Australian Renewable Energy Exports

Green Hydrogen Power System Tender Document

MACQUARIE University
SYDNEY · AUSTRALIA

ENGG4001 Professional Practice, Session 1, 2022
Group Mon_16_05

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Division of labour and workload acknowledgement

Table 1: Division of Labour

Member name	SID	Sections responsible
Chan Alex Ros	44419775	Testing, Hydrogen Storage/Transport Requirements
David Nguyen	46494871	Inclusions and Exclusions, Electrolysis Requirements, PEM electrolyzer detailed design
Duy Phan	45853193	Reflection, Electrolysis Requirements, PEM electrolyzer detailed design, alternative design of submarine cable export
Jaime Sun	45662398	Introduction, Tracking System Requirements
Joanna Gunawan	45981736	Inclusions and Exclusions, Hydrogen Storage/Transport Requirements
Nicholas Morjanoff	45162972	Conceptual design, Solar Grid Requirements
Rajiv Mehta	45433062	Justification, Constraints, Software System Requirements
Scott Lin	45985995	Testing, Submarine Cable Requirements
Trung Hieu Uong	44497067	Conceptual design, Solar Grid Requirements, Constraints, alternative design of submarine cable export.
William Giles	45970912	Deliverables, Submarine Cable Requirements

Revision History

Table 2: Revision History

Date	Version	Description	Person/Author
3/06/2022	1.4	Final tender submitted, adjusted based on peer-feedback and with additional specifications added to the detailed design section	Group Mon_16_05
19/05/2022	1.3	Draft of final tender submitted for peer-review	Group Mon_16_05
31/03/2022	1.2	Finalised scoping document, taking into account peer feedback	Group Mon_16_05
17/03/2022	1.1	Draft of scoping document submitted for peer-review	Group Mon_16_05
8/03/2022	1.0	Initial template made available to team using online file sharing	Group Mon_16_05

Terms, definitions, and abbreviated terms

Table 3: Abbreviations and Definitions

Abbreviation	Definition
Asm	Prefix for Assumption
Con	Prefix for Constraints
FoS/SF	Factor of Safety/Safety Factor
FR_GHS_x	Functional Requirements for Green Hydrogen Storage
FR_PEM_x	Functional Requirements for PEM Electrolysis System
FR_PV_x	Functional Requirements for Photovoltaic Solar Panel
FR_SC_x	Functional Requirements for Submarine Cables
FR_STR_x	Functional Requirements for Software System
GHPS	Green Hydrogen Power System
HSS	Hydrogen Storage System
HVDC	High Voltage Direct Current
IR_GHS_x	Interface Requirements for Green Hydrogen Storage
IR_PEM_x	Interface Requirements for PEM Electrolysis System
MVP	Minimum Viable Product
PEHPS	PEM Electrolysis Hydrogen Plant System
PEM	Polymer Electrolyte Membrane, or Proton-Exchange Membrane
PR_GHS_x	Performance Requirements for Green Hydrogen Storage
PR_PEM_x	Performance Requirements for PEM Electrolysis System
PR_PV_x	Performance Requirements for Photovoltaic Solar Panel
PR_SC_x	Performance Requirements for Submarine Cables
PR_STR_x	Performance Requirements for Software System
PSPS	Photovoltaic Solar Panel System
PV	Photovoltaic
SCS	Submarine Cable System
TOMS	Tracking/Ordering Management System
TPM	Technical Performance Measure
BOP	Balanced-of-plant part
MPP	Maximum power point

1 Introduction

Each year, Australia exports about 15.26 exajoules of energy in the form of non-renewable fossil fuels (see Appendix A.1.). The burning of these fossil fuels releases carbon dioxide into the atmosphere leading to increases in the average global temperature and it is this process which is the main cause of global warming with 89% of global carbon dioxide emissions coming from fossil fuels [1].

Australia ranks highly in the world for exporting fossil fuels, taking the top spot for exports of metallurgical coal and also for Liquid Natural Gas (LNG) and is also the second biggest exporter of thermal coal. If we look at the impact Australia's exports have on total global emissions, Australia places third, with only Russia and Saudi Arabia's exports having a larger contribution to the global emissions of carbon dioxide. The fossil fuel products that Australia exports come from mining and looking at this aspect Australia ranks as the fifth biggest miner of fossil fuels [2].

Australia is also spending a lot of money on finding new sources of coal, oil and gas with totals of AUD124.2 million for coal and AUD1.4 billion combined on oil and gas, which is a significant investment made to keep the exportation of these fossil fuels going at this current pace [2].

Despite Australia's apparent high ranking for fossil fuel exports, Australia has a target of reaching a net zero carbon emission scheme by the year 2050. The Australian government wants to drive this initiative using technology which will seek to preserve existing industries and position Australia as a leading country in low emission technologies. It will look to new technologies to expand its choices that it can take and has committed to spending 20 billion dollars on such new technologies with the aim to attract around 80 billion dollars of private and public investments by looking at clean hydrogen, carbon capture and storage as well as seeking to continue advancing solar technology to make it even more affordable [3].

With this in mind, the Australian Federal Government has asked our group to design the systems necessary to completely replace these energy exports with renewables, in order to transition the country to net-zero emissions.

1.1 Scope

This document discusses a Green Hydrogen Power System (GHPS) designed to replace Australia's yearly non renewable energy exports with renewable energy sources. It will detail the problem definition (1.2), the subsystems that make up the GHPS (1.3), Assumptions that our organisation holds about the problem and system (1.4), requirements of the system (2.0), including the constraints of the project (2.1), functional requirements of each subsystem (2.2), performance requirements (2.3) and interface requirements and signoffs (2.4, 2.5).

This document will then detail the Technical Performance Measure (TPMs) associated with the GHPS and its subsystems (3.0), detail the deliverables that this organization will be responsible for completing and delivering (4.0), the inclusions and exclusions for this project (5.0), the justification for the design of the GHPS (6.0) and finally a reflection on the expected impact on society that this project will contribute to (7.0)

1.2 Problem Definition

Our Organization has been approached to come up with a net zero system to replace Australia's current non renewable fossil fuel export commitments. The system which we will need to develop must be able to match or exceed the 15.26 exajoules of energy exported yearly to other countries by finding renewable energy alternatives to the current crop of fossil fuels such as coal, Liquid Petroleum Gas (LPG) and LNG.

The renewable energy sources that are targeted by the system will need to be captured with the intention of using them as our new export product. The system will need to transform the energy captured so that it is ultimately suitable for exportation outside of Australia including facilitating the exportation. We will have to find a suitable method of transporting the captured and transformed energy within the system developed and outside of the system to external buyers. The system will need to be able to control the energy captured appropriately using various methods appropriate to the system that is developed, be secure and the type of renewable energy targeted. Finally the energy captured and output needs to be trackable by the system we are to develop so that it is known whether the system meets the target of 15.26 exajoules of renewable energy exported.

Renewable energy sources suitable for targeting by the system must not have a carbon footprint attached to their collection, any waste produced will be monitored and the system must look to minimise any carbon costs it produces or is required in its operation. Finally the system needs to be something that is available year round to provide the energy to export and be maintainable.

1.3 Deliverables

Throughout the 13-week project, several documents will be delivered to the client. The deliverable documentations show the progress of the project and how the team has handled the project problem.

Table 4: Deliverables

Deliverable ID	Project	Description	Due
D01	Scoping Document	Scoping document states the plan of the project in detail to provide the client with the process of a subsystem . It includes the following: ● Scope ● Problem Definition ● Assumptions ● Constraints ● Functional Requirements ● Performance Requirements ● Interface Requirements ● Inclusions and Exclusions ● TPMs	31/03/2022
D02	Final Document	This document contains the scoping document along with the design document and testing document. ● The design document is based on the conceptual design involving multiple designs relied on the project progress. ● The testing document displays the TPMs and tests taken addressing the requirements and validity of the tests.	03/06/2022
D03	Prototyping Design	Implementing the design for clients to consider.	30/05/2022
D04	Statement of Work	Presenting the changes in the design as needed after implementing.	30/05/2022
D05	Completed Design	Delivering the final design after adjustment based on client feedback.	30/05/2022
D06	Video Presentation	Presenting a 5-minute video on the finished detailed version of the subsystem displaying the features of the design and failures and successes involved in the tests.	30/05/2022
D07	Cycle of life Document	Short description of disposal, safety, maintenance guides.	30/05/2022

1.4 Subsystems

The GHPS project can be broken down into 5 separate subsystems as seen below in Figure 1, all of which will have a high-level overview described in this section. The individual subsystems can also be duplicated as needed to scale up the production of green hydrogen and is designed with the view that the GHPS will have multiples of each subsystem to reach our desired energy export quota or future quotas.

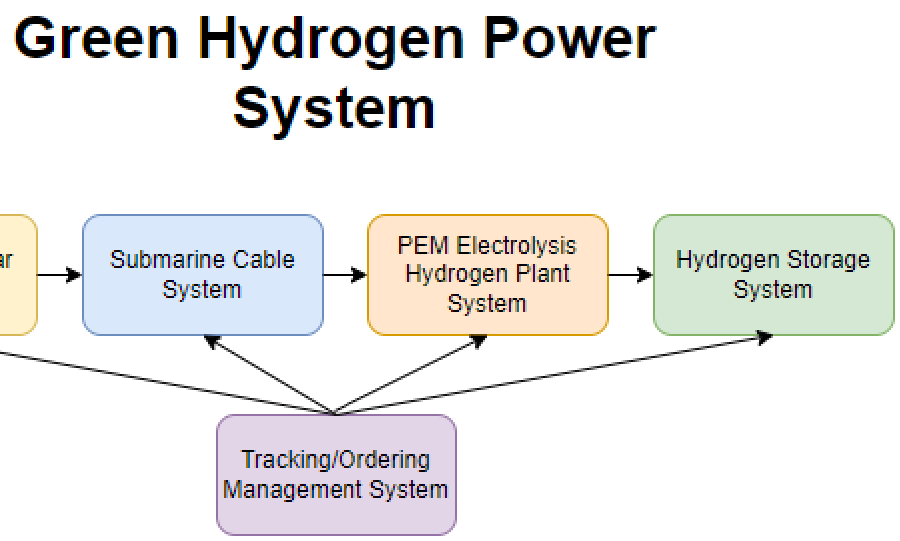

Figure 1: Breakdown of the different subsystems present

The subsystems as seen above in Figure 1 will make up the overall GHPS that we will be producing. It will capture and use solar energy using the PSPS, transfer that energy using the SCS to the PEHPS which will produce green hydrogen. The green hydrogen will then be stored in our HSS all the while being tracked, orders managed and deliveries fulfilled using the TOMS.

1.4.1 Photovoltaic Solar Panel System

The Photovoltaic Solar Panel System (PSPS) will provide our overall GHPS with the power needed to perform electrolysis on seawater to separate out the hydrogen used as our main energy exportation product. It will capture solar energy and convert it into electrical energy which will be directed to our PEM Electrolysis Hydrogen Plant System (PEHPS) via the Submarine Cable System (SCS). This subsystem will be located on land in the Gascoyne region of Western Australia which has adequate access to solar energy all year round. The overall surface area of solar panels required is approximately 17000 km^2. See figure 2 in section 1.3.3 for the relationship between PSPS, SCS and PEHPS and the flow of solar energy in the GHPS system.

1.4.2 PEM Electrolysis Hydrogen Plant System

The PEHPS subsystem will process water fed into it to produce the main exportation product of green hydrogen. This subsystem will be powered by our PSPS subsystem via the SCS subsystem and will be located off-shore of the Australian coast. See figure 2 in section 1.3.3 for the relationship between PSPS, SCS and PEHPS and the flow of solar energy in the GHPS system. The hydrogen produced by this subsystem will then be transferred to our HSS. There may be multiple Electrolysis plants within our larger PEHPS to produce the needed green hydrogen product.

1.4.3 Submarine Cable System

The SCS subsystems function will be to facilitate the transfer of electrical energy from the PSPS through seawater to power our PEHPS. See figure 2 below for the relationship between PSPS, SCS and PEHPS and the flow of solar energy in the GHPS system. There may be multiple submarine cables within our SCS to connect multiple electrolysis plants with electricity.

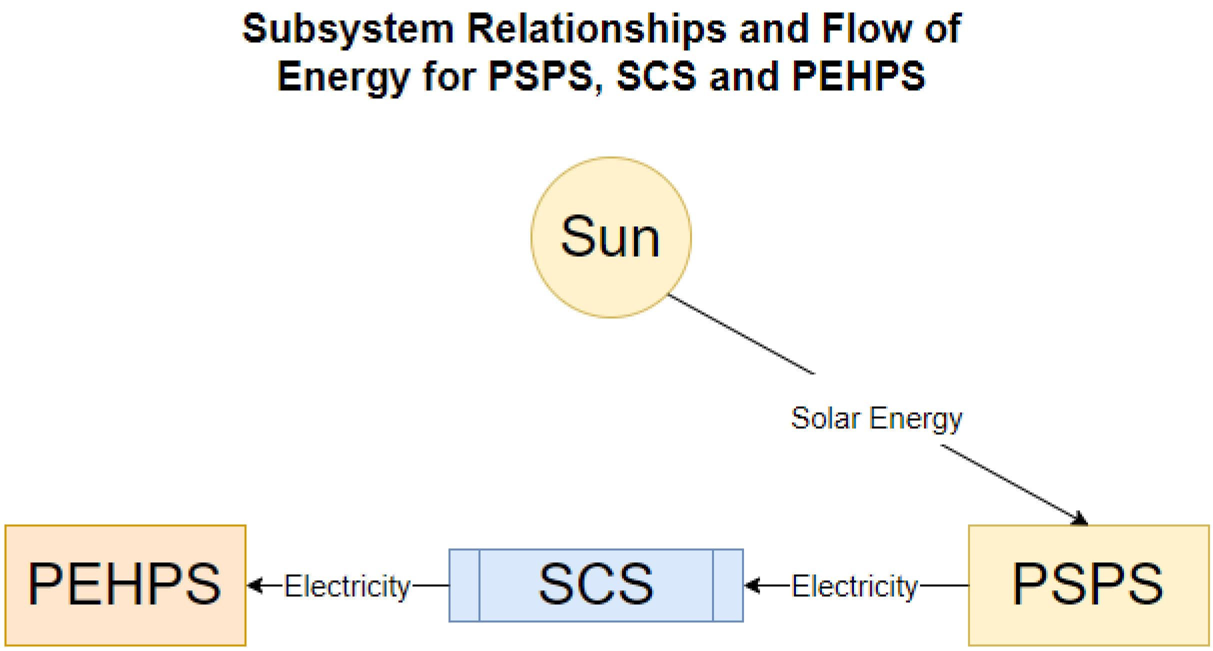

Figure 2: Describing the flow of solar energy and the relationship between PSPS, SCS and PEHPS

1.4.4 Hydrogen Storage System

The Hydrogen Storage System (HSS) will be used to store the green hydrogen safely until such a time it is ready for export to external customers. The hydrogen will be coming from the PEHPS and in addition to storing the hydrogen safely it will need to be able to interface with the Tracking/Order Management System (TOMS) through peripheral devices and/or manual data entry to log the movement and inventory levels of our green hydrogen product. There may be many individual storage facilities within the overall HSS and these will be linked via our TOMS.

The HSS will specifically consist of a warehouse of a suitable size that can house the liquid hydrogen containers in a secure fenced off facility. The hydrogen containers will be temperature controlled and have internet access. There will be a number of peripheral devices for use by staff in the day to day operations for the management of the green hydrogen stored on location. The warehouse will also come equipped with a loading area where the liquid hydrogen tanks can be loaded and unloaded as necessary. The liquid hydrogen tanks will be stored in containers within the warehouse and the movement of these containers will be controlled through machinery such as forklift trucks and powered loaders.

1.3.5 Tracking/Order Management System

The TOMS is a cloud based web application that will be responsible for coordinating and tracking the movement of our green hydrogen product through the overall GHPS. It will be able to receive orders for and then coordinate the fulfillment of these orders for our green hydrogen. The TOMS will also be able to track the state of the various subsystems of the GHPS, control their outputs and perform emergency shutdown procedures for the individual subsystems. It will also maintain error logs that may be used for troubleshooting. There will also be some small peripheral devices used in the tracking system such as barcode scanners or hand held devices that users of the system can use to interact with the TOMS for either inventory management or any of the other functions described for the TOMS here.

1.3.6 Transport

Transport for this system will not be considered a main subsystem like the other subsystems mentioned above as we will look to outsource transportation of materials within the system to external contractors with the deciding factors for hire being cost and proven safety record. Exportation of green hydrogen goods will also be through commercial shipping providers. The decision for hiring these contractors will be determined at a later stage.

1.5 Assumptions

From the starting stage of the project, there are multiple assumptions that have been made to keep the system designs on the right track. This section will state preconditions that we have assumed for the project.

Table 5: Assumptions

Assumption ID	Description	Importance
Asm_01	Any carbon cost incurred for building the system will not be significant enough to need to take into consideration when determining the net zero achievement of the system.	High
Asm_02	There will be enough funding available to build and run this system.	High
Asm_03	We do not need to source buyers for these energy exports.	High
Asm_04	Any carbon cost incurred for transport within the system will not be significant enough to be considered when determining the net zero achievement of the system.	High
Asm_05	There are enough skilled workers or a capacity to retrain existing workers to staff the proposed system.	High

2 Requirements

This subsection will present the primary requirements that need to be met with every single subsystem based on the initial requirements. It is divided into four sub-requirements, namely:

- Constraints
- Functional Requirements
- Performance Requirements
- Interface Requirements

2.1 Constraints

Table 6: Constraints

Constraint ID	Constraint category	Constraint	Description
Con01	Time	Timeframe	This constraint has been imposed to ensure that a practical solution will be delivered within 13 weeks.
Con02	Technical	Desired energy quantity	The design needs to be able to meet the current export levels of energy of Australia.
Con03		Renewable sources	The design needs to utilize natural resources instead of fossil fuel to produce energy.
Con04		Transportation	The produced energy needs to be transported to other countries. Safety hazards need to be highly considered during transportation.
Con05		Controlling	The design requires the output to be desirable and consistent.
Con06		Tracking	The energy needs to be tracked during the processes of production and transportation.
Con07		Net Zero	The production and exportation of the energy must result in a minimum of a net zero emission rate.
Con08		Net Zero by 2050	The design for the project must be designed to be implemented and fully operational by 2050.
Con09	Regulatory	Environmental threats of construction	The damages to the local environment need to be minimized during the process of the design implementation.
Con10	Personal	Experience	The team needs to have sufficient disciplines to cover multiple fields of the entire project such as electrical, software.
Con11		COVID-19 threats	The dangers of COVID-19 threatens team members that impacts on the progress of the project.

2.2 Functional Requirements

The section will state all particular requirements that all subsystems must meet the client's needs. The table below will show all functional requirements that are identified for all subsystems to ensure the whole design to perform properly.

Table 7: Functional Requirements

Requirement ID	**Description**	**Importance**
FR_PV_01	The system shall only use renewable energy sources.	High
FR_PV_02	The photovoltaic solar farm shall capture energy.	High
FR_PV_03	The solar energy must be used to power electrolysis.	High
FR_PV_04	The energy will be transported from the photovoltaic solar farm to the hydrogen electrolysers using submarine cables.	High
FR_PV_05	The energy shall be controlled using green hydrogen storage tanks.	High
FR_PV_06	The energy shall be tracked using a web-based order and service management system.	High
FR_GHS_01	Liquefied hydrogen shall be stored in cryogenic tanks.	High
FR_GHS_02	Production of compressed hydrogen cylinders.	High
FR_GHS_03	Cryo-compressed hydrogen storage must be kept at high density pressures.	High
FR_GHS_04	Electricity must be supplied for temperature monitoring and control 24 hours a day.	High
FR_STR_01	System must always be available.	High
FR_STR_02	System must be able to update small sections at a time without shutting the entire system off.	High
FR_STR_03	System must be able to keep track of where inventory is moving.	High
FR_STR_04	System must implement a GPS tracker to track the movement of hydrogen through the system.	High
FR_STR_05	System must be deployed in the cloud.	High
FR_STR_06	System must be able to take and record orders.	High
FR_STR_07	System must be able to add and remove stock.	High
FR_STR_08	System must be able to store current stock.	High
FR_STR_09	System should be able to use barcodes for inventory management.	Moderate
FR_STR_10	System must be able to process serial numbers for inventory management.	High
FR_STR_11	System must be able to determine the location of stock.	High
FR_STR_12	System must be able to allow users to adjust the power output from different solar grid locations to various production plants.	High
FR_STR_13	System must be able to display the real-time (3 seconds) status of each power plant.	High
FR_STR_14	System must be able to display the real-time (3 seconds) status of each solar grid.	High
FR_STR_15	System should be able to calculate the power loss for quality control.	Moderate
FR_STR_16	System must be able to calculate the amount of Hydrogen being produced.	High
FR_STR_17	System must be able to measure the amount of waste being produced.	High
FR_STR_18	System must be able to keep back up data on previous dates up to 35 days.	High
FR_STR_19	System must be able to determine errors.	High
FR_STR_20	System must be able to notify users of errors.	High
FR_STR_21	System must be able to recover if it fails.	High
FR_STR_22	System must be able to keep a record of all previous errors and solutions.	High
FR_STR_23	System must be able to instruct new users on how to use it with tooltips.	High
FR_STR_24	System must be able to create, update and delete users.	High
FR_STR_25	System must be able to create, update and delete passwords.	High

Requirement ID	Description	Importance
FR_STR_26	System must be able to grant, change and disable different levels of access for users.	High
FR_STR_27	System passwords must be secured.	High
FR_STR_28	System must keep a record of all users.	High
FR_STR_29	System must grant all users a unique identifier.	High
FR_STR_30	Individual subsystems must have an emergency shut off.	High
FR_STR_31	System should display error messages to users in a clear noticeable fashion.	Moderate
FR_STR_32	System should notify the user of incoming orders.	High
FR_PEM_01	System must use salt water to produce green hydrogen.	Moderate
FR_PEM_02	System must adhere to Australian standards with certified renewable energy (ME-093 Hydrogen Technologies).	High
FR_PEM_03	The power supply for the system is from solar power.	High
FR_PEM_04	System must output green hydrogen without any leakage.	High
FR_PEM_05	System must produce only pure oxygen as a by-product.	High
FR_PEM_06	System must have such a scheme to minimize the damages of electrolytic corrosion from chloride anions in seawater.	High

2.3 Performance Requirements

The section contains all the performance requirements of the subsystem. This contains all the measurable requirements belonging to the subsystems.

Table 8: Performance Requirements

Requirement ID	Description	Importance
PR_SC_01	The submarine cable must not lose more than 3% of power per 1,000 km.	High
PR_GHS_01	Liquid hydrogen must be stored at -253 degrees Celsius at 1 atm.	High
PR_STR_01	System should be able to give users updated information on screen within 3 seconds of when data has been requested.	Moderate
PR_STR_02	System should be able to render the different landing pages within 3 seconds of being requested.	Low
PR_STR_03	System's GPS unit should be able to track the current vessel within 1km of location.	Low
PR_STR_04	System's must update the changes in power production levels within 20min.	Moderate
PR_STR_05	System's subsystems' emergency process must activate within 1 second.	High
PR_STR_06	System must adjust the power level value within 5-seconds.	High
PR_STR_07	System must inform users of errors within 5 seconds of discovery.	High
PR_PEM_01	System must output 60–80 percent efficiency.	High
PR_PEM_02	1.145E+12 litres of water will be supplied to the hydrogen electrolysers each year.	High
PR_PEM_03	System must receive 24.73 exajoules per year of solar energy for powering electrolysis.	High
PR_PEM_04	System must output hydrogen equivalent to 15.26 exajoules per year. The required hydrogen amount is about 1.272E+8 tonnes per year.	High

2.4 Interface Requirements

This section contains all the interface requirements of the subsystems. This is important as the subsystems need to be designed in conjunction with each other.

Table 9: Interface Requirements

Interface ID	Description	Importance
IR_PEM_01	System must be able to be integrated for storage.	High
IR_PEM_02	System must be able to be integrated for distribution.	High
IR_PEM_03	System must be able to be tracked via the software subsystem.	High
IR_GHS_01	System must use PEM electrolysis to produce green hydrogen.	High
IR_GHS_02	Power to the green hydrogen system is transported through submarine cables.	High
IR_GHS_03	Green hydrogen system is exported via compressed gas and liquefaction.	High

2.5 Interface Sign-offs

This section contains the confirmation and signature between teams that they have interfaced. Each sign-off must include details about the interface itself, such as the topic discussed.

Table 10: Interface Sign-Offs

Interface ID	**Interface Subsystem**	**Subsystem Signoff**	**Accepting Subsystem Signoff**	**Description**	**Date**
IR_PEM_01	Hydrogen Storage System	David	Joanna	The condition of hydrogen to be stored properly during the process of exportation.	16/03/2022
IR_HYP_02	PEM Electrolysis Hydrogen Plant System	David	Duy	Type of electrolysis required to produce hydrogen and reach sufficient quantity per year.	16/03/2022
IR_PEM_03	Photovoltaic Solar Panel System	David	Trung	Electrolysis subsystem is powered by the voltage produced by the PV subsystem.	16/03/2022
IR_PEM_04	Tracking/Order Management System	David	Rajiv	The amount of hydrogen needs to be tracked in the manufacturing and exportation process.	16/03/2022
IR_HYP_05	Submarine Cable System	David	Scott	How the power from the photovoltaic solar farm will be transported to the hydrogen plants.	16/03/2022

3 Inclusions and Exclusions

3.1 Inclusions

In conclusion to this project, the idea proposed by Team 5 will include the following:

1. Breakdown of subsystem for GPHS
    a. Production of green hydrogen from photovoltaic solar panels to operate electrolysers in PEM Electrolysis Hydrogen Plant
    b. Desalination
    c. Liquidation and compression of hydrogen for exportation
2. Software tracking system to locate orders transported internationally or domestically
    a. GPS tracking
    b. Inventory control
    c. Power and efficiency tracker
3. Methods of waste management
    a. Excess salt waste from electrolysis
4. Analysis of solar electricity grid network integration
5. PEM Electrolysis Hydrogen Plant Design
    a. Loss in power from power cables
    b. Location
    c. Water capacity
    d. Solar electricity grid network integration
    e. Power output and Efficiency of system
    f. Transportation
    g. Corrosion protection maintenance
6. Storage solution

3.2 Exclusions

Furthermore, the idea proposed by Team 5 will exclude the following:

1. Expenses of project and materials
    a. Life cycle of project (length of project)
    b. Insurance implications
    c. Financial constraints
2. Software tracking services
    a. Amount of energy to be exported to designated countries
3. Political and social implications
    a. Regulations/ agreements/ contracts from countries using hydrogen
    b. Transfer of hydrogen to energy process of other countries
    c. Exportation of energy to designated countries
    d. Quality of exported hydrogen
4. External Factors
    a. Political and social implications
    b. Unforeseen weather conditions
5. PEM Electrolysis Hydrogen Plant Design
    a. Corrosion Protection via Cathodic Protection and Coating Materials and Procedures

4 Technical Performance Measures

Technical Performance Measure (TPM) is essential in verifying the performance of the solution to make sure that the design meets the goals and requirements of the project. In addition, it describes how each concept is managed and performed, documenting the failures and successes that occur in each testing measure. For each TPM, the document will describe the purpose, the requirements that are related, the risk level of the test and most importantly the possible causes of failure.

4.1 Summary of TPMs

Table 11: Summary of TPM

TPM Code	**TPM Name**
TPM01	PV Solar Farm Efficiency
TPM02	Power Transfer Efficiency of Submarine Power Cables
TPM03	Liquid Hydrogen Storage Conditions
TPM04	Software System User Interface Responsiveness
TPM05	Software System GPS Accuracy
TPM06	Software System Power Level Responsiveness
TPM07	Instantaneous Emergency Shutoff
TPM08	Software System Error Handling
TPM09	Electrolysis Process Efficiency
TPM10	Production of Hydrogen

4.2 Detailed TPMs

Table 12: Efficiency of PV Solar Farm

TPM Code	TPM01
Name of TPM	Efficiency of PV Solar Farm
Purpose of TPM	To ensure that the PV solar panel efficiently captures the solar energy.
Source Requirement	FR_PV_02
Risk Level	Low
What should be measured?	The energy captured from the solar panel and its overall efficiency.
How should it be measured?	1. Read the meter on the solar panels for the amount of energy captured.
How often should it be measured?	Weekly
Measure of Success	The energy captured from the solar panel meets the rated efficiency.
Measures of Failure	The energy captured from the panel does not meet the rated efficiency.
Possible Causes of Failure	- Weather Condition - Maintenance - Wire cables

Table 13: Power Transfer Efficiency of Submarine Power Cables

TPM Code	TPM02
Name of TPM	Power Transfer Efficiency of Submarine Power Cables
Purpose of TPM	To ensure that the submarine power cables supply sufficient power to the electrolysis plants.
Source Requirement	PR_SC_01
Risk Level	Low
What should be measured?	Amount of power lost through the submarine cables.
How should it be measured?	1. Read the meters on the transformers on both ends of the submarine cable.
How often should it be measured?	Daily
Measure of Success	The difference in power from the start of the submarine cable and the end of the submarine cable is equal to or less than 0.006%.
Measures of Failure	The difference in power from the start of the submarine cable and the end of the submarine cable is greater than 0.006%.
Possible Causes of Failure	- Incorrect meter readings - Faulty submarine cables

Table 14: Liquid Hydrogen Storage Conditions

TPM Code	TPM03
Name of TPM	Liquid Hydrogen Storage Conditions
Purpose of TPM	To ensure that the liquid hydrogen is stored under the correct conditions.
Source Requirement	PR_GHS_01
Risk Level	Low
What should be measured?	The temperature of the liquid hydrogen.
How should it be measured?	1. Read the meters on the storage units of the liquid hydrogen.
How often should it be measured?	Daily
Measure of Success	The liquid hydrogen stays below -253 degrees celsius.
Measures of Failure	The liquid hydrogen rises above -253 degrees celsius.
Possible Causes of Failure	- Incorrect meter readings - Faulty storage units

Table 15: Software System User Interface Responsiveness

TPM Code	TPM04
Name of TPM	Software System User Interface Responsiveness
Purpose of TPM	To ensure the software system gives updated information within 3 seconds of a request.
Source Requirement	PR_STR_01 & PR_STR_02
Risk Level	Low
What should be measured?	Response time of the software system for requests.
How should it be measured?	1. Make a request on the software system for updated information or another page. 2. Measure how long it takes for the software system to respond.
How often should it be measured?	Monthly and when more systems are added
Measure of Success	The software system responds in 3 seconds or less.
Measures of Failure	The software system takes longer than 3 seconds to respond.
Possible Causes of Failure	- Software bugs - Unoptimised software solution

Table 16: Software System GPS Accuracy.

TPM Code	TPM05
Name of TPM	Software System GPS Accuracy
Purpose of TPM	To ensure the accuracy of the software system's GPS tracking feature.
Source Requirement	PR_STR_03
Risk Level	Low
What should be measured?	The accuracy of the software system's GPS tracking feature.
How should it be measured?	1. Check the GPS coordinates that the software system provides. 2. Compare the coordinates from step 1 to the GPS coordinates onboard the vessel that it is tracking.
How often should it be measured?	Every 5 minutes until the result is deemed as acceptable and then monthly
Measure of Success	The coordinates provided by the software system and the vessel are within 1 km of each other.
Measures of Failure	The coordinates provided by the software system and the vessel are not within 1 km of each other.
Possible Causes of Failure	- Software bugs - Faulty GPS system onboard the vessel being tracked

Table 17: Software System Power Level Responsiveness

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TPM Code	TPM06
Name of TPM	Software System Power Level Responsiveness
Purpose of TPM	To ensure that the software system updates changes in power production levels within 20 minutes.
Source Requirement	PR_STR_04
Risk Level	Low
What should be measured?	Response time of the software system for power production level changes.
How should it be measured?	1. Measure the time it takes for the software system to update its information when a measurable change occurs in the power production level occurs.
How often should it be measured?	Initially, then weekly
Measure of Success	The information provided by the software system on the power production level is updated within 20 minutes of the change occurring.
Measures of Failure	The information provided by the software system on the power production level takes longer than 20 minutes to update.

TPM Code	TPM06
Possible Causes of Failure	- Software bugs - Faulty sensors

Table 18: Instantaneous Emergency Shutoff

TPM Code	TPM07
Name of TPM	Instantaneous Emergency Shutoff
Purpose of TPM	To ensure that the emergency shutoff for each subsystem is instantaneous.
Source Requirement	PR_STR_05
Risk Level	Low
What should be measured?	The time it takes between the emergency shutoff being pressed and the specified subsystem to begin taking the steps towards shutting down.
How should it be measured?	1. The emergency shutoff for a particular subsystem is pressed. 2. Measure the amount of time it takes between step 1 and the specified subsystem to begin the process of shutting down.
How often should it be measured?	Initially, then monthly
Measure of Success	The specified subsystem starts its process for shutting down within 1 second of the emergency shutoff being pressed.
Measures of Failure	The specified subsystem takes longer than 1 second to begin its process of shutting down after the emergency shutoff has been pressed.
Possible Causes of Failure	- Software bugs

Table 19: Software System Error Handling

TPM Code	TPM08
Name of TPM	Software System Error Handling
Purpose of TPM	To ensure the software system handles errors or emergencies in a controlled manner.
Source Requirement	PR_STR_06 & PR_STR_07
Risk Level	Low
What should be measured?	There are two aspects to measure: - Power level adjustment - The signal from the system to the user
How should it be measured?	1. Measure the power level through the system when the system initiates a change in power. The system shall display the information to the user in specified time.

TPM Code	TPM08
How often should it be measured?	Daily
Measure of Success	The system must adjust the power level within five seconds. In addition the system must display any relevant information of changes or errors to the user within five seconds.
Measures of Failure	The system does not maintain power level according to the situation. The system does not display information to the user. Furthermore, the system displaying incorrect information to the user is also a failure.
Possible Causes of Failure	- Software bugs

Table 20: Electrolysis Process Efficiency

TPM Code	TPM09
Name of TPM	Electrolysis Process Efficiency
Purpose of TPM	To ensure the electrolysis process which produces hydrogen and oxygen is performing at the required efficiency.
Source Requirement	PR_PEM_01
Risk Level	Low
What should be measured?	The amount of hydrogen produced through the electrolysis process.
How should it be measured?	Using a gas sensor to measure the concentration of hydrogen produced in the storage space.
How often should it be measured?	Every second
Measure of Success	The amount of hydrogen energy stored should be at least 60% of the amount of energy inputted into the electrolysis process.
Measures of Failure	The amount of hydrogen energy produced does not meet the 60% of the input energy.
Possible Causes of Failure	- Issue with the electrolysis process - Hydrogen produced was not fully captured

Table 21: Production of Hydrogen

TPM Code	TPM10
Name of TPM	Production of Hydrogen
Purpose of TPM	To ensure the hydrogen energy produced meets the energy required yearly as described in the problem statement.
Source Requirement	PR_PEM_02 & PR_PEM_03 & PR_PEM_04
Risk Level	Low

TPM Code	TPM10
What should be measured?	The amount of hydrogen produced.
How should it be measured?	Measure the total volume and concentration of the hydrogen produced in the storage system.
How often should it be measured?	Yearly
Measure of Success	The system produces 1.272E+8 tons of hydrogen per year.
Measures of Failure	The system does not produce adequate amounts of hydrogen to meet the demand.
Possible Causes of Failure	- Subsystem problems such as PV solar panel capture and wire cable energy transfer - Not enough of resources or energy

5 Justification

In 2021, the Australian Government decided that it would join other global powers and aim for a net zero approach by 2050. [4] According to the then Minister of Industry, Energy and Emissions Reduction Angus Taylor, the plan for this net zero approach should look ahead to the following; ‘technology not taxes; expand choices not mandates; drive down the cost of a range of new technologies; keep energy prices down with affordable and reliable power; and, be accountable for progress.’ These goals heavily influenced the team’s decision making when looking at the subsystems of the Green Hydrogen Power Project.

Exportation of Hydrogen: When it came to choosing the optimal way to export energy around the world to replace the current exportation of LNG and LPG exports, the choice of Hydrogen was clearly the optimal choice. [5] At first the team looked at exporting electricity through ‘powered submarine cables’, though many issues arise with using this i.e. the largest submarine power cable in the world is only 720 Km meaning that it would become very difficult to export to countries around the world. As a solution to the transportation of energy problem the team decided to export Green Hydrogen as it can be physically transported in containers plus it being a viable energy resource as it produces more energy per kilogram when compared to gasoline.

Electrolysis Plants: In order to obtain the hydrogen necessary to match the current exports of Australia, the team decided that it would perform electrolysis of seawater to split Hydrogen from the other substances found in seawater. The main thought process when designing these plants was to focus on functional capability. As Australia needs to at the very least meet the same energy export levels, the plants need to go through 1.145E+12 litres of water in a year (see Appendix A.2.). This means that the plants have to be as efficient as possible. In order to achieve this one of the biggest factors to consider was location of these plants, mainly that it needed access to large amounts of water and electricity to perform the electrolysis. As a result, the team decided to have the plants approximately 2km off-shore. This comes with three main advantages, the first being that the plant would always have access to water, there would be minimal loss of electricity that is being transported into the plant, making exportation easier as they would not require to dock on land. The main negative of using these plants is the corrosion rate of the plant. [6]In order to minimize this problem, the team decided to use a zinc alloy and coating for ‘Cathodic Protection.’ The team determined that implementing the alternative of using a desalination plant to produce fresh water for electrolysis was not feasible. For instance, the Victorian Desalination Plant can only deliver a maximum of 150 billion litres of water/year meaning that multiple plants would be required to meet the water requirements for exportation. [7]As the Victorian Desalination Plant cost $5.7 billion to produce, having multiple plants such as these to meet water demand seems unfeasible as cost but also finding land to place these plants would indicate that this is not an effective method. Therefore, by using a Cathodic Protection system, the electrolysis could be done with sea water and the corrosion of metals can be extended as the maintenance and replacements for the coating and zinc alloy would be cheap and maintainable.

Solar Grid: In order to generate enough electricity to perform electrolysis of seawater the team has decided to use solar power. [8] This was due to the country having one of the highest DNI and GHI values on the planet. The group leader of CSIRO, Wes Stein, stated “In theory, there is enough sun falling on a square of about 50 kilometres by 50 kilometres (or 0.03 per cent of Australia) to provide all of Australia's electricity.” The team decided that with this knowledge, designing the system for maintainability would be at the forefront. As the system would be running constantly and for years before the panels get replaced by innovations to the current technology level, maintaining the system is the most important objective to make sure the system is always working efficiently but also to cut down on costs when changes and repairs need to be made. Therefore, designing the solar grids for maintainability is the optional choice for the overall system.

Software: The software for this system fulfills many important roles in the overall system. Its main purpose is to track various subsystems within the Green Hydrogen Project and alert users on any issues. The software tracks the amount of hydrogen being produced, the amount of solar power being generated from the solar grids, the amount of electricity being sent to each electrolysis plant, the orders of hydrogen from each client, the inventory of hydrogen stored, GPS tracking of all exports and the amount of waste being produced by the electrolysis plants. The system also keeps a record of all users and their different levels of access. As the Green Hydrogen Project heavily involves meeting the correct levels of exportation, the team decided that the design of the software needs to be focused on reliability as if the software stops working at any point, then there is a high potential for other key subsystems to fail. For instance, if the tracker for the solar power electricity generation is broken, then too much or not enough electricity could be sent to the plant causing problems in the electrolysis process and extra waste could be produced. Therefore, designing the software to be focused on reliability is the optimal choice for this system.

6 Reflection

Regarding the abundant amount of non-renewable fossil fuels that Australia exports for energy use overseas, we have recognized that very large amounts of carbon dioxide are released into the atmosphere when these nonrenewable fuel sources are burned. The more nonrenewable sources are consumed, the more quantities of carbon emission will be added to our environment. In 2017, Australia contributed 1.4% to the global carbon dioxide from fossil fuels and about 5% if accounted for by its exportation [9]. This number illustrates the carbon footprint of Australia is quite similar to Russia, ranking fifth in the highest carbon dioxide emitters around the world. With the significant amount of carbon dioxide released, climate change in Australia is inevitable.

According to the NSW government records, the increase in NSW temperature has occurred since 1910, leading the coastal areas to have heavy rain and severe storms frequently [10]. The sea level has also increased. This causes more severe flooding and erosion. The NSW government has to pay $250 million per year for damages due to floods [11]. Based on these real data, the whole country should be responsible for society and the environment to find greener resources replacing fossil fuels to keep the Earth safe before it is too late to take action. This can not be done by an individual or a group of people, the entire society should take the responsibility of the transition.

The solution introduced above by the Green Hydrogen Project could be the effective approach that brings multiple benefits to society. The hydrogen industrial field may create a broader range of job opportunities up to thousands of jobs, many of those located in rural areas. It can make the high income added $11 billions per year to GDP for the next decades. Even the number can become higher if the global markets grow rapidly [12].

The higher potential of using hydrogen to store the electricity from solar power is to cut down the high amount of carbon dioxide emission to zero. It provides the right direction to eliminate greenhouse gasses that raise the Earth's temperature. Furthermore, fresher air significantly reduces the occurrence of respiratory problems and cancers [12].

To conclude, the Green Hydrogen Power System is to solve the global demand for energy resources via cutting edge technologies and exploit the existing ability of exportation in Australia. The valuable experience gained through the project as well as the ideas generated may encourage the use of renewable energy solutions on a local or even global level to assist with societies. Even though Australia is still far away from generating hydrogen with competitive prices with fossil fuels, it is inevitable, because wind and solar energy were expensive when they had been invented a decade ago, then their costs were reduced significantly in the end. CSIRO forecasts that the cost of hydrogen production will also be reduced by 83% by 2040, and this kind of energy source will capture the energy market share from 2030 [13].

7 Design Specifications

7.1 Conceptual Design

The conceptual design for our solution consists of a photovoltaic solar farm, which will provide electricity to an electrolysis plant to produce green hydrogen for export. The electrolysis plant will use seawater and will be located offshore so that the large quantities of water required do not have to be pumped long distances. To increase the energy density of the green hydrogen for efficient transport, it will then be liquefied and stored in insulated pressure tanks.

Based on the energy requirements for electrolysis, the efficiency of the selected solar PV cells, and the average local solar irradiation, the solar farm is expected to cover about 17000 km^2 of land in Western Australia (WA).

The power generated by the solar farm will be transmitted across considerable distances to the PEM Electrolysis Hydrogen Plant System using HVDC transmission lines. At the receiving end, the voltage is stepped down to an appropriate level as an input voltage for the electrolysis plant and for liquefaction.

The gaseous green hydrogen output by the electrolysis plant will then be converted into liquid hydrogen. The liquid hydrogen will then be stored in insulated pressure tanks and loaded onto cargo ships for overseas export.

More detail about each of the subsystems above is provided in the following sections.

7.1.1 Photovoltaic Solar Panel System

To capture the amount of renewable energy we require each year, a large PV solar farm will be used. The PV cells will convert sunlight into usable energy in the form of direct current electricity.

Based on Australia's natural concentration of solar energy, or the daily solar exposure in different regions, the best location for a solar farm would be in the north-western parts of Australia (see figure below). A typical value for solar energy exposure of 22.5 MJ/m^2 was selected based on mapping of these regions as shown in Appendix A.4.

The efficiency of photovoltaic solar cells is constantly being improved with time. Laboratory PV efficiencies are currently approaching 40%, and are expected to surpass it in the near future [14, p. 266], [53]. However in terms of currently-available commercial PV modules, efficiencies are closer to 20%, thus a value of 21.4% was chosen for the solar farm design calculations based on one popular model [20], [22].

Based on the required energy output, the daily solar exposure, and the PV panel efficiency, the area of land required for the solar farm was estimated as 16920 km^2 as shown in Appendix A.4.

Using the solar exposure map below, the Gascoyne region of WA around Carnarvon is an ideal location for the solar farm, as it is close to the coast and has the lowest population of any region in WA [31]. Statistics for the town of Carnarvon show the climate is ideal for a solar farm, averaging 211 days of clear sunshine, with only 41 days of rain each year [32].

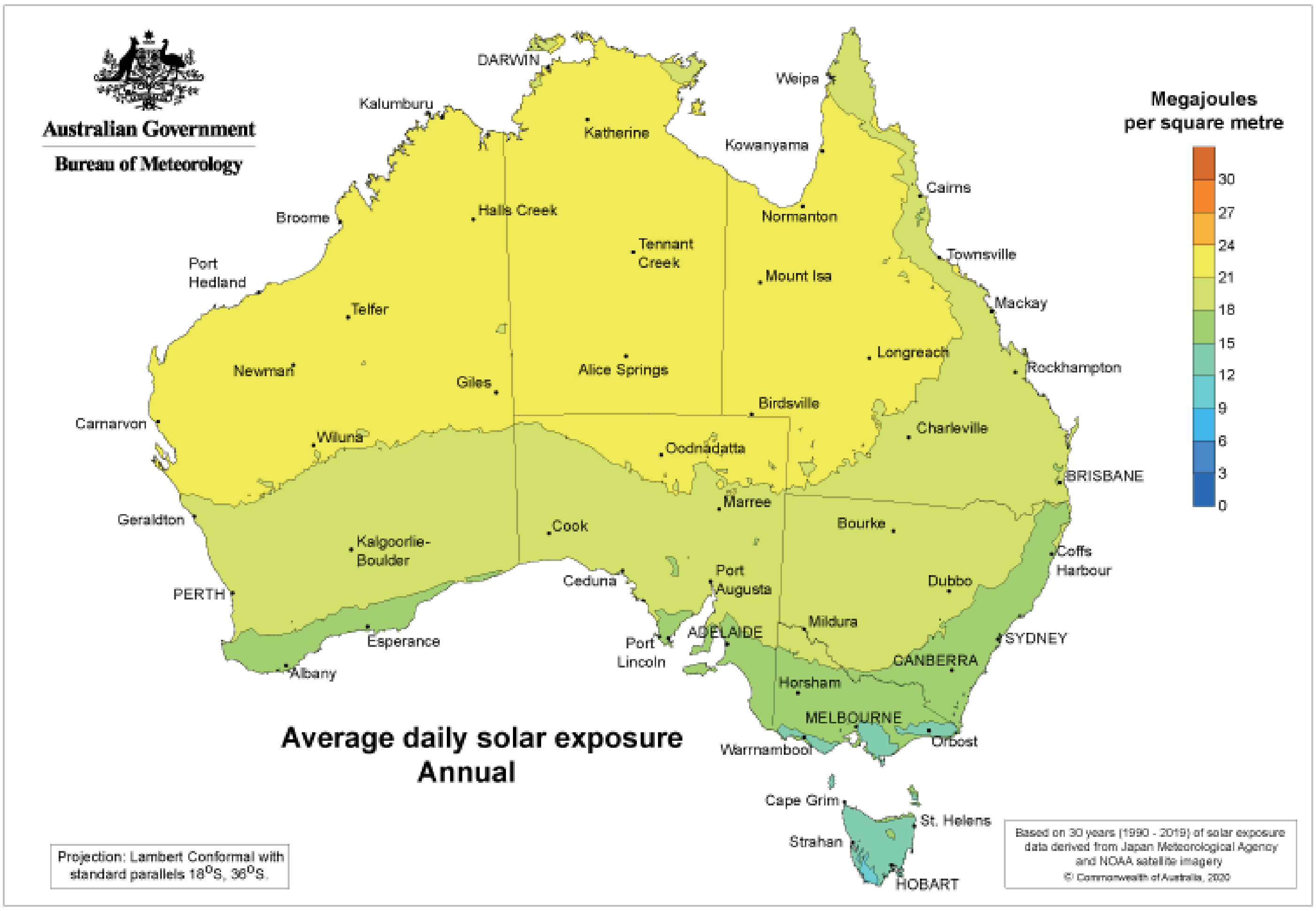


Figure 3: Australian daily solar exposure map, averaged over a whole year [54]

7.1.2 PEM Electrolysis Hydrogen Plant System

For transportation reasons, we chose to use green hydrogen to carry our renewable energy. The production of green hydrogen through electrolysis requires two inputs: electrical energy and water [15]. The bulk of the energy captured by the solar farm is thus converted into hydrogen, via electrolysis of water. The remaining energy generated by the solar farm is either spent liquifying the hydrogen, or consumed by efficiency losses during transmission via power lines.

Based on the energy content of hydrogen and the required annual exports of energy of 15.26 exajoules, the annual export of green hydrogen will be 1.272E+08 tonnes. This equates to an average production rate of 348,456 tonnes of hydrogen per day as shown in Appendix A.2.

Based on the efficiency of current PEM electrolysis, the electrolysis plant needs to be supplied with 1.145E+12 litres of water annually to generate the required amounts of green hydrogen. This translates to a required supply rate of 3.136E+09 litres of water per day as shown in Appendix A.2.

Because of the large quantities of water required, the electrolysis plant will be using seawater direct from the ocean. The main challenge with this approach is corrosion caused by the presence of chloride anions in the seawater [16, p. 6624]. In order to resist corrosion, the anodes will be given negatively-charged coatings that repel the negatively charged chloride [16, p. 6625]. These coatings will consist of an outer layer of nickel-iron hydroxide deposited on top of nickel sulfide [17], [16, p. 6625].

7.1.3 Hydrogen Storage System

Hydrogen gas is 11 times less dense than air at standard atmospheric pressure [18]. Because it has such a low density, it takes up a large volume, making it inefficient to transport in the quantities required. Converting the hydrogen to liquid form increases the density of hydrogen by 789 times, and thus massively increases the amount of energy that can be stored and transported for a given volume [18].

The liquefaction process involves cooling the hydrogen down to -253°C and maintaining it at that temperature [18]. The storage facility will require a 24-hour supply of electricity to maintain the hydrogen at these temperatures and power any control systems.

Based on current liquefaction efficiencies, over a whole year, liquefaction of our green hydrogen will consume 4.58E+18 joules, or 4.58 exajoules of energy as shown in Appendix A.2.

7.1.4 Submarine Cable System

The electricity generated by the solar farm will be transported to the electrolysis plant through overhead transmission power lines and submarine cables. The electrolysis plant is assumed to be located about 2 km offshore, which will be traversed by the undersea submarine cables. Based on this distance and typical losses in HVDC submarine cables, the expected power losses will be about 0.006%. The additional energy required to overcome this loss is then 1.76E+15 joules per year as shown in Appendix A.3.

In order to reduce the transmission losses in the submarine cables, the voltage will be stepped up and down at each end using converter stations. Assuming only one step at each end is required, an additional 4.16E+17 joules per year needs to be supplied to overcome the converter losses.

Although it has not yet been finalised, the land-based overhead power transmission will also introduce transmission losses. This will be accounted for once the exact locations of the solar farm and electrolysis plant(s) have been decided.

7.1.5 Tracking/Ordering Management System

To keep track of the energy as it moves through the Green Hydrogen Power System, a web-based order and service management system (TOMS) will be used. This cloud-based system will be used to place orders for our hydrogen, and manage the operation of each of the above subsystems to ensure the requested shipments of hydrogen end up reaching our customers.

The TOMS will also allow intervention in the event of critical failures by allowing staff to initiate emergency shutdowns.

7.2 Detailed Design

This section of the report will go over the design of the GHPS by discussing in detail the specific design of each of the subsystems PSPS, PEHPS, HSS, SCS, TOMS and the initial cost estimates for the transportation of the Hydrogