Final Knowledge Sharing Report

Green Hydrogen Feasibility Study

City of Cockburn

23 December 2021

The Power of Commitment

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Executive Summary

The City of Cockburn Council ("the City") is aiming to develop the Henderson Waste Recovery Park into a renewable energy park through the installation of on-site renewable power and production of green hydrogen. The project aims to economically displace the City of Cockburn's fossil fuel use with green hydrogen produced on site, driven by the City's desire to reduce carbon emissions and make use of vacant landfill cell space.

This report details the methodology and outcomes of the Green Hydrogen Feasibility Study for the City of Cockburn. The study successfully developed a design for an on-site greenfields solar field and green hydrogen plant—which also makes use of existing landfill gas power—for the refuelling of heavy vehicles (note that fuel cell vehicles outside the scope of this study).

The highly modular and expandable design supports a staged expansion of the facilities—which GHD recommends taking to allow a lower up-front capital investment, an opportunity for the City of Cockburn to build capability with a smaller scale plant, and the ability to leverage potential future cost reductions of hydrogen technologies. Stage 1 of the expansion strategy focuses on the refuelling of the City's refuse collection heavy vehicles (as the most economic option) and is the subject of this feasibility study. The recommended staging strategy, and reasoning behind it, is discussed in Section 2.3.

The works performed during this study include framing and options studies, creation of concept designs and technical specifications, market engagement, risk assessments, and cost estimates.

Stage 1 of the project will displace up to 1,410 L/day (over 500,000 L/year) of diesel by replacing the heavy vehicle diesel fuel with green hydrogen. This will have a direct vehicle emissions reduction of 100%, and a lifecycle carbon emissions reduction of over 90%. Sustainability principles are also incorporated into the design wherever possible, including designing for the use of the site's problematic leachate runoff water. Treatment of this leachate provides an abundant source of feedwater to the hydrogen plant, while simultaneously recycling a problematic waste product—tying into circular economy principles. Despite the technical challenge, using leachate in the green hydrogen plant adds value for the City, as well as the project's business case.

The Stage 1 design developed throughout the study features a 1.2 MWac east-west solar field, a fully containerised water treatment plant, and a modular hydrogen production and refuelling plant containing a 1.25 MW electrolyser capable of producing the required 440 kg/day hydrogen production and 1,000 kg (approximately two days' production) hydrogen storage. This highly modular—and predominately containerised—overall design facilitates ease of transport, installation, and future expansion.

The engineering work performed during this study confirms that there are no technical barriers to developing projects of this nature in Australia, and the study presents a fit-for-purpose green hydrogen solution for the City of Cockburn's Henderson Waste Recovery Park.

The CAPEX estimate for Stage 1 is $24.5 million, with an NPC of $33.3 million and LCOH of $21.2/kg H_2. The LCOH reduces to $13.4/kg based on 50% CAPEX funding from an external agency such as the Australian Government or ARENA. The cost estimates are discussed further in Section 12.

The target LCOH is $7–10/kg H_2 to compete with current diesel prices for refuse collection vehicles. While the project costs are currently higher than the diesel base case, there are opportunities to further improve project economics in the next phases of the project. The next phases of the project will investigate a range of potential activities to lower the levelised cost of hydrogen to support the project. These include:

- Funding opportunities with State and Federal government bodies
- Partnerships with current hydrogen and energy companies to provide hydrogen and a lower cost of supply
- Partnerships with technology suppliers to investigate potential CAPEX and OPEX reductions
- Partnerships with similar heavy waste vehicle manufactures and/or councils
- Engineering optimisation to further refine the level of engineering definition

Acknowledgment of Country

We acknowledge Aboriginal and Torres Strait Islander peoples as the Traditional Owners of all lands throughout Australia on which we do business, and we pay our respects to Elders, past, present, and emerging.

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Glossary

Table 1 Glossary

Term/Abbreviation	Definition
AC	Alternating Current
ARC	Aquatic and Recreation Centre
AS	Australian Standard
ASME	American Society of Mechanical Engineers
AUD	Australian Dollars
BOP	Balance of Plant
°C	Degree Celsius
CAPEX	Capital Expenditure
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DC	Direct Current
DWER	Department of Water and Environmental Regulation
DI	Deionisation
EP	Environmental Protection
EPC	Engineering, Procurement, and Construction Contract
EPCM	Engineering, Procurement, and Construction Management
FAT	Factory Acceptance Testing
FEED	Front-End Engineering Design
FID	Financial Investment Decision
FOREX	Foreign Exchange
ft	Feet
FTE	Full-time equivalent
GST	Goods and Services Tax
H_2	Hydrogen
HAZOP	Hazard and Operability Study
HMI	Human-Machine Interface
hr	Hours
HSE	Health, Safety & Environment
HV	Heavy Vehicle
ISO	International Standards Organisation
kg	Kilogram (mass)
kJ	Kilojoule = 10^3 Joules
km	Kilometre = 10^3 metres
kV	Kilovolts = 10^3 Volts
kW	Kilowatt = 10^3 Watts
kWh	Kilowatt hour
L	Litres
LCE	Life Cycle Emissions

Term/Abbreviation	Definition
LCOH	Levelised Cost of Hydrogen
LEL	Lower Explosive Limit
LV	Light Vehicle
m/s	Metres per second
m	Metres
m^3	Cubic metre
MAV	MAVERICK solar module
MJ	Megajoule = 10^6 Joules
MPag	Mega Pascal gauge
MPPT	Maximum Power Point Tracking
MVA	Mega Volt Amperes
MW	Megawatts = 10^6 Watts
MWh	Megawatt hours = 10^3 kWh
NIOSH	National Institute for Occupational Safety and Health
NFPA	National Fire Protection Association
Nm^3	Normal meter cubed
O&M	Operating & Maintenance
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PEM	Polymer Electrolyte Membrane
PLC	Programmable Logic Controller
ppm	Parts Per Million
PV	Photovoltaic
PVDB	Photo Voltaic Distribution Board
REL	Recommended Exposure Limit
RFQ	Request for Quotation
RMU	Ring Main Unit
RO	Reverse Osmosis
SAE	Society of Automotive Engineers
SCADA	Supervisory Control and Data Acquisition
SMEs	Small and Medium-sized Enterprises
SMR	Steam Methane Reforming
SWIS	South West Interconnected System
t	Metric tonne = 10^3 kg
tpa	Tonnes per annum
UPS	Uninterruptable Power Supply
W	Watt (electric power)
WBS	Work Breakdown Structure
yr	year

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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).

Disclaimer

The Study represents and expresses the research, information, findings, outcomes and recommendations solely of the Recipient and does not in any way represent the views, decisions, recommendations or policy of the Department. The Department does not accept any responsibility for the Study in any matter whatsoever and does not endorse expressly or impliedly any views, information, product, process or outcome arising out of or in relation to the Study.

1. Introduction

A green hydrogen industry is currently emerging in Australia and around the world which hopes to provide a low carbon fuel replacement for many applications, including in the mining, power, and transport sectors.

Green hydrogen uses electricity generated from renewable sources to produce hydrogen gas through the electrolysis of water; (with oxygen gas as the by-product). The green hydrogen can then be used in a range of applications as a gas or liquid fuel, either through combustion or in a fuel cell. The only product of both of these processes is energy and water, making green hydrogen a zero carbon emissions fuel to both produce and use.

Australia has potential to become a world leader in the emerging green hydrogen market and is currently being encouraged by state and federal government. The Western Australian Renewable Hydrogen Strategy and Roadmap, launched in 2019 and 2020 respectively, aim to "drive WA's position as a major producer and exporter of renewable hydrogen, and detail the WA Government's commitment to support and facilitate industry efforts to develop a renewable hydrogen industry in WA"[1].

1.1 Project Background

The City of Cockburn Council is aiming to develop the Henderson Waste Recovery Park into a renewable energy park. They plan to install renewable power on site and utilise this with some of the power generated from landfill gas to generate hydrogen via electrolysis. The hydrogen will be utilised as a low carbon replacement energy source for their heavy vehicle, light vehicles and other energy users in the council.

GHD has been engaged to perform a feasibility study for the generation of green hydrogen from solar power for use as a transport fuel for waste collection and light vehicle fleets in the City of Cockburn. The study also reviewed other potential uses for hydrogen in the council such as usage at the Aquatic and Recreation Centre.

Of the different options assessed it was determined that the preferred first stage of development is to replace liquid fuels for the heavy vehicle (refuse) fleet on site at the Henderson Waste Facility. This feasibility study only examines this scope (Stage 1) in detail, but consideration is made for subsequent stages that may be implemented in the future.

1.2 Purpose of This Report

This report summarises the outcomes of GHD's Study into Green Hydrogen for City of Cockburn project.

Key components of the Study included:

- Investigate generating hydrogen from solar power for use as a transport fuel for waste collection and light vehicle fleets in the City of Cockburn.
- Review the option for providing hydrogen for cogeneration at the Aquatic and Recreation Centre and the new administration building.
- Project Planning and Basis of Design.
- Technical specification documentation for Request for Quotation.
- Request for Quotation and review of vendor submissions.
- Development of CAPEX, OPEX, and lifecycle costs.
- Final report including project delivery and review of OHS and environmental considerations.

This report aims to document the study, including all methodology, assumptions, designs, findings, and recommendations.

[1] https://www.wa.gov.au/government/publications/western-australian-renewable-hydrogen-strategy-and-roadmap

1.3

1.3 Scope and Limitations

This report has been prepared by GHD for City of Cockburn and may only be used and relied on by City of Cockburn for the purpose agreed between GHD and City of Cockburn as set out in section 2 of this report.

GHD otherwise disclaims responsibility to any person other than City of Cockburn arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in this report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared the preliminary cost estimate set out in section 12 of this report ("Cost Estimate") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD as set out in this report

The Cost Estimate has been prepared for the purpose of a feasibility study and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the project can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

1.4 Exclusions from Study Scope

This study's scope excludes the following aspects of the project:

- Analysis of operating parameters of the landfill gas plant
- Any works associated with the hydrogen fuel cell vehicles (or other end users of the hydrogen fuel)
- Any detailed works associated with Stages 2 and 3 of the recommended project expansion, with the exception that the engineering done under this study incorporates easy expandability

2. Project Framing

2.1 Project Framing Overview

Project framing is a critical step to any project in order to clearly define the project objectives, constraints, and scope. An effective framing process ensures that the project drivers and limitations are well understood, and that the project will ultimately achieve the desired outcomes.

The overall project objective is to economically displace the City of Cockburn's fossil fuel use with green hydrogen produced on site.

Key drivers of this project include:

- Reduce the City of Cockburn's carbon emissions
- Produce an economical green energy solution (e.g. comparable costs to current diesel use)
- Make use of vacant space on the landfill cells
- If possible, help correct Henderson Waste Recovery Park's water balance issue (discussed in Section 2.2.2)

The following sections outline the method taken to frame the project scope; including a technology review, scope framing of the hydrogen use cases, and staging development.

2.2 Technology Review

An initial technology review of power sources, water sources, and hydrogen production guided the technical direction of the study, as detailed below.

2.2.1 Renewable Power

The only existing power generation on site is landfill gas power. Landfill gas is collected from the capped landfill cells is currently being combusted through gas engines on site to sell firm power to the grid. Landfill gas therefore provides a readily available firm source of power. Biogas is considered a renewable resource produced biologically through anaerobic digestion. Biogas from landfill—or landfill gas—typically comprises approximately 60% methane. By collecting and combusting the landfill gas, it is diverted through the gas plant to extract energy before it is released as predominately carbon dioxide and water vapour instead of methane. Given that methane has a nearly 21 times higher global warming affect than carbon dioxide, biogas combustion results in a net reduction in greenhouse gas emissions. For this reason, the landfill gas power is considered to be "green" power.

Power to supply the hydrogen plant is a crucial part of the project, and several available options were compared to decide the preferred power generation technology for the project. The power sources assessed include solar, wind, landfill gas power, and grid connection.

