
| **LCOH** | Levelised cost of hydrogen |
| **LH2** | Liquefied hydrogen |
| **LNG** | Liquified natural gas |
| **LP** | Low pressure |
| **LPG** | Liquified petroleum gas |
| **LPS** | Lower polyester segment |
| **LRS** | Lower riser segment |
| **MCC** | Motor control centre |
| **MLA** | Marine loading arm |
| **MoU** | Memorandum of understanding |
| **MARS** | Marine sediments |
| **MDO** | Marine diesel oil |
| **MLCW** | Mooring line clump weight |
| **MPA** | Maritime and Port Authority |
| **MWPA** | Mid-West Ports Authority |
| **MTI** | Ministry of Trade and Industry |
| **MTOFSA** | Maritime Transport and Offshore Facilities Security Act |
| **NEMA** | National Electrical Manufacturers Association |
| **NFPA** | National Fire Protection Association |
| **NH3** | Ammonia |
| **NPV** | Net present value |
| **O&M** | Operations and maintenance |
| **OCIMF** | Oil Companies International Marine Forum |
| **OEM** | Original equipment manufacturer |
| **OPEX** | Operational expenditure |
| **P&ID** | Piping and instrumentation diagram |
| **PAA** | Port Authorities Act |
| **PIANC** | Permanent International Association of Navigational Congresses |
| **PLC** | Programmable logic controller |
| **PLEM** | Pipeline end manifold |
| **PMC** | Project management contractor |
| **Provaris** | Provaris Energy |
| **QRA** | Quantitative risk assessment |
| **QRH** | Quick release hooks |
| **RBA** | Reserve Bank of Australia |
| **REV** | Riser end valve |
| **s/s** | Seam to seam |
| **SAL** | Single anchor loading |
| **SBWHA** | Shark Bay World Heritage Area |
| **SGD** | Singapore dollar |
| **SMR** | Steam methane rolling |
| **SPA** | Shipping and Pilotage Act |
| **SPM** | Single point mooring |
| **T&T** | Turner & Townsend |
| **TCE** | Target cost estimate |
| **TEMA** | Tubular Exchanger Manufactures Association |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organisation |
| **UKC** | Under-keel clearance |
| **UPS** | Upper polyester segment |
| **URS** | Upper riser segment |
| **USD** | United States dollar |
| **UXO** | Unexploded ordnance |
| **VFD** | Variable frequency drive |
| **WT** | Wall thickness |
| **YMAC** | Yamatji Marlpa Aboriginal Corporation |

# Appendix A

## Reference Guidelines, Standards and Codes

**Table A.1 presents a list of guidelines, standards and codes that have been referred to in this Study. This is not considered a comprehensive list and only identifies the most significant guidance referred to in this Study.**

| Guidance Typew | Title |
|---|---|
| Australian / New Zealand Standards | AS/NZS 2885.4:2016 Pipelines – Gas and liquid petroleum Submarine Pipeline Systems |
| American Guidelines | Acoustical Society of America (ASA) |
| | American Petroleum Institute (API) |
| | API 520 Sizing, Selection, and Installation of Pressure-relieving Devices |
| | API 2000 Venting Atmospheric and Low-Pressure Storage Tanks |
| | American National Standards Institute (ANSI) |
| | American Society of Heating and Air-Conditioning Engineers (ASHRAE) |
| | American Society of Mechanical Engineers (ASME) |
| | B16.34 Valves Flanged, Threaded and Welded End |
| | American Society for Testing and Materials (ASTM) |
| | American Welding Society (AWS) |
| | National Electrical Manufacturers Association (NEMA) |
| | NFPA 72 National Fire Alarm Code |
| British Standards | BS 6349 Part 1 Maritime Structures – General Criteria |
| | BS 6349 Part 2 Maritime Structures – Design of Quay Walls, Jetties and Dolphins |
| | BS 6349 Part 4 Maritime Structures – Design of Fendering and Mooring System |
| Eurocodes | BS EN 1990 – Basis of Structural Design |
| | BS EN 1992 – Design of Concrete Structures |
| | BS EN 1993 – Design of Steel Structures |
| | BS EN 1997 – Geotechnical Design |
| International | Association for Materials Protection and Performance (AMPP) |
| | CSA B51:19 Boiler, Pressure Vessel and Pressure Piping Code |
| | Institute of Electrical and Electronics Engineers (IEEE) |
| | International Electrotechnical Commission (IES) |
| | International Organisation for Standardization (ISO) |
| | International Society of Automation (ISA) |
| | Tubular Exchanger Manufacturers Association (TEMA) |
| PIANC Guidelines | PIANC WG3: Guidelines for the Design of Fender Systems |
| | PIANC WG121: Harbour Approach Channels – Design Guidelines |
| | PIANC WG158: Masterplans for the Development of Existing Ports |
| Vessel Design | American Bureau of Shipping (ABS) |
| | Det Norske Veritas (DNV) |
| Vessel Mooring | OCIMF Mooring Equipment Guidelines (MEG4) |
| Vessel Security | International Ship and Port Facility Security (ISPS) Code |
| Work Healthy and Safety | National Code of Practice for Noise management and Protection of Hearing at Work 2004 |
| | Safe Design of Structures Code of Practice 2012 |
| | Western Australia Work Health and Safety Act 2020 |

**Table A.1**
Reference Guidelines, Standards and Codes

# Appendix B

## Project Execution Plan

# B1 Project Delivery Model

## B1.1 Overview

The contracting and procurement strategy will have a significant effect on the subsequent phases of the overall Project. A preferred method has not been selected as part of this Study, however a number of strategies have been reviewed in Section B1.2 and are to be further investigated at the next phase of the Project along with others that have not been identified. The strategy may also differ for the onshore facilities (at the loading and receiving terminal) and the delivery of the GH2 carriers.

There are a range of project delivery models that are commonly adopted to deliver large scale infrastructure projects however there has not been any precedent set for large scale hydrogen production projects in Australia. A number of factors are to be considered when selecting the preferred approach which include the following (note this is not considered an exhaustive list):

- Alignment with the objectives of the broader Project and owner (assumed as the Project Proponents)
- Level of control the owner wants to retain
- Complexity of the Project
- Remote location of the Project
- Maturity of engineering
- Allocation of risk to each party
- Time constraints
- Experience and capability of the owner
- Project capital cost
- Requirements of finances and the accepting level of risk
- Access to expertise, for example the desired project delivery expertise may only be available with a limited set of companies and not widely accessible on the market
- Complexity and interfaces between the various specialist equipment packages
- OEM selection noting some OEMs may favour a turnkey EPC model, particular those capable of delivering large or multiple plant segments

## B1.2 Project Delivery Models to Consider

### B1.2.1 Integrated Owner's Team

An owner's team is augmented by staff from a project management contractor (PMC), who bring engineering skills as well as the procurement and construction management of the contract packages on behalf of the owner.

A summary of advantages and disadvantages to this model is provided in Table B.1. It is recommended to consider an integrated owner's team delivery model as it could provide the quickest, lowest cost and most efficient delivery strategy, however it generally relies on an owner with capital delivery experience and does not support spreading owner's risk through lump sum contractors.

| Advantages | Disadvantages |
| --- | --- |
| Small independent team focussed on the owner's interest | Less time and cost certainty |
| Flexibility in the detailed procurement of the overall program of works allowing for separation of technical scopes, access to competitive engineering pricing for detailed engineering, access to preferred specialised engineering expertise where required, opportunity to capture market efficiency and reduce overall cost | PMC unlikely to be able to take on principal contractor risk |
| High quality outcomes and certainty of delivery through the combined benefits of an owner's engineer for consistent technical oversight across all works and access to tier 1 project management systems | Owner is required to have operational knowledge to undertake decision making |
| Allows owner quick access to a wide range of skills in the PMC on an as required basis | |
| Able to provide safety net as engineer or contractor of last resort in event of main works failure | |

**Table B.1**
Integrated Owner's Team Summary

### B1.2.2 Single EPC Turnkey

Sole contractor EPC (engineer, procure and construct) works are carried out on a lump sum design and construct basis. The contractor will carry the owner's feasibility study design through detailed design, construction, and commissioning. Design checks, quality issues and commercial aspects of the contract are then managed by owner's team with assistance from an owner engineer to advise on technical aspects.

A summary of advantages and disadvantages to this model is provided in Table B.2. It is recommended to consider a negotiated form of single EPC turnkey as it will provide the cost certainty to allow progression of the Project.

| Advantages | Disadvantages |
|---|---|
| Single point of accountability as principal contractor risk can be clearly assigned | Limited market players willing to take lump sum risk on a project with a large capital cost |
| High level of cost and schedule certainty | Typical takes a long time to negotiate, as a result design (and Project) may stall until EPC agreed |
| Allows for full vendor/design integration risk management by contractor | Expensive as fixed price will contain a high level of risk allowance |
| | Little control of design and subcontractor decisions |
| | Requires high levels of contract administration, noting there may be peripheral utility and other items outside the battery limits that will require separate contracts to enable the contractor to progress. Project delivery capability is therefore still required in the owner's team to ensure interfaces are managed efficiently. |

**Table B.2**
Single EPC Turnkey Summary

### B1.2.3 Managing Contractor

A sole managing contractor carries out all works on a pass-through design and construct (D&C) basis. In this instance the contractor is involved earlier than EPC, and the engineers are novated to carry out design from concept design through to construction and commissioning. Design checks, quality issues and commercial aspects of the contract are then managed by the owner's team with assistance from an overall owner's engineer.

The key difference from an EPC turnkey approach is that a managing contractor acts more as a project manager allowing the owner to select the key subcontractors on recommendation. Costs are typically passed through to the owner so the managing contractor takes on less risk, though often incentivised to a target cost and schedule i.e. the managing contractor may be engaged early through early contractor involvement (ECI) process to determine a target cost estimate (TCE).

A summary of advantages and disadvantages to this model is provided in Table B.3. It is recommended to consider a managing contractor model or variation as it provides good market support and cost and time certainty.

| Advantages | Disadvantages |
|---|---|
| Single point of accountability | Can be expensive in tender phase to develop a mature enough design for TCE |
| • Programme risk wrapped into one package | Limited pool to only top tier contractors (however pool is likely larger than for lump sum EPC) |
| • Principal contractor risk clearly assigned | Lower cost and schedule certainty and majority of cost and time risk remains with the owner |
| Allows some cost control through TCE process | Lower control of delivery details post TCE |
| Collaborative in nature, flexible to adapt to market conditions and interface works | Lower control of delivery details post TCE |
| More market participants, as model has lower balance sheet risk to contractors | Can still require significant contract administration. Variations to TCE and schedule often managed as lump sum variations by contractor |
| Provides flexibility with OEMs who may prefer to deliver multiple packages | |

**Table B.3**
Managing Contractor Summary

### B1.2.4 EPCM Contractor

An engineering, procurement and construction management (EPCM) contractor is engaged to provide detailed design, procurement and then construction management services using a detailed procurement strategy that has been discussed and agreed with the owner's team. The EPCM contractor engagement can be regarded as a form of professional service contract. This strategy is commonly used in mining and industrial process plant construction projects for established owners.

A summary of advantages and disadvantages to this model is provided in Table B.4. It is recommended to consider a EPCM contractor as it provides a quick delivery model with flexible contractor allocation, transportation costs and the ability to retain design control.

| Advantages | Disadvantages |
|---|---|
| Can be one of the quickest models to deliver as the design may be progressed without delay and long lead items procured in accordance with an integrated schedule | Owner can be bound to various contractual relationships for construction related works including resolution of disputes |
| Flexible contract allocation with transparent cost. Either the owner or EPCM contractor as an agent of the owner can enter into construction and procurement agreements, but the EPCM contractor will generally accept only limited liability. | Less time and cost certainty as EPCM contractors will generally not take responsibility for delivery to cost and schedule |
| Ability to control the detail of engineering throughout the course of the project | Owner is required to have operational knowledge to participate in the decisions making with the EPCM |
| Access to tier 2 contractors to reduce head contractor margin | Can be bureaucratic and lead to shadowing of EPCM with expanded owner's team if not performing well |
| Access to management resource pool (tier 1 EPCM contractors) | |

**Table B.4**
EPCM Contractor Summary

# B2 Operations and Maintenance Strategy

## B2.1 Overview

Once the construction and commissioning stage is complete the facility will be handed over to the owner. The owner will either provide operations and maintenance (O&M) services themselves or engage a third party, usually on a long term three to five year contract. These options are discussed further in Section B2.2. As a minimum, the following O&M services will be required:

- Advisory services in advance of acceptance testing, commissioning and handover of the facility, for example on anticipated manning levels, logistics and administrative activities
- Interfacing with the lead construction contractor during testing and commissioning stage. It may be sensible for operating personnel to be taking control of the facility during these stages under the supervision of the construction contractor noting that liability needs to be clearly managed
- Operation of the processing facility after handover
- Maintenance of the facility including scheduled and unscheduled maintenance and major overhauls
- Procuring and maintaining an inventory of spare parts
- Preparing management plans and operating procedures
- Delivering operational performance to an agreed level
- Complying with operational requirements imposed under the regulatory regime, for example environmental and safety compliance
- Maintaining interface relationships between utility suppliers
- An early assessment of the personnel required for the operational phase of the onshore compression facilities can be found in Section 11.

## B2.2 Operations and Maintenance Strategies to Consider

### B2.2.1 Operations and Maintenance by Owner

O&M by the owner is highly dependent on the previous experience and capability of the owner. A summary of advantages and disadvantages to this model is provided in Table B.5. It is not well understood if the owner has the capability or intention to operate the facility, however implementing an O&M by owner strategy or a variation may be warranted.

| Advantages | Disadvantages |
|---|---|
| Retain control, develop and maintain in-house expertise and foster independence which avoids being held to O&M contractors | Requires large and strong owner's team |
| Opportunity to form partnerships with key equipment and technology providers who could assist with the training of owner's staff | Need to build trained force, training employees can take months if not years |
| Ability to share O&M learnings and processes across a portfolio of owner projects | Financers may prefer a more proven model |
| Full control of asset operational history | |

**Table B.5**
Operations and Maintenance by Owner Summary

### B2.2.2 Operations and Maintenance by Third Party

Requires establishing a contractual arrangement between the owner and a professional O&M company to operate and maintain the facility. A third-party contractor would be engaged to both operate the plant and to conduct routine and scheduled maintenance. The O&M contract would be specified for a fixed term with associated key performance indicators (KPI). The third party could be a standalone contractor, part of the construction consortia or a key equipment vendor. A summary of advantages and disadvantages to this model is provided in Table B.6 and it is recommended to consider an O&M by third party strategy for this Project.

| Advantages | Disadvantages |
|---|---|
| Properly drafted O&M agreements can be an effective way to manage operational risk, if as a minimum they include payments and incentives, performance guarantees, caps and limitations on liability, interfaces with other project contracts | May be difficult to break contract due to practical aspects of changing out the majority of site personnel |
| Professional O&M operators may increase the chance of obtaining project finance as lenders can draw upon track record of O&M contractor to mitigate risk | Difficult to match short and long term KPIs. Targets for O&M contracts are often short term which can mean the facility will be pushed with scant regard for long term health of the asset. |
| No expense for staff training as it would be built into the contract | Limited owner window in the asset's operational history |
| Focused workforce | If O&M is a project stakeholder, for example part of the construction consortia or a key equipment vendor, then care should be taken to avoid any conflict of interest |
| If O&M provider is the construction contractor, then key liabilities around the construction/commissioning handover and operational interfaces are wrapped up | |
| Could provide a short to medium solution if the owner has a longer-term desire to operate | |

**Table B.6**
Operations and Maintenance by Third Party Summary

www.provaris.energy