- Wind power was not preferred due to the site conditions
- Solar power was desirable, provided a non-penetrative solution can be supplied to avoid disturbing the landfill cap
- Landfill gas was desirable due to its availability and ability to supply firm power
- Grid power was not preferred due to the desire for on-site generation

Following the review of available power technologies, it was determined that solar PV and landfill gas power are complementary technologies that, together, are able to make good use of the available land and resources while also providing a firm power supply (i.e. landfill gas power can supply power when sunlight is not available to power the solar farm). Together, these technologies are able to provide economical and green power while meeting the project aims.

2.2.2 Water

For product of hydrogen via electrolysis of water, a reliable water supply is essential. It is identified that there is not currently potable water at the hydrogen plant location, however there is a surplus of leachate on site, as well as bore water and a water main approximately 500 m from the site.

The City of Cockburn has advised that there is a water balance issue on site where they have an excess of dirty runoff water from the landfills; water which is collected and stored in large leachate ponds on site. Treatment of leachate for hydrogen production provides an abundant source of water for supply to the hydrogen plant, while simultaneously recycling a problematic waste product—tying into circular economy principles. It is acknowledged that treatment of leachate to achieve the same quality as bore water presents a more complex technical challenge.

A bore field exists approximately 50 m from the hydrogen plant location.

Scheme water offers another source of water, from a water main running along Dalison Avenue, 500 m south of the hydrogen plant location. Given that the City of Cockburn has expressed construction plans around this area, including opening an entrance to the Henderson Waste Recover Park from this road in the near future, this potable water source is another viable option.

Bore and scheme water offer a straight-forward water source in terms of water treatment; however, from a sustainability perspective and despite the technical challenge, leachate is the preferred water source for the reasons discussed above.

2.2.3 Hydrogen

There are multiple technologies available to source hydrogen fuel, including purchase of hydrogen from a third party, steam methane reforming, and electrolysis.

Purchasing hydrogen from a third party and having it delivered on site for refuelling is the simplest way of sourcing hydrogen fuel. However, this option is out of scope based on the project objective and drivers discussed in Section 2.1.

Historically, steam methane reforming (SMR) from natural gas is one of the most common methods to produce hydrogen around the world. This process is also possible using renewable biogas as the feed gas. Hence, steam methane reforming of the available landfill gas on site is a potentially viable hydrogen source. However, this option is not assessed as the project scope is for generation of hydrogen via electrolysis using renewable energy sources. It is also noted that pursuit of steam methane reforming of landfill gas leads to limited options for the site to incorporate solar into the SMR facility in the future.

Electrolysis is current the primary technology for green hydrogen production from renewable energy around the world. This technology, along with a solar field to power it, makes optimal use of the available landfill cell space as well as assisting the site's water balance problem by using treated leachate waste as feedwater. It also provides an opportunity for the City of Cockburn and WA to gain experience and familiarity with this emerging (and increasingly popular) green technology. For these reasons, hydrogen production via electrolysis is the clear preference.

2.3 Scope Framing

Following the technology review, the project identified the basis of green hydrogen production via electrolysis, potentially using treated leachate (supplemented with bore or scheme water where required) as a water source, powered by a complementary solar PV and landfill gas power sources. Further screening assessment of the different hydrogen use cases was performed to identify the go forward option for the study.

2.3.1 Hydrogen Use Cases

The target areas identified for hydrogen use by the City of Cockburn were:

1. Hydrogen refuelling of heavy vehicle (HV) fleets on site
2. Hydrogen refuelling of light vehicle (LV) fleets (offsite at depot)

3. Hydrogen fuel for embedded co-generation at the Cockburn Aquatic and Recreation Centre (ARC) to offset power and gas

These use case options were analysed to find the option that was most likely to be viable based on the project constraints; predominately based around finding the most economical green solution.

A preliminary screening study revealed the heavy vehicle use case as the most economically viable, and therefore the preferred, option.

2.3.2 Staging

A key outcome of the framing work was the confirmation that this project supports a staged approach, starting with the re-fuelling of heavy vehicles on site as Stage 1.

Both the solar field and hydrogen plant components are highly modular and expandable, and this supports a staged expansion of the renewable power and hydrogen production facilities as required. The options developed during the scope framing step identified that limited to no opportunity would be lost in pursuing a staged approach to the project. The work completed during this step confirmed that staging provides the lowest up-front capital, the ability to leverage potential future cost reduction of hydrogen technologies, and provides an opportunity for the City of Cockburn to be able to incrementally build their understanding and capability in hydrogen.

Figure 1 shows a summary of the proposed staging strategy as well as preliminary estimates of hydrogen production in each stage. This staged approach provides enhanced value to the City of Cockburn via a clear and achievable path to transforming a significant portion of the city's operations to green hydrogen. Stage 1 of the expansion strategy covers the scope of this feasibility study.

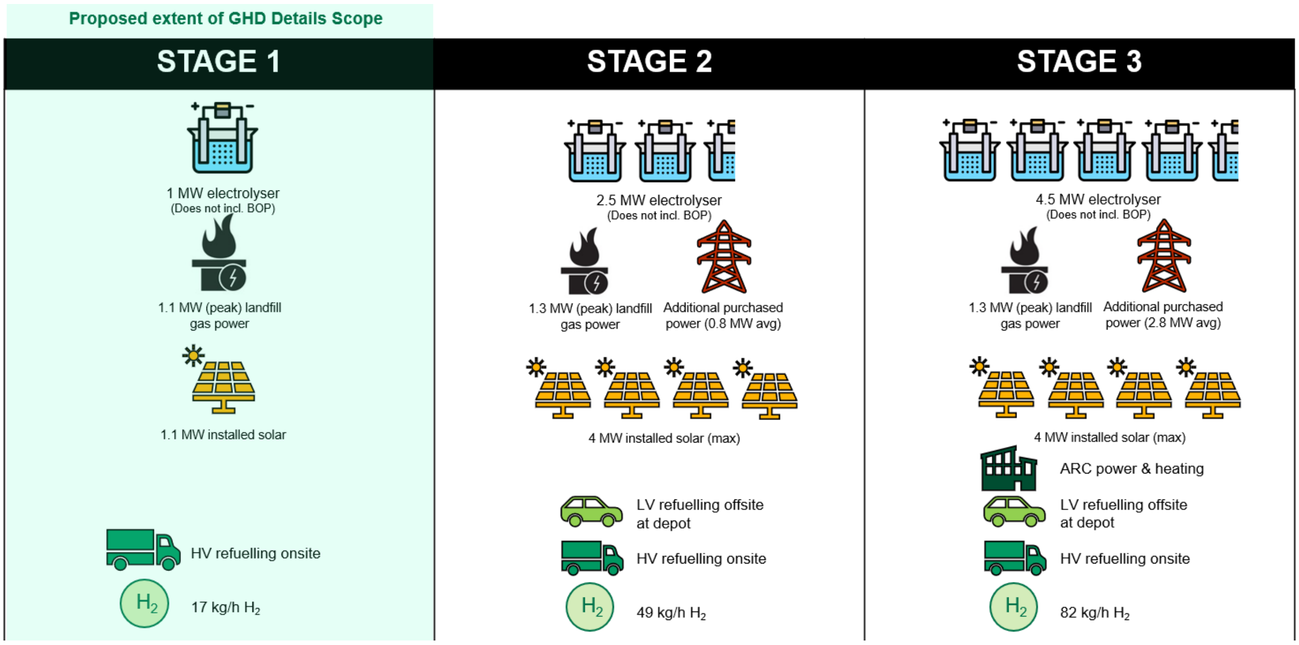

Figure 1 Staging strategy overview

Note that the 4 MW limitation on the solar expansion is based on an estimate of available land area on the nominated landfill cells. Figure 2 shows the locations of the Stage 1 and expansion solar and hydrogen plant locations. All the solar expansion areas are situated on sloped sides of landfill cells.

Figure 2 *Site layout showing staged expansion*

2.4 Framing Outcomes

The framing outcomes were:

– Feasibility study to focus on the hydrogen heavy vehicle fleet use case
– Solar PV installed on the landfill cells as well as the existing landfill gas plant will supply power to the hydrogen plant
– Treated leachate, supplemented with bore/scheme water if/when required, is a favourable water source for the hydrogen plant
– Hydrogen will be produced via electrolysis
– There is a pathway for future expansion to add the other hydrogen use cases (light vehicles Stage 2 and ARC power and heating Stage 3) which will be taken into account but not studied in any detail during this study

3. Project Overview

The project consists of three interlinking packages: solar field, water treatment, and hydrogen production and refuelling. The proposed solar field, supplemented by landfill gas power, supplies the required power. The water treatment facilities prepare raw water for supply to the hydrogen facility. Finally, the hydrogen production and refuelling plant produces, stores, and supplies hydrogen fuel for vehicle filling.

3.1 Site Layout

The desalination water treatment facility and hydrogen production and refuelling plant are co-located at the selected plant location. Figure 3 shows the overall site layout, including:

- The solar field to the north-west
- The landfill gas plant to the immediate north of the leachate ponds
- The water treatment and hydrogen plant to the south

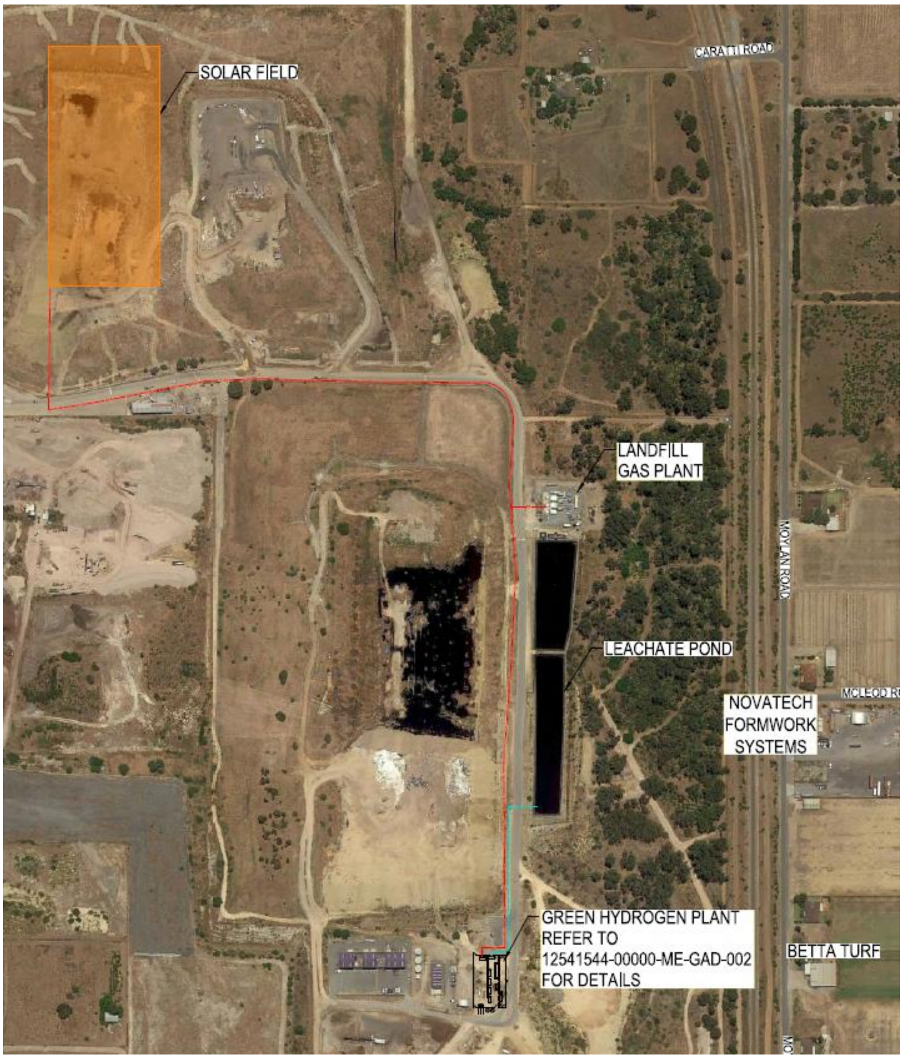

Figure 3 Overall site layout

3.2 Scope Packages

The project is split into three main packages of work (power, water, and hydrogen) plus balance of plant, as detailed below.

3.2.1 Power Sources

The Stage 1 green hydrogen plant is powered by a 1.2 MWac solar field positioned on the top of Cell 6 of the Henderson Waste Recovery Park and supplemented with landfill gas power from the on-site gas plant (currently producing 3 MW continuous power, operated by a third party). The solar field and gas power are sufficient to provide the full power requirements of the green hydrogen plant for Stage 1 at all times; no additional power purchased from the grid is required.

The solar package incorporates all civil and structural requirements of the solar field, electrical requirements (including inverters, transformers, switchgear, protection, cabling, and wiring up to the 22 kV load terminals), and instrumentation, communications, monitoring, and control systems.

3.2.2 Water Treatment

The water treatment package supplies water to all users at the facility, including as feed to the water deionisation unit and subsequent electrolyser, as cooling water makeup, fire water, and occasional wash water.

Water is supplied to the hydrogen plant from an on-site water source. Several options exist, including existing leachate ponds, existing bore field, or scheme water.

In the case of using leachate as the raw water source, the quality of the leachate would require pre-treatment prior to being delivered to the main desalination water treatment plant. Leachate could be blended with bore or scheme water to make up the supply water to control the feedwater quality if required. Pre-treated leachate would be provided by the City of Cockburn and stored in raw water tank(s), which would serve as a buffer volume between the water supply and the site water treatment.

Once entering the water treatment plant, the raw water is filtered and routed to a reverse osmosis unit to deliver water to a treated water quality. Water suitable for human contact at a safety shower and an eye wash station is also supplied. The water treatment package also incorporates all required pumping, piping and valving, waste water storage and pumps, backwash and/or cleaning equipment, chemical storage and dosing facilities as required, instrumentation and control system, and electrical equipment.

3.2.3 Hydrogen Production and Refuelling

The hydrogen production and refuelling equipment is provided as a complete modular package, consisting of several containers or skids. The equipment consists of water deionisation (DI), hydrogen generation unit (electrolyser) and supporting equipment, hydrogen storage, and hydrogen dispenser for vehicle filling. The hydrogen production and refuelling package also incorporates all appropriate relieving and vent equipment, hydrogen compression equipment, cooling equipment, hydrogen conditioning, chemical storage and dosing facilities as required, all required piping and valving, instrumentation and control system, and electrical equipment.

Refuse trucks typically take 25 to 32 kg at 35 MPag (H35). The hydrogen will be conditioned and dried to meet AS ISO 14687 Grade D quality for use in vehicles. The plant design incorporates heavy vehicle access for refuelling on site.

3.2.4 Balance of Plant

All remaining works required for the project will be sourced separately, including civils, piping and pumping outside of the vendor packages, cabling, fencing, lighting, etc.

Approximately 660 m of 22 kV high voltage cabling is required to link the solar field to the landfill gas plant, with a further 22 kV high voltage cable of approximately 480 m required to link the landfill gas plant to the hydrogen plant. This provides a 22 kV transmission backbone that is sized to be suitable for the full power load expected through to Stage 3 of the project expansion.

A waste water pipeline is required between the hydrogen plant and the leachate pond, with a length of approximately 240 m.

Utilities, including instrument air and nitrogen for purging, will be supplied externally.

A fire water system is also included in the balance of plant—primarily intended to cool down walls and areas where hydrogen fire may impinge and cause integrity failure, not to extinguish the hydrogen fire. A deluge system will be installed for enclosed containers of equipment.

3.3 Basis of Operations

The following assumptions are made for the facility:

– The facility will operate on a basis of 24 hours per day and seven days per week for a nominal 330 days per annum, which allows for periodic shutdown and maintenance activities.
– Hours of operation for hydrogen dispensing will be aligned with the heavy vehicle fleet shift which will be nominally Monday to Friday 6am to 6pm.
– At all other times, the site will not be manned but will be operating. Therefore, remote control for operation and shutdown is required at all times.
– The heavy vehicle fleet comprises 20 garbage trucks.
– To accommodate periods off-line, 2 days' worth of production will be accommodated in bulk hydrogen storage. When the production facility is not available for longer periods of time, hydrogen will be trucked in and stored on site for dispensing to the fleet. Sourcing a potential hydrogen producer is currently outside the scope of this project.

Requirements for the facility are stated in Table 2.

Table 2 Facility requirements

Requirement	Performance Standard
Hydrogen production	System should be capable of producing and dispensing a minimum of 440 kg of hydrogen per day
Hydrogen generation technology	The system shall include an electrolysis system to generate hydrogen for the system
Purity of hydrogen	The hydrogen will be conditioned and dried to meet AS ISO 14687 Grade D quality for use in vehicles
Hydrogen storage	A minimum of two days' worth of hydrogen production should be able to be stored (i.e. minimum 880 kg)
Dispensing Pressure	System will dispense hydrogen at 350 bar (H35)
Refuelling Time	Fill time of no more than 15 minutes for a full fill (approximately 30 kg)
	Plant design will incorporate heavy vehicle access for refuelling on site
SAE Standards	The system should comply with the following SAE standards: – SAE J2799 (communications) – SAE J2601-2 (heavy duty vehicles refuelling)

4. Market Engagement

A number of vendors were approached for each of the three main packages (solar, water, and hydrogen) for budget quotes and technical information.

Vendor responses were reviewed in detail and were summarised in Technical Bid Evaluations. Key information was listed to identify whether it was compliant with the technical requirements specified. Clarifications were then developed and issued to the vendors.

The vendor data that met the project requirements was used to inform the technical aspects of the design and develop the cost estimates later in the study.

A notable observation that came out of the hydrogen vendor engagement was that the scaling of cost with increased electrolyser size is not necessarily linear. The cost-to-production ratio differs depending on the vendor and their standard package sizes, hence it is recommended that electrolyser sizing is evaluated on a per vendor basis in future design phases of the project.

5. Process Design

5.1 Introduction

The process considered in this study is gaseous hydrogen production through electrolysis, using bore, scheme, and/or pre-treated leachate water feed. The gaseous hydrogen will be produced, compressed, stored, and distributed directly to fuel cell electric vehicles on site.

5.2 Technology Review

This section provides an overview of technology choices for the main process units. These technologies were primarily guided by vendor recommendations during the market engagement phase of the study.

The main process units include:

– Water treatment
– Electrolyser, including alkaline and PEM
– Hydrogen compression
– Hydrogen storage
– Hydrogen refuelling

5.2.1 Water Treatment

It is understood that the treatment of leachate water is more complex due to the significantly poorer water quality. Additional pre-treatment is required prior to the leachate being fed into the main desalination plant if this water source is used. This will most like include the following sequence of treatments:

– Biological treatment to remove the nitrogen, organics, etc. Dissolved air flotation followed by carbon filters (if necessary) is typically used to achieve this.
– Chemical dosing to remove iron, manganese, etc. This is often achieved via chlorination to oxidise, then multimedia filtration to remove the oxidised components.
– Dechlorination to remove the risk that the chlorine (added in previous steps) will damage the reverse osmosis membranes. Dechlorination can be achieved through the use of activated carbon or sodium bisulphate.
– Reverse osmosis.

In the case of using leachate as the raw water source, the City of Cockburn would provide pre-treatment of this nature and deliver the pre-treated leachate (of quality similar to bore water) to the plant’s raw water storage tanks.

The main desalination water treatment package consists of an industry standard reverse osmosis (RO) train, including media filters, cartridge filters, and RO membrane filters. This system reduces the membrane size in stages to capture entrained solids of progressively smaller sizes so as to prevent any filters from becoming blocked.

The water treatment system recommended by the vendor also includes a duplex softener system which removes hardness by exchanging calcium and magnesium ions for sodium ions in the feed water. Combined with antiscalant dosing, these units will prevent calcium carbonate precipitation on membrane surfaces and eliminate the requirement for a second pass RO design.

Regeneration of the depleted softening exchange resin will occur approximately every 10 hours and take approximately 90 minutes. This process is done automatically and will utilise the standby softener unit of the duplex system, allowing the RO plant to continue production. Each softener regeneration uses approximately 8.25 kg of saturated brine solution of salt which is a consumable.

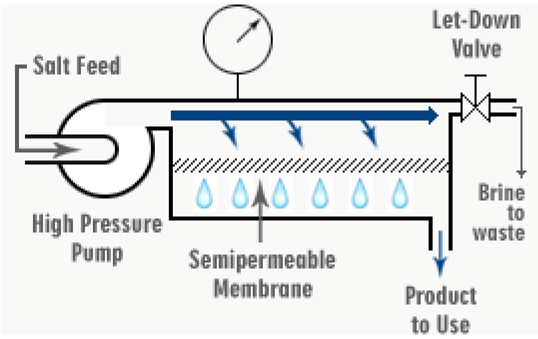

Figure 4 ***Reverse osmosis desalination process schematic[2]***

5.2.2 Electrolyser

There are two types of electrolyser units commercially available: Alkaline and Polymer Electrolyte Membrane (PEM). Although Alkaline and PEM units are functionally similar, the electrolysis reaction is different and this means each type has different characteristics and costs, which can provide relative advantages and disadvantages.

Alkaline electrolysers are the more mature and low-cost technology, with the chemical reaction occurring between two electrodes in a solution of liquid potassium hydroxide electrolyte. At the cathode, hydroxide and hydrogen ions are produced from water. The hydroxide ions travel through the electrolyte to the anode, where they release an electron and combine to produce water molecules and oxygen gas. These units require lower cost materials and catalysts, and as a better-known technology they offer lower technology and cost risk. However, alkaline electrolysers require onsite storage of hazardous potassium hydroxide which must meet regulatory requirements. They also have a lower turndown capacity, reduced ramp rates, and an increased risk of impurities in the produced hydrogen gas. Alkaline electrolysers run at lower pressures than PEM, requiring additional compression of the gas to storage and refuelling pressures.

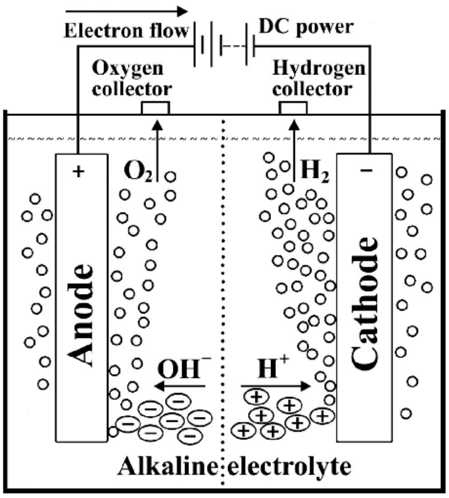

Figure 5 ***Alkaline electrolyser diagram[3]***

In a PEM electrolyser unit, water reacts at the anode to produce oxygen, hydrogen ions, and free electrons. The electrons travel along the external electrical circuit to the cathode. The hydrogen ions travel across the solid polymer electrolyte to the negatively charged cathode. At the cathode, the hydrogen ions combine with the electrons from the external circuit to produce hydrogen gas.

PEM units can operate at high pressure and offer greater flexibility in operation, being able to respond more quickly than alkaline units to load changes and provide a greater turndown range. However, PEM electrolysers

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[2] Image sourced from https://novatron.net.au/about-reverse-osmosis/
[3] Image sourced from Hydrogen production by alkaline water electrolysis by D. Santos, C. Sequeira, J. Figueiredo

require expensive platinum group catalysts and membranes, which are both expensive to replace. PEM electrolysers are less tolerant to water impurities than alkaline units but produce higher purity hydrogen gas.

A significant investment in research and development of PEM technology is being actively undertaken by a number of tier one suppliers, which has already led to significant improvements in performance and efficiency of PEM electrolysers.

The benefits of PEM technology are notably applicable to small scale production such as is the focus of this study report. Greater turndown and improved ramp rates are important in single-train installations, both areas where PEM has the advantage over alkaline technology. One of the most critical aspects of hydrogen fuel for fuel cell electric vehicles is purity, which contaminated fuel carrying the risk of causing damage to the fuel cell. In this area, PEM technology is again clearly superior to alkaline.

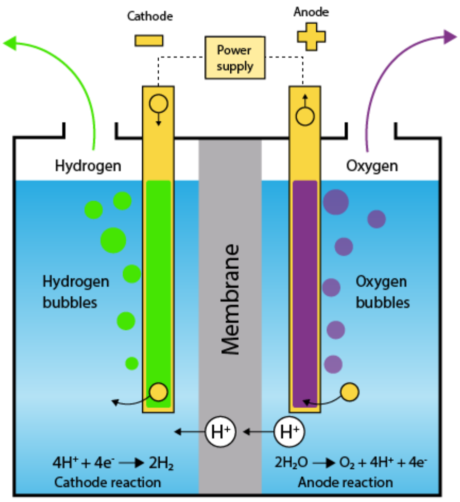

Figure 6 *PEM electrolyser diagram*[4]

5.2.3 Hydrogen Compression

Diaphragm gas compressors will be used for all hydrogen compression. Diaphragm compressors use a hydraulic system, a linear reciprocating piston, and metal diaphragm plates. The compressor does not use dynamic seals and the triple diaphragm set ensures that the process gas is completely isolated from the hydraulic oil; this eliminates the risk of gas contamination and therefore eliminates the need for filters and oil removal systems. Diaphragm compressors also feature high compression ratios (up to 10:1).

The compressor nominated by the hydrogen package vendor is a two-stage 90 kW diaphragm compressor.

5.2.4 Hydrogen Storage

The preferred industry technology for high pressure hydrogen storage is tube manifolds—multiple pressurised cylinders/tubes arranged in stacks—as opposed to one large storage vessel.

The hydrogen storage arrangement proposed by the hydrogen package vendor is a triple-tier tube rack configuration with a high, medium, and low bank. This cascade storage system provides 500 bar storage in the lower vessel, 700 bar in the middle, and 1,000 bar on top. Each rack is 10 m long and 0.8 m wide, with roughly 100 kg (at 500 bar) storage total per rack.

[4] Image sourced from https://byjus.com/jee/water-electrolysis/

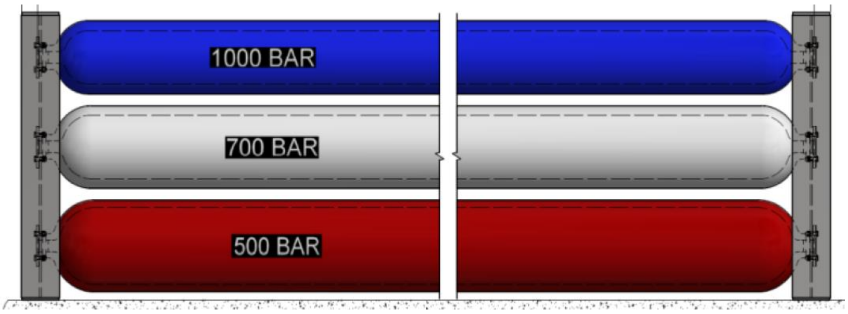

Figure 7 *Hydrogen storage rack sketch*[5]

5.2.5 Hydrogen Refuelling

The hydrogen dispenser recommended by the hydrogen package vendor offers H35 pressure with a dispenser pre-cooler. The dispenser is approximately 1.2 x 2.4 x 0.8 m size (excluding pre-cooler) and includes safety features such as a break-away hose, remote E-stop, combustible gas alarm (CGD), and purge system monitoring. The dispenser and pre-cooler are SAE J2601 compliant and has a meter accuracy of 3%.

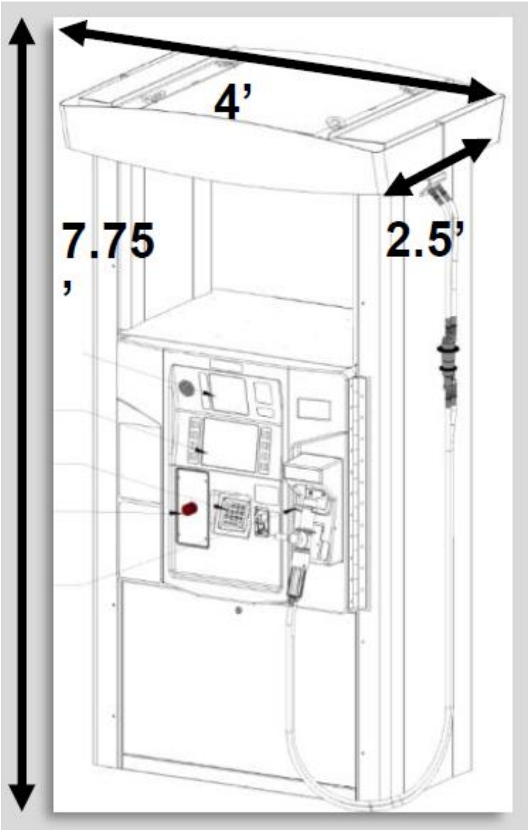

Figure 8 *Hydrogen dispenser diagram*[5]

5.3 Hydrogen Plant Design

The main process equipment for Stage 1 is comprised of the packages indicated in Table 3. Refer to the Basis of Design, Technical Specifications, and Bid Analysis Summary Report (included in the Appendices) for more information, including venting, piping, and other associated equipment. Note that these are subject to final vendor selection and may change.

[5] Image courtesy of ENGV

Table 3 Main process equipment packages

Equipment	Size (Installed) / Comments
Desalination Package	
Raw water storage tank	10,000 L
Media filters	N/A
Duplex softener system	N/A
Cartridge filter	5 micron rated
Cartridge filter	1 micron rated
Antiscalant dosing	N/A
RO high pressure pump	N/A
RO unit	10,000 L/day (417 L/h) output of permeate water
Permeate water storage tank	2,800 L
Waste water storage tank	5,000 L, LDPE 55 L/h reject from desalination 240 L/h reject from DI/electrolysis
Fire water	10,000 L storage tank
Wash water	N/A
Hydrogen Production and Refuelling Package	
Deionisation water treatment	355 L/h consumption at full flow
PEM electrolyser	1.25 MW 250 Nm^3/hr, 531 kg/day (22 kg/hr) 99.5% purity
Process cooling	353 kW at beginning of life 496 kW at end of life
Compressor	Two-stage 90 kW diaphragm compressor
Chiller	N/A
High pressure storage	1,000 kg, 500 bar
H35 dispenser	20 HV @ average 25 kg/fill Average 2.5 kg/min dispensing
Dispenser pre-cooler	Pre-cool compliant with SAE J2601 protocols
Hydrogen vent	15 L/min steady state 4154 L/min during maintenance/start/stop
Oxygen vent	2077 L/m steady state
Balance of Plant	
Electrical cabling	Approximately 1.2 km of 22 kV high voltage power cable
Instrument air	<6 Nm^3/h steady state 78 Nm^3/h max rate 1 second average
Nitrogen for purge	2 Nm^3 @ 10 barg / 4 Nm^3 @ 18 barg 18.6 Nm^3 recommended on site
Piping connections	To leachate pond (waste water) and bore
Miscellaneous site works	Civils, lighting, fencing, etc.

5.4 Hydrogen Plant Layout

5.4.1 Overview

The proposed hydrogen plant layout incorporates indicative footprints for each of the packages and takes into account separation distances required for hydrogen units and storage, according to relevant Australian (AS1940, AS2022, NFPA2) and international standards. Hydrogen storage capacity is limited to avoid the facility being classified as a Major Hazard Facility and plant layout will be selected to minimise pipe runs and cabling.

5.4.2 Plant Layout Considerations

The following main items are considered in the proposed plant layout design:

- Boundary separation distances / site boundary / future expansions
- Process blocks—area allocations / separations
- Preliminary Hazardous Areas classification
- Storage—capacity, location
- Traffic/truck refuelling
- Fire protection, emergency response access/egress

The layout considers the following key safety and operability factors to support a flexible and safe site:

- Adequate spacing and separation distances between plant facilities allowing for major hazard incidents, constructability, maintenance access, and isolation
- Oxygen and hydrogen vent designs and positioning to be considered carefully to allow for good dispersion of gases, and to be positioned at an adequate distance from any potential ignition sources
- Perimeter access road for emergency services access
- Appropriate road surface finishes to manage storm water run-off, traffic movements and accessibility during weather events
- Separate controlled access to the main process plant area via fenced and secured gates

5.4.3 Proposed Location

Three sites were initially investigated for the hydrogen plant, resulting in the most appropriate site being selected as the preferred option. This recommended hydrogen plant location was decided based on ease of vehicle access, a geotechnical investigation, and the most adherent to the siting criteria.

5.4.4 Proposed Plant Layout

The proposed plant layout features the following characteristics:

- Containerised packages for water treatment, electrolysis, hydrogen compression, and hydrogen storage
- Adequate spacing around equipment for maintenance vehicle movement and access
- 14 m separation between hydrogen equipment and security fence as per NFPA requirements
- Unused space for future expansion stages
- Separate heavy vehicle and maintenance vehicle access to minimize interaction between maintenance personnel and heavy vehicle refuelling
- Double lane heavy vehicle drive-through for overtaking
- Vehicle barrier between heavy vehicle refuelling lanes and plant equipment for safety
- Security requirements such as fences and automated gates will be reviewed during later phases

Table 4 shows the sizes and quantity of the main plant components following vendor engagement.

Table 4 Plant components' footprints

Package	Components
Water treatment (desalination)	1 x 20 ft container 1 x 5,000 L waste water storage tank 1 x safety shower and eye wash station module
Water RO/DI & hydrogen production	1 x 40 ft container (double storey) for water purification, electrolysis, hydrogen conditioning 1 x 20 ft container for transformer and rectifiers
Hydrogen compression	1 x 20 ft container
Hydrogen storage	10 x 3-tube racks (9.8 m x 0.8 m)
Hydrogen refuelling	1 x dispenser (1.2 x 0.8 m) 1 x pre-cooler
Balance of plant	1 x 10,000 L raw water storage tank 1 x 10,000 L fire water storage tank 1 x ~20 ft utilities container 1 x ~20 ft high voltage electrical supply kiosk 2 x buildings (10 x 5 m) – warehouse and control room (to be located elsewhere on Henderson Waste Recovery Park as determined optimal during a subsequent phase of the project)

5.5 Process Plant Control System Architecture

The site will be highly automated with each package (solar, water and hydrogen) to be provided with a control system that will provide a safe and reliable operation of their equipment.

All process equipment will be controlled via a Programmable Logic Controller (PLC) providing both automatic and local manual control, operating as a system. Normal operation of the equipment will be automatic, with monitoring and operating control from both a local Human-Machine Interface (HMI) and remote control-room via a SCADA system.

6. Power System Design

Power for the electrolyser and balance of plant will be supplied by the solar field and landfill gas power station. A small portion of the power used will be required for running pumps, compressors, and general lighting.

6.1 Power Supply

Power supply to the hydrogen plant will be balanced between the solar field and landfill gas plant. No power purchased from the grid will be required during Stage 1 of the project.

6.1.1 Solar Field

In Stage 1, it is proposed that solar panels cover the top surface of Cell 6, which has an available square area of approximately 42 x 203 m. An estimated 1.2 MWac is able to fit on the available Stage 1 solar area. It is recommended that this capacity be maximised.

A critical feature of the solar field is that the structural design must avoid disturbances and penetration of the landfill cap. The recommended design is an east-west 10-degree tilt solar array system. This was selected over a north-facing 30-degree tilt system due to its lower cost, lower use of resources, and lower embedded CO_2. This configuration is also low weight (>20 times lighter than north facing) and features an innovative installation method which minimises heavy vehicle traffic and installation time. The maximised solar array would be arranged into one column of 29 MAVERICK solar modules (MAVs) with a separation of 1 m for service access and cable tray installation. A MAV is a structural element of 90 solar modules (5 by 18) that is easily shipped and quickly installed as one component. The overall system performance is estimated at 81.8% and average daily capacity factor of 23%.

An additional benefit of this technology selection is that MAVs can be fully relocated up to five times if required and are lower cost to recycle at end of life. The ability to disconnect and “fold up” the MAVs is relatively easy with standard equipment and can be extremely beneficial if any site subsidence occurs and ground works are needed. East-west arrays provide a 9% lower specific energy generation per year as compared to north-facing arrays, however they also give a lower cost per kWh of AC energy generation and provide a broader and flatter generation curve across a day than north-facing arrays.

A number of string inverters (between 60–120 kW per inverter) are recommended to provide the best balance of performance, cost, redundancy and backup, along with rapid local service and replacement.

A purpose-built plant room will house the inverters, two PV distribution boards (PVDB) and protection cabinets, one control system cabinet, and the fire detection system. The plant room will be raised off the ground and mounted to above-ground concrete blocks to allow cable trays to pass under the open grated floor. The plant will be the size of a 40-foot container with an open-sided roof to provide shade and protection to the equipment while preventing gas entrapment. All equipment mounted in the plant room will be at least IP65 rated and designed to operate in an outdoor environment, within 5 km of the ocean.

A kiosk substation, housing a transformer, low voltage switchboard, protection equipment, and communication equipment will also be supplied. The solar field will be connected to the 22 kV Ring Main Unit (RMU) which will be situated at the southern end of Cell 6 for high voltage distribution.

6.1.2 Landfill Gas Plant

The renewable power supplied by the solar field will be supplemented by power generated from landfill gas. This facility is already on site and is outside the scope of this study, apart from a connection from the landfill gas power generation to the hydrogen generation facility.

The existing landfill gas power station can provide a continuous 3 MW supply of power. It will be utilised when the output from the solar field does not meet the demand from the hydrogen plant.

6.2 Power Smoothing

The hydrogen production facility is proposed to operate 24 hours per day and will require a continuous power supply. The proposed solar farm is capable of generating up to 1,200 kW during the day and is sized such that it will not be curtailed (turned down) during normal operation of the hydrogen facility. The landfill gas power station is required to supply any shortfall in electricity.

The landfill gas power station and solar field work together to provide the required demand for the hydrogen plant. The landfill gas power station supplies all the power required by the hydrogen facility except for that supplied by the solar. The landfill gas power station also provides sufficient spinning reserve to allow it to pick up the load in the event that a cloud reduces the output of the solar field. Spinning reserve required is approximately 80% of the solar field output.

Assumptions made on the landfill gas plant include:

– That it operates 24 hours per day and 7 days per week
– That it has a generation capacity of 3 MW
– That it will operate with sufficient spinning reserve to offset loss of solar generation during a cloud event

A battery energy storage system was considered to smooth the fluctuations during cloud events. Based on the information available, it is understood that the landfill gas power station will respond fast enough to provide sufficient spinning reserve. Additionally, batteries have a high capital cost which does not benefit this project. During the day, the solar field will be providing constant high power to the electrolyser, thus no additional backup storage is required.

6.3 Power Distribution and Users

The estimated power consumption breakdown is shown in Table 5.

Table 5 Power consumption

Description	Hydrogen Facility (approximate average operating requirements)	Hydrogen Facility (installed capacity)
Power for the electrolyser unit	960 kW (stack only, average) (50.4 kWh/kg) 53 kW beginning of life 74 kW at end of life	1.25 MW (stack only) 71 kW at beginning of life 99 kW at end of life
Power for hydrogen compression	70 kW	95 kW
Estimated power for balance of plant	75 kW	100 kW
Total power consumption (estimated)	1,150–1,200 kW	Up to 1,500–1,550 kW

Power distribution from the solar field and gas plant will be via underground 22 kV cables. The high voltage cabling distances required include:

– Approximately 660 m between the solar field and gas plant
– Approximately 480 m between the gas plant and hydrogen plant

Aboveground cabling is more cost effective as compared with buried, however carries an increased risk of interruptions to power transmission due to the high volume of heavy vehicle movements on site (including large-scale earth moving equipment). Due to this, burying the cables was deemed the preferred base case option. This may be reviewed during future project design phases.

6.3.1 Cooling Power for Electrolyser Unit

The electrolyser imparts a notable cooling load, which increases over its life as the stack efficiency declines. Table 6 outlines the expected cooling loads at the beginning and end of the electrolyser's life, showing both the operational average and installed loads (based on vendor data).

The minimum energy performance standards dictate the efficiency that chillers must achieve in Australia, as shown in Figure 9. As a water-cooled chiller of maximum cooling load of 496 kW, a coefficient of performance of 5 is used to calculate the power loads required to provide the electrolyser cooling, as shown in Table 6.

Table 6 Cooling and power loads of the electrolyser

	Cooling load average (kW)	Cooling load installed (kW)
Beginning of life	265	353
End of life	370	496
	Power load average (kW)	**Power load installed (kW)**
Beginning of life	53	71
End of life	74	99

Efficiency Regulations

As of December 2012 Chillers with capacities greater than 350kW sold in Australia must comply with the minimum energy performance standards (MEPS) regulations. Table 1 shows the efficiency ratings that chillers must achieve, when tested in accordance with AS/NZS 4776. Chillers with capacities less than 350kW are covered by the National Construction Code (formerly the Building Code of Australia). For water cooled chillers, the minimum COP is 4.2 and the minimum IPLV is 5.2; for air cooled chillers the minimum COP is 2.5 and the minimum IPLV is 3.4.

Table 1: MEPS Ratings

Capacity (kW)	Minimum COP		Minimum IPLV	
	Air cooled	Water cooled	Air cooled	Water cooled
350-499	2.70	5.00	3.70	5.50
500-699	2.70	5.10	3.70	6.00
700-999	2.70	5.50	4.10	6.20
1,000-1,499	2.70	5.80	4.10	6.50
>1,500	2.70	6.00	4.10	6.50

Figure 9 Minimum energy performance standards for chillers[6]

6.4 Power Supply Control System Architecture

The Solar Farm will have its own control system that allows for external control inputs, load setpoints, and SCADA integration with the wider site control system. External SCADA and control interface will be via Modbus TCP/IP.

The Solar Farm control systems ensures that the Solar Farm is able to start, synchronise with the upstream power supply, shut down, and operate safely over the full range of operating conditions including changing loads,

[6] https://www.energy.gov.au/sites/default/files/hvac-factsheet-chiller-efficiency.pdf

transient solar output reduction, and re-instatement after power system fault conditions without any remote or local intervention or support.

The Solar Farm will be designed, installed, and interfaced to permit the following:

- Automated and unmanned operation for extended periods
- Remote control, operation and monitoring
- Local manual operation via local control facilities
- PV Array maximum power point tracking (MPPT)
- Automated and manual PV Array output reduction from full load down to no load and any point in between
- Remote circuit breaker control

7. Sustainability and Circular Economy Principles

A circular economy is one that exchanges the typical cycle of "make, use, dispose" in favour of as much re-use and recycling as possible. It is based on three principles: design out waste and pollution, keep products and materials in use, and regenerate natural systems.

An effort has been made to apply circular economy principles wherever possible throughout this project. The best opportunity for this is the recycling of the site’s leachate for feedwater to the hydrogen plant; effectively turning a problematic waste product into green fuel for heavy vehicles.

The entire project itself will displace up to 1,410 L/day (over 500,000 L/year) of diesel by replacing the heavy vehicle diesel fuel with green hydrogen. This will have a direct carbon emissions reduction of up to 1.38 million kg CO_2 per year (or the equivalent of planting 22,819 trees and growing them for 10 years[7]).

The lifecycle emissions of renewable hydrogen production also provide a 92% reduction in carbon emissions over the current diesel fuel (more information in Section 7.2).

Typically, the water consumption for green hydrogen and diesel production are roughly the same. However, since this project is able to use 100% wastewater (leachate) as feedwater, the effective clean water consumption is negligible. Hence, if leachate is used as the raw water source, this project will result in an 8,500 L/day (100%) reduction in lifecycle water consumption with regards to fuel.

The following sub-sections describe in more detail the environmental impacts of the project.

7.1 Emissions and Waste Streams

Emissions for gaseous, liquid, and solids generated as a result of the facility are summarised in Table 7.

During operation, the solar field and hydrogen plant will produce negligible waste streams, the main effluent being oxygen gas which is not harmful to the environment. Cooling water for the electrolyser is a closed system, however it will dispose of relatively clean water during blowdown. Hydrogen gas venting to atmosphere may occur during maintenance or emergency events, as well as nitrogen gas venting during purging.

The water treatment plants emit the majority of waste products during operation, with brine wastewater being deposited back into the leachate ponds. However, if leachate is used as the raw water source, the water treatment process will have a net consumption of water from the leachate ponds—a beneficial outcome considering the site’s overbalance of leachate from landfill runoff water.

Construction activities may contribute significant solid, liquid, and gaseous waste, however these will be once-only for the construction and installation of the greenfields project. Construction waste from future expansion stages will likely be considerably lower since the main infrastructure will already be in place.

[7] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 7 Emission type per process

Process	Emission Type	Description	Destination
Electrolyser	Gas	Oxygen	Vent to atmosphere
Hydrogen equipment purging	Gas	Nitrogen	Vent to atmosphere
Water treatment (desalination, deionisation)	Liquid	Brine water	Leachate ponds on site
Cooling Water	Blowdown, evaporation, and drift	Vendor to advise	Wastewater system on site
Other wastewater sources – wash water, storm water run-off	Liquid	Water may contain some solids, should be fairly clean (no oil used on site for e.g. compressors)	Wastewater system on site / drains
Construction activities	Gas	Emissions from construction equipment	Vent to atmosphere
Construction activities	Liquid	Effluent from ablutions, wash down water from general construction activities	To be disposed of safely on / offsite
Construction activities	Solid	Solid waste	To be disposed of safely on / offsite

7.2 Carbon Emissions Analysis

This section presents a high-level estimate of lifecycle emissions from the proposed solar and green hydrogen plant, using metrics available from past GHD projects and from publicly available research data. The aim of the estimate is to account for the total life cycle emissions (LCE) associated with each of the main components and/or construction materials used in development of the plant. It is acknowledged that this estimate is highly uncertain, particularly for areas like equipment manufacture where very little data is available. Margins have been applied to publicly available data for steel fabrication to try and account for this uncertainty, and no credit has been taken for steel recycling for conservatism.

The estimate is summarised in Table 8 and is dominated by emissions associated with the solar farm. Solar farm emissions are based on data from a 2012 study by the US NREL[8], assuming a 30-year life and 23% capacity factor (approximately 85 GWh total power output).

For comparative purposes, the table also provides an estimate of the emissions generated by producing the equivalent amount of energy using the existing sources feeding the South West Interconnected System (SWIS), WA's main energy source, or using brown coal. These are based on existing emissions intensity metrics from the Australian Government[9,10], and indicate that to generate the equivalent 85 GWh with current SWIS sources would incur approximately 13 times more carbon dioxide equivalent (CO_2e) emissions in scope 2 emissions alone, while using brown coal would generate approximately 30 times more in scope 2. This accounts for the power generation emissions only, not for the full life cycle emissions of the existing infrastructure used to generate the power which would be significantly higher. An estimate of energy payback time is also provided, using the same metric from SWIS[9], which was found to be approximately 2.2 years.

[8] NREL/FS-6A20-56487, Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics, National Renewable Energy Laboratory, 2012
[9] National Greenhouse Accounts Factors, Australian National Greenhouse Accounts, Department of Industry, Science, Energy and Resources, October 2020
[10] Retirement of Coal Fired Power Stations, The Senate Environment and Communications References Committee, March 2017

Table 8 Life cycle emissions estimate for solar and green hydrogen plant

Source	Units	Value
Solar farm LCE (including supporting steel and concrete)	t-CO_2e	3,385
Steel equipment LCE (excluding solar farm)	t-CO_2e	439
Concrete LCE (excluding solar farm)	t-CO_2e	49
Equipment shipping LCE	t-CO_2e	38
Margin for miscellaneous items (earthworks, plastic equipment, cables etc.)	%	10
TOTAL LCE	t-CO_2e	**4,301**
Estimated Scope 2 emissions for equivalent power from current SWIS	t-CO_2e	57,543
Estimated Scope 2 emissions for equivalent power from brown coal	t-CO_2e	128,625
Approx. annual emissions offset by solar generation (from SWIS)	t-CO_2e	1,918
Estimated energy payback time	yr	2.2

For comparison with the City of Cockburn's current fuel, approximately 53,940 t-CO_{2e} of lifecycle emissions are released for the production of diesel fuel (over the same 30-year timeframe as the above analysis). Hence, this project will result in a 92% lifecycle emissions reduction in terms of fuel production.

7.3 Dispersion Modelling

Dispersion modelling was performed to assess the potential impact to personnel and surrounding areas associated with the following venting scenarios:

– Continuous low flow venting of oxygen from electrolyser
– Venting the full inventory of hydrogen during emergency depressurisation

Modelling was performed using DNVGL's PHAST (Process Hazard Analysis Software Tool) version 8.4, using the basis shown in Table 9. The hydrogen case conservatively assumes that the full contents of the inventory are discharged at a constant flowrate, with only the vent line as a restriction. This results in a very fast discharge, with the release completed in 81 seconds. In reality, restriction orifices will be used to limit depressurisation rates, and inventory discharge will likely be significantly slower.

Table 9 Dispersion Modelling Basis

Parameter	Unit	Oxygen Case	Hydrogen Case
Upstream Pressure	MPag	1	25
Upstream Temperature	°C	60	30
Upstream Fluid Density	kg/m^3	1.2	83.5
Mass Flow	kg/hr	177	Calculated
Stored Inventory	kg	N/A	1,000
Vent Line Nominal Bore	mm	50	50
Total Piping Length to Vent	m	20	20
Height of Release	m	10	10
Release Orientation	-	Vertical (vent stack)	
Wind Speed	m/s	1.5 (Case 1) / 5 (Case 2)	
Weather Stability Class	-	F: Stable, night with moderate clouds and light/moderate winds (Case 1) D: Neutral, little sun and high wind or overcast/windy night (Case 2)	
Ambient Temperature	°C	25	
Ambient Relative Humidity	%	70	
Surface Roughness	micron	30 (few, isolated obstacles)	

Results of the dispersion modelling are shown in Figure 10 for the oxygen venting case and Figure 11 for the hydrogen venting case. The lines shown represent a concentration of 50% of Lower Explosive Limit (LEL), which is 20,000 ppm for hydrogen and as Oxygen is not flammable a concentration of 3,927 ppm for Oxygen was calculated by PHAST as an equivalent threshold. This is considered an acceptable threshold to avoid a risk of ignition. The blue line represents the lower wind speed case of 1.5 m/s (low mixing of material into the air), while the purple line represents the 5 m/s case (higher mixing into air).

The results indicate that neither scenario results in an ignition risk below the height of the vent outlet, which is located 10 m above grade. The ignition risk above the vent height extends for a maximum horizontal distance of:

– 10 m for the oxygen case based on wind speed of 1.5 m/s
– 29 m for the hydrogen case based on wind speed of 5 m/s.

Given the height and relatively small radius of the gas plumes, there is not considered to be any risk to personnel on site or in surrounding areas. This should be confirmed in subsequent phases when more detailed design information is available.

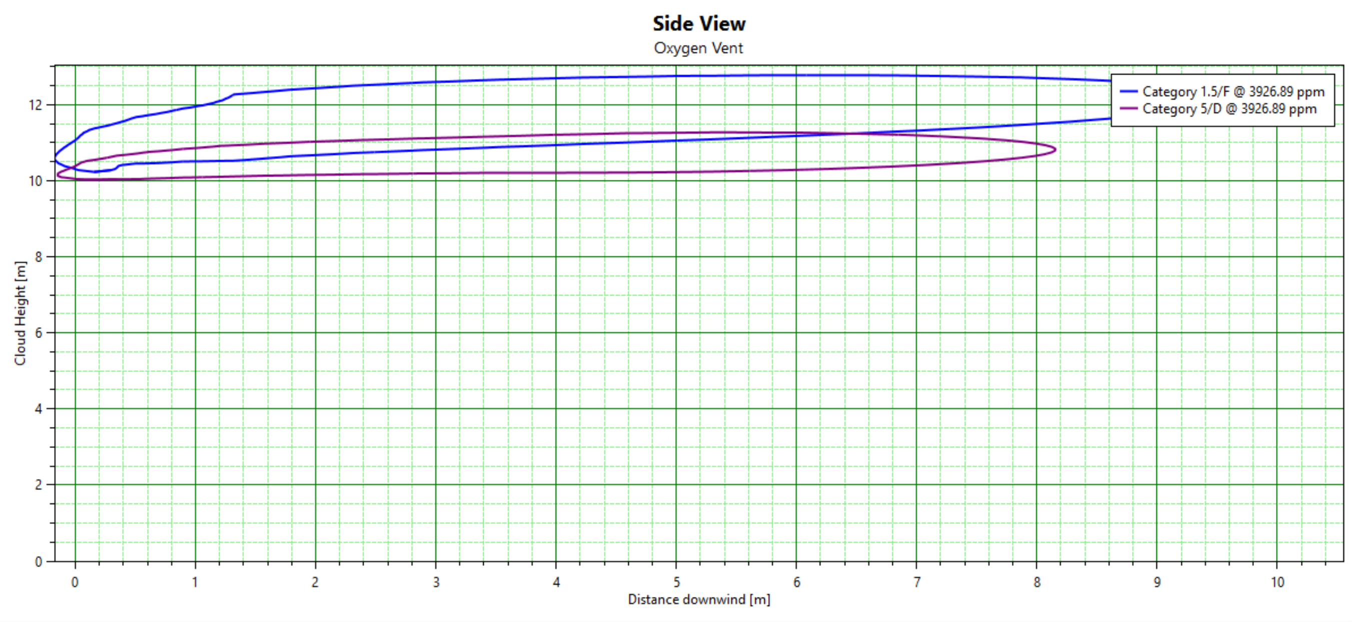

Figure 10 Oxygen Dispersion during Continuous Venting from Electrolyser

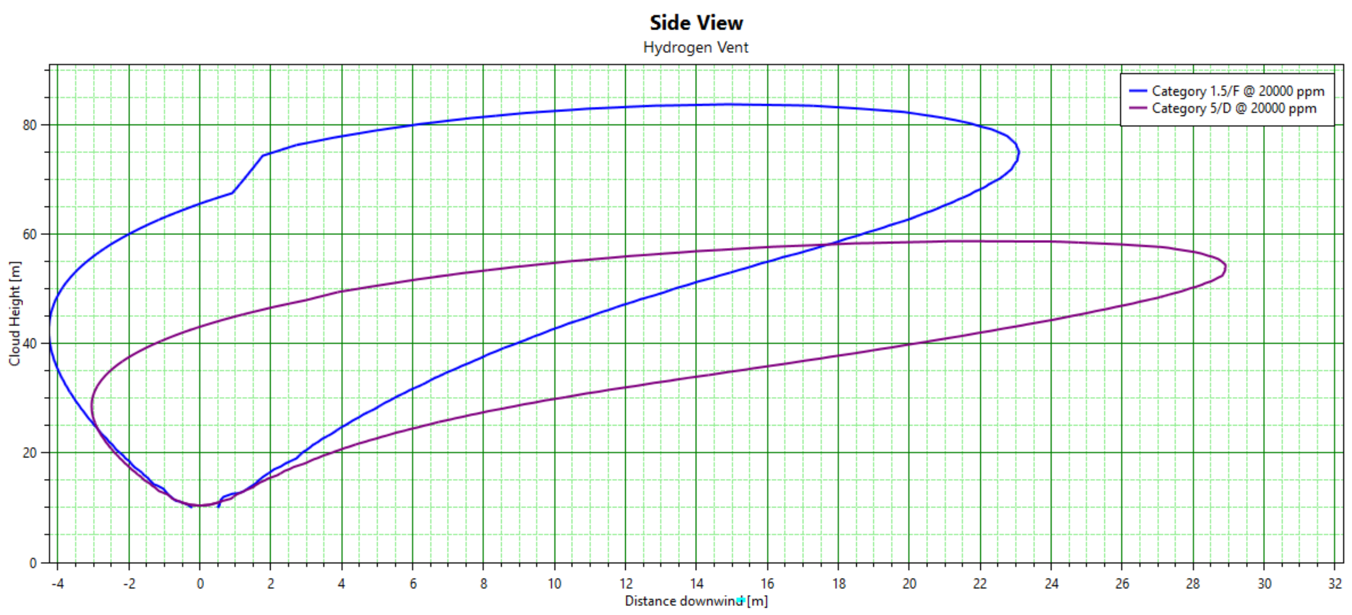

Figure 11 Hydrogen Dispersion During Emergency Depressurisation

7.4 Noise and Vibration

Noise and vibration are sources of emissions which can have a detrimental impact on personnel and the environment at high levels. The National Institute for Occupational Safety and Health (NIOSH) has a Recommended Exposure Limit (REL) for occupational noise exposure which has been widely referenced across the world. The NIOSH REL for occupational noise exposure is an eight-hour time-weighted average of 85 decibels, A-weighted.

The major sources of noise and vibration on this project are contained within the package equipment, notably the electrolyser package, the hydrogen compression package, and the water treatment package. These packages are either containerised or skid mounted, and are provided with noise emission guarantees by the suppliers not to exceed the NIOSH REL specification.

Furthermore, noise testing is typically part of the Factory Acceptance Testing (FAT) requirements which are placed upon suppliers of package equipment via the individual equipment specifications. In this way, compliance with the NIOSH REL can be confirmed, thus mitigating the risks associated with occupational noise exposure.

7.5 Local and State Government Approvals Plan Review

GHD have performed initial assessment of environmental and planning requirements for the project. The preliminary assessment of potential environmental impacts against relevant environmental legislation identified that the following may be required:

– Amendment of Works Approval under Part V of the Environmental Protection Act 1986
– Development Application approval under the Planning and Development Act 2005 (WA)
– Dangerous Goods Licence

7.5.1 Environmental Protection Act 1986 (WA) Part V

Part V of the Environmental Protection (EP) Act enables the Department of Water and Environmental Regulation (DWER) to regulate waste, emissions, and discharges to the environment, and native vegetation clearing, with clarifications provided in the Environmental Protection Regulations 1987 / Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Specified premises with potential to cause emissions and discharges to air, land, or water are known as “prescribed premises” (described in Schedule 1 of the Environmental Protection Regulations 1987 (EP Regulations) and trigger regulation under the EP Act. The EP Act requires a works approval to be obtained before constructing a prescribed premises and makes it an offence to cause an emission or discharge unless a license or registration is held for the premises. Works Approvals and Licenses are the key statutory tools the DWER use to regulate industry in WA and are intended to prevent pollution during both the construction and operational phases.

Unless a project is already assessed under Part IV of the EP Act, the clearing of native vegetation in WA requires a permit under Part V of the EP Act (except when a project is assessed under Schedule 6 of the EP Act or is prescribed by regulation in the Environmental Protection (Clearing Native Vegetation) Regulations 2004 and not in an Environmentally Sensitive Area). Permits can be granted subject to any conditions that DWER considers are necessary for controlling environmental harm or offsetting the loss of vegetation. When preparing a native vegetation clearing application an assessment of the works against the “Ten Clearing Principles” should be undertaken to determine whether this project is likely to be at variance to the Principles. The Ten Clearing Principles aim to ensure that all potential impacts resulting from removal of native vegetation can be assessed in an integrated way. The selected site location is already cleared, therefore no additional clearing will be required.

The current site will have an existing Part V Works and operating license under the current waste facility operations. The green hydrogen project will require an amended to the existing Works and Operating Approvals under Part V, due to the site works and operations changes from the green hydrogen project.

7.5.2 Development Application

The Planning and Development Act 2005 is managed by Local government, Department of Planning, and Land and Heritage—the project will require a development application approval to develop the site within a planning scheme area. The application will include application form/s signed by the landowner, a complete set of development plans, elevations, certificate of title, and technical reports.

It is recommended that a development application be accompanied by a supporting report. This report should outline the proposed development, including building design and site related features, and address amenity related issues such as noise, traffic, access, dust, buffering to adjoining uses, construction works, and the operational staging.

In addition to addressing the relevant provisions of a local planning scheme or region scheme, the development application should also acknowledge relevant state and local planning policies.

7.5.3 Dangerous Goods Licensing Requirements

Dangerous goods requirements for the site will primarily be driven by the quantity of hydrogen storage and inventory on site.

The thresholds levels are listed below:

– Dangerous Good License: 5000 litres hydrogen
– Major Hazard Facility Notification Form: 5 tonnes hydrogen (threshold of 10% of 50 tonnes hydrogen major hazard facility)
– Major Hazard Facility: 50 tonnes of hydrogen

Given the plant will store 48 hours' production (circa 1,000 kg) and minimal process inventory, it is anticipated that the site will fall under a Dangerous Good licence but not require Major Hazard facility notification of licencing. However, given the project is in an emerging market (green hydrogen), GHD recommend ongoing engagement with the relevant regulators to monitor any new or evolving requirements.

8. Contracting and Procurement Strategy

8.1 Overview

The recommended contracting strategy is to award a solar package engineering, procurement, and construction contract (EPC) (Package 1), and free issue the process packages and construction contract (Package 2).

The advantages of this contracting model include the ability to specify key plant that impact production (e.g. performance, costs, etc.) and the ability to award to specialist firms. Under this model, solar, water treatment, hydrogen production and refuelling, and then all piping, electrical, and civil could be awarded to specialist vendors. The main disadvantage is that the interfaces between the free issue packages need to be managed.

8.2 Strategies Considered

An internal contracting strategy workshop assessed various contracting strategies against project-specific criteria. Two processes were used to assess the contracting strategy options: a “trade-offs” assessment of contract models and a comparison assessment between contract models.

The contracting models assessed included:

Table 10 Contracting strategy options

	Solar	Water	Hydrogen	Balance of Plant
1. Full EPC	EPC 1			
2. Process and solar EPCs	EPC 1	EPC 2		
3. Process and solar EPCs with free issue utility packages	EPC 1	Free Issue to EPC 2	EPC 2	
4. Solar EPC, free issue process packages, and balance of plant EPC(s)	EPC 1	Free Issue to EPC 2	Free Issue to EPC 2	EPC 2
5. Full EPCM	EPCM			

The project criteria that these contracting models were assessed against included scope definition, schedule, operating cost, cost certainty, plant design/quality/performance, capital cost, owner’s team resources, non-financial objectives, risk, and other stakeholders.

In both assessment processes, contracting model 4 from the above list was identified as the optimal model. Note that balance of plant EPC for this strategy will likely be split into high voltage power EPC and remaining balance of plant EPC unless a suitable contractor is capable of both.

8.3 Contracting Strategy

As per section 8.2, the strategy for the execution phase works is split as follows:

- EPC contract for solar facility
- EPC contract for high-voltage equipment
- City of Cockburn procurement of water treatment package and free issue to EPC Contractor
- City of Cockburn procurement of hydrogen production and loading package (includes electrolyser, compressor, storage, and refuelling) and free issue to balance of plant EPC Contractor
- EPC contract for balance of plant, including all civil, electrical, mechanical, and structural scope; this contract includes responsibility for overall integration of the free issue packages

As noted previously, the high voltage power EPC and balance of plant EPC may be awarded to one contractor if they possess the capability.

8.3.1 City of Cockburn Project Team

The City of Cockburn is the project owner and will facilitate the procurement of free issue packages and award EPC contracts. The City of Cockburn will also engage a project support contract (e.g. Owner's Engineer) to provide the required project delivery and technical capability. Functions which are determined to not be performed by the City of Cockburn project team will fall to the Owner's Engineer to execute.

8.3.2 Owner's Engineer

The Owner's Engineer will provide project management and engineering services which will support the City of Cockburn team. Major areas of support are expected to include contractor and interface management, procurement, scheduling and resource management, and technical resources for package engineering, reviews (including design reviews, model reviews, constructability reviews and HAZOPs), and construction verification.

The Owner's Engineer will develop Front-End Engineering Design (FEED) documentation and technical procurement activities (closely supporting the City of Cockburn procurement processes) to define the EPC packages required to complete the project scope. The Owner's Engineer will also detail the procurement packages and manage the package engineering process needed to deliver the water treatment package and the hydrogen production and loading package.

Detailed design will be performed by the EPC Contractors and reviewed by the Owner's Engineer.

8.4 Power Supply Agreements and Grid Connection

The proposed power supply for the hydrogen plant includes a solar PV installation operating parallel with the existing landfill gas fired power station. The landfill gas power station, owned by Waste Gas Resources, is connected to the SWIS and is proposed to operate at all times the hydrogen plant is operating. The landfill gas power station will provide the voltage and frequency reference for the solar PV system and will supply the balancing power required above what the solar PV system can provide to the hydrogen plant.

It is understood the Waste Gas Resources contract with Synergy is about to expire and the owner is looking for new opportunities with City of Cockburn. This study assumes that a suitable agreement can be put in place between City of Cockburn and Waste Gas Resources for the supply of power to the project.

9. Construction, Transport, and Logistics

9.1 Overview

The site is located in the City of Cockburn next to Kwinana (an industrial area), making it an ideal location in terms of transportation and heavy vehicle access. The site is 7 km north-east of Fremantle Port (Kwinana Bulk Terminal) where all equipment can be shipped.

All main project packages (solar, water, and hydrogen) can be delivered as a highly modular packages which are transportable via standard road and sea freight. All major process plant equipment will be containerised, and the solar field configuration is also designed for ease of transport and installation.

9.2 Modular Build Strategy

9.2.1 Solar

The recommended east-west solar field configuration features an innovative installation method using “fold out” MAVs which minimise heavy vehicle traffic and installation time.

The various solar package equipment originates in China, UK, EU, and Australia.

9.2.2 Water Treatment

The water treatment plant offered is a fully containerised system with almost all equipment installed inside a 20’ standard ISO shipping container. The waste water storage tank will be supplied loose as it cannot physically fit inside the sea container. Also provided as a standalone item will be the safety shower and eye wash station module with local storage.

All the major components of the water treatment package are sourced from local Australian agents/distributors.

9.2.3 Hydrogen Production and Refuelling

All hydrogen production equipment is fully containerised. The hydrogen storage (consisting of modular tubing racks), the hydrogen compression skids, and hydrogen dispenser are supplied loose. The hydrogen production and refuelling equipment originates in USA and Dubai.

9.3 Construction Resources

A local contractor will be engaged to install all process equipment as well as balance of plant requirements including (but not limited to) civils, piping, roads, fencing, lighting, and cabling. All materials are readily available from local suppliers.

9.4 Construction Schedule

The project is estimated to have a 23-month duration from kick-off of the FEED study, or a 14-month duration from a Financial Investment Decision (FID). The solar farm, hydrogen plant, and high voltage equipment are the long lead items.

Table 11 Schedule key dates

	Start	End
FEED	03-Jan-2022	03-Jul-2022
FID	04-Jul-2022	30-Sep-2022
Water Treatment	03-Oct-2022	17-Mar-2023
Solar Facility	03-Oct-2022	14-Nov-2023
Electrolyser	03-Oct-2022	29-Sept-2023
Site EPCs (BOP and High Voltage)	03-Oct-2022	05-Dec-2023

10. Operations and Maintenance

10.1 Overview

The integrated solar, hydrogen, and water plants will be designed for a high level of automation and minimal manual plant operations support. The site is located in the metropolitan region of Perth, Western Australia and has a high level of access to skilled operation and maintenance personnel.

At the current phase of the project, it is assumed the City of Cockburn will provide a single full time representative to manage the solar and hydrogen plant operations. The City of Cockburn representative will be supported via maintenance contracts with the various equipment packages. The City of Cockburn representative may be engaged directly, potentially with a shared work arrangement with other personnel currently working on the Henderson Waste Facility. Alternately, the City of Cockburn representative could be engaged under contract by a suitable qualified operations and maintenance (O&M) service provider.

Refuelling activities will be performed by the heavy vehicle operators. The refuelling system will be of a simple, safe and automated design—similar to those used for retail hydrogen refuelling.

10.2 Jobs

One full-time equivalent (FTE) employee is required to run the facility, as described above (Section 10.1). All other O&M activities may be outsourced to specialist third party contractors.

10.3 Defects Liability

A minimum of one year (12 months) warranty is provided by all equipment manufacturers. This warrants that the equipment shall be free from material defects in design, materials, and workmanship that affect performance. Parts requiring replacement as a result of fair wear and tear are excluded.

Broadly, the following warranties are offered:

- Solar modules and DC connectors/cables normally:
  - Solar panels: 10 years
  - Inverters: 5 years
  - Cables: 2-5 years
  - Solar System: 2 years
- Water treatment plant: first of 12 months from commissioning or 15 months from delivery
- Hydrogen production and refuelling: 1 year, can be extended upon execution of O&M agreement

Warranty agreements will be confirmed at a later phase of the project.

10.4 Operations and Maintenance

Operations and maintenance activities are centred around the key equipment packages, such as the water treatment, electrolyser, hydrogen compression and storage, and solar field. For these types of equipment packages, the operations and maintenance requirements are typically clearly defined by the original equipment manufacturer (OEM), and indeed in most cases must be followed as required for warranty purposes.

11. Risk

11.1 Overview

A preliminary risk workshop was conducted early in the project to identify risks that may impact the overall success of the project.

Risks, and associated mitigation strategies, were identified early so that they could be incorporated into the final design. These risks and mitigations were reviewed throughout the study and residual risk rankings were calculated as part of the final phase of the study.

A systematic process was applied to identify key risks which may impact on the following:

- Safety
- Financial
- Reputation
- Operations / Delivery
- Environmental health
- Compliance
- Project quality
- Project cost
- Project schedule

A risk assessment matrix of consequence/severity and likelihood/probability guide was used to rank all identified risk events from low risk (1) to extreme risk (25). This process was conducted twice: firstly for the unmitigated risk events (Initial Risk Ranking), and secondly with the recommended mitigations in place (Residual Risk Rankings).

11.2 Key Risks

The risk analysis process yielded 34 risk events with the following category breakdown:

Table 12 Risk ranking category breakdown

Risk Ranking	Number of events (Initial Risk Rankings)	Number of events (Residual Risk Rankings)
Low	5	19
Moderate	18	14
Substantial	7	1
High	4	0
Extreme	0	0

12. Cost Estimates

12.1 CAPEX

12.1.1 Basis of Estimate

A budget-level Capital Expenditure (CAPEX) estimate has been developed following market engagement and completion of the concept design. This cost estimate has a target accuracy of -15% to +25%.

The estimate basis is the following:

- Currency is AUD. Major equipment more likely comes from overseas, however, for the purpose of this high-level estimate, it is assumed currency exchanges are minor or not taken into consideration. Please note foreign exchange (FOREX) fluctuation is part of Owner's costs.
- Pricing is as of third quarter 2021
- Based on preliminary quantities
- No contracts and subcontracts are identified at this stage. Estimate is based on the following contracting strategy:
  - Hydrogen process (supply only)
  - Solar works (EPC complete package)
  - Balance of plant (supply and install, free issue water and hydrogen packages)

The estimate includes the following:

- Project direct costs:
  - Direct man hours
  - Direct labour costs (labour installation for major equipment and materials is derived from vendor's advice in budget quotes, crewed-up method, and/or using industry standard and experiences.)
  - Plant and equipment cost
  - Bulk material cost
  - Spares (2% of supplied item cost)
  - Contractors distributable costs (allocated per task)
  - Freight cost (included in the supplied cost, or 8% has been included in the supplied cost if not provided in quotations)
  - Construction equipment cost (as applicable, and included in contractor distributables)
  - Growth (where applicable)—to capture additional quantities due to concept layouts and pricing quality. Growth is also an allowance to cover unmeasurable quantities, accuracy of the take-off, offcut, structure connections, wastes, overpour etc.
- Project indirect costs—essential to support construction but that cannot be attributed to, nor become a part of, the permanent plant structure:
  - Common distributables—the overall site indirect costs required to support the direct-cost effort of the project (factored off direct costs & based on historically implemented projects)
  - Professional services—cost of engineering service support during the implementation phase (factored on direct costs based on previous project studies)
  - Owner’s costs—cost of project management, and supporting functions, to manage the project (factored off directs estimate based on historical projects)
  - Contingency—an allowance to cover the cost of unknown risks that may occur within the scope, over the project life.

12.1.2 Exclusions

The following factors are excluded from the cost estimate, but may contribute to the overall costs:

- Escalation
- GST
- Sunk costs (e.g. previous and this study costs)
- External funding
- Any impacts as a result of ground conditions not yet investigated
- Land acquisitions
- Operation costs
- Value improvement, opportunity, or capital cost savings
- Cost impacts due to change of locations
- Contaminated materials
- Upgrades to the biogas facility or network connection

12.1.3 CAPEX Results

The capital cost estimate came to $24,489,654.

12.2 Lifecycle Cost Analysis (Including OPEX)

The overall purpose of this project is solely to decarbonise the City of Cockburn's heavy vehicle fleet, not to produce a revenue stream from the sale of hydrogen. The produced hydrogen will be used internally, as a replacement to purchasing diesel fuel. Hence, this project does not produce revenue, and EBITDA cash flow estimations and internal rate of return analyses are not applicable.

The most useful lifecycle economic analyses are net present cost (NPC) and levelised cost of hydrogen (LCOH), the latter of which can be used to compare the cost of the hydrogen produced with the current cost of diesel.

For comparison, the average diesel price in Perth for 2021 was $1.38/L. The diesel-to-hydrogen equivalence for refuse collection vehicles is 5–7 L diesel per kg H_2. Hence, a LCOH of $7–10/kg H_2 would be comparable to current diesel costs in this application.

Table 13 Lifecycle cost analysis summary

Fixed OPEX	$397,698
Variable OPEX	$272,369
NPC of Total Costs	$33,349,710
Lifetime Output (kg H_2)	1,574,191
Levelised Cost of Hydrogen ($/kg H_2)	$21.19

These costs are based on an NPC calculation assuming a life of 20 years, discount rate of 7%, and inflation rate of 1.7%. The model does not account for revenue, depreciation, external funding, or other potential income.

12.2.1 Sensitivities

The LCOH analysis was run with the following sensitivity scenarios:

- 50% External CAPEX Funding
- Build Own Operate Model

Table 14 Lifecycle cost analysis summary (50% funding)

NPC of Total Costs	$21,104,883
Levelised Cost of Hydrogen ($/kg H_2)	$13.41

Table 15 Lifecycle cost analysis summary (Build Own Operate)

NPC of Total Costs	$24,727,248
Levelised Cost of Hydrogen ($/kg H_2)	$15.71

Note that there may be other factors such as depreciation and tax offsets which may further improve the financial data. These have not been included in the above analyses and would require further input from the City of Cockburn financial team.

12.3 Funding

12.3.1 Sources and Uses

Commonwealth and State Governments, and private industry, have grown increasingly interested in assessing the potential for green hydrogen production as part of a portfolio of technological solutions to reduce carbon emissions. This has resulted in the formation of official policy positions and associated funding opportunities, in both Western Australia and Australia-wide via the Commonwealth Government.

GHD believe that it is likely the project would receive funding, with 50% of capital costs a likely funding target.

12.3.2 WA Renewable Hydrogen Fund

In Western Australia, the *Renewable Hydrogen Strategy* was launched in July 2019 and updated with a larger pool of initiatives and more ambitious timeframes in November 2020. As part of this strategy, the Western Australian Government has developed a Renewable Hydrogen Fund. The Renewable Hydrogen Fund provides leveraged funding opportunities to facilitate private sector investment to the renewable hydrogen industry.

Round 1 of the Renewable Hydrogen Fund was centred on $10 million of funding for feasibility studies and capital investment projects. The funding round saw seven private sector proponents receive funding for pre-feasibility studies into renewable hydrogen production opportunities. This study was a recipient of Round 1 funding.

Submissions to Round 2 of the Renewable Hydrogen Fund, providing $5 million of funding, closed in February 2021, with no timeline available on the award of funding. It is not yet clear whether there will be a third round of funding. However, given the Western Australian Government has consistently indicated that the fund is oversubscribed, it is likely the fund will continue.

12.3.3 ARENA

The Commonwealth Government has provided significant funding support for early stage renewable hydrogen studies and capital investment projects through a variety of channels. This includes the Australian Renewable Energy Agency's ('ARENA') *Renewable Hydrogen Development Funding Round*, which was announced in 2019, called for submissions in 2020, and has provided over $100 million in capital funding for pilot projects across Australia.

ARENA's standing program, the *Advancing Renewables Program,* may be a suitable source of funding to progress this study. The program guidelines are broad and are suggestive of an openness to consider a study of this nature. In order to qualify for funding, the following conditions must be met:

1. The proponent is an Australian corporation, Commonwealth or State Government entity
2. The activity described in the proposal involves a Renewable Energy Technology
3. Is not focussed on basic research, or teaching
4. The project will take place in Australia
5. A knowledge-sharing agreement is in place
6. All intellectual property must be owned by the proponent or related parties

The *Advancing Renewables Program* is a merit-based fund but is a standing fund, meaning applications can be progressed at any time at ARENA's discretion and there is not a direct competitive process. The principal merit-based requirement is the ability for the proponent's proposal to contribute to the program's outcomes, being:

– Reduction in the cost of renewable energy
– Increase in the value delivered by renewable energy
– Improvement in technology readiness and commercial readiness of Renewable Energy Technologies
– Reduction or removal of barriers to renewable energy uptake
– Increased skills, capacity, and knowledge relevant to Renewable Energy Technologies

The program is open until 2022. ARENA also states the proponent is expected to typically at least match the funding being sought from ARENA. Further information can be found in the Program Guidelines.

12.3.4 Regional Clean Hydrogen Hubs

Through the 2021–22 Budget, the Australian Government will invest an additional $275.5 million to accelerate the development of an Australian hydrogen industry.

The package includes:

– $240 million to support up to four additional regional hydrogen hubs, building on the $54 million for the first hydrogen hub announced in last year's Budget

– $20 million for up to ten hydrogen hub feasibility studies, taking the Australian Government's total investment in developing hydrogen hubs to $314 million
– $9.7 million to support development and implementation of trials of a Guarantee of Origin hydrogen emissions certification scheme for Australian hydrogen
– $2.4 million to support legal reforms required for the development of hubs and to address other regulatory barriers to large-scale hydrogen industry growth

This new funding will increase the Australian Government's total support for a hydrogen industry to over $850 million.

12.3.5 Manufacturing Modernisation Fund

The Manufacturing Modernisation Fund supports manufacturers by co-funding capital investments and associated reskilling to:

– Adopt new technologies
– Encourage innovation
– Become more productive and competitive in the market and
– Create more jobs

The program aims to support Small and Medium-sized Enterprises (SMEs) through:

– Investment in transformative manufacturing technology and processes
– Jobs growth and a more highly skilled workforce in the manufacturing sector

Round 2 will run over three years (2020–21 to 2022–23) and supports transformative investments in technologies and processes, including:

– Buying, constructing, installing, or commissioning of manufacturing plant and equipment
– Integrating production-related software that is directly related to capital investment
– Relevant training and skills development to assist in integrating the new technology into a business, including upskilling and accreditation in advanced processes
– Process design and engineering directly related to capital investment
– Fit-out, alterations and/or extensions to buildings directly related to capital investment

The City of Cockburn Green Hydrogen project may consider the Manufacturing Modernisation Fund for the hydrogen powered garbage truck component of the project. An application would potentially have to be in conjunction with a hydrogen powered garbage truck manufacturer.

12.3.6 Hydrogen Fuelled Transport Program

The Hydrogen Fuelled Transport Program (which is in an expression of interest phase at the time of this report) aims to assess the potential for hydrogen fuelled transport applications to be deployed in Western Australia. The program hopes to identify projects that could be co-funded by State Government and that will:

– Aggregate demand for renewable hydrogen and related transport products (e.g. fuel, vehicles, refuelling infrastructure) across the supply chain in WA
– Deploy hydrogen vehicles and refuelling station infrastructure in WA within a 36 month period
– Provide evidence of the viability of using hydrogen fuelled transport in WA, and demonstrate the benefits of increasing the scale of hydrogen vehicle deployments
– Demonstrate the fossil fuel reduction benefits of hydrogen fuelled transport
– Demonstrate the creation of local jobs
– Promote cost efficiencies of using renewable hydrogen for the transport sector in WA

The WA State Government has set aside an initial amount of $10 million for this program, with an application submission deadline of 13 January 2022. The City of Cockburn Green Hydrogen project may consider submitting an expression of interest application for this program to undertake a part or full scope.

13. Next Steps

The following section is based on the assumption that the project receives financial approval.

Following this feasibility study, the recommended next steps are as follows:

– Submit funding request to appropriate agencies, for example Hydrogen Fuelled Transport Program
– End of study project framing
– Appoint an Owner’s Engineer
– Owner’s Engineer to develop a project definition / FEED study
– Owner’s Engineer and City of Cockburn to develop a vehicle conversion plan
– Owner’s Engineer to carry out a tender process to identify suitable package equipment Suppliers and EPC Contractors
– Acquire all planning and environmental approvals for the project
– Detailed engineering carried out by selected EPC Contractors
– Construction and commissioning

13.1 End of Study Project Framing

Project framing should be updated based on the new information from this study.

The purpose of this re-evaluation is to confirm the direction of the project in the following phases, incorporate the learnings from this study, and re-align the project delivery strategy with the project drivers. This step will ensure that, going forward, the project moves along the optimal path.

13.2 Project Definition / FEED

13.2.1 Plant Design

Additional engineering design is required to take the project from a feasibility level to a place where all early engineering activities have been completed, and sufficient detail is available to fully specify the project requirements for all interfacing parties. This Front-End Engineering Design—undertaken by the Owner’s Engineer—will support the development of the design, technical, and performance specifications, and clear scope definition to permit subsequent tendering, assessment, and award of the execution phase EPC packages.

The FEED phase will provide a more accurate CAPEX (typically +/-10 to 15%). Typically, this will include further engagement with technology vendors and construction partners. The FEED study will also be expected to provide the planning approvals strategy approach. Any design requirements imposed by the planning process, however, must be understood at the tender phase.

Risk studies will be completed at various stages of design development. A preliminary hazard assessment and HAZOP will be completed based on the FEED study design development. The expectation will be that detailed risk assessments will happen during the detailed design phase.

Typical FEED study duration is expected to be between six and nine months. Costs would vary depending on the level of design development required. A value in the region of 2% of CAPEX is considered typical, noting the expected design input required by the technology supplier.

13.2.2 Vehicle Conversion Plan

A vehicle conversion plan will be developed to determine how the existing diesel fleet will be converted to hydrogen fuel cell vehicles. This will most likely be a staged transition over a period of time.

This process will involve discussions with vendors who have experience in this type of vehicle conversion, and a potential preliminary trial (see Section 12.3.6). The plan will be developed by the Owner’s Engineer in collaboration with the City of Cockburn.

13.3 Tender / Procurement

The Owner's Engineer will develop technical specifications and documentation for the tender of suitable package equipment Suppliers and EPC Contractors. As the design nears completion, lists of potential Suppliers and Contractors will be compiled. Discussion will progress with all interested parties after a short expression of interest process.

The tender evaluation and clarification process will be completed by the Owner's Engineer. Negotiation will proceed with successful tenderers, and contracts will be awarded subject to successful financial close of the project.

13.4 Detailed Design

The detailed design phase removes uncertainties and provides a completed project design. Upon award of EPC contracts, the EPC Contractors will perform detailed design works with the Owner's Engineer reviewing the design for compliance to the project technical requirements.

13.5 Construction and Commissioning

The construction phase will begin ahead of procured items arriving on site. The EPC Contractors are expected to start civil/structural works several months before equipment arrives on site. Once the equipment has arrived on site, the Contractors will install, commission, and test the facility under the Owner's Engineer's supervision.

The package Suppliers will undergo manufacturing and factory testing before delivering the relevant equipment to site as discussed above.

The Owner's Engineer will be represented on site to oversee all activities, supporting the Contractor(s) to fulfil their commitments, and provide assurance that the plant is commissioned and tested in accordance with the agreed procedures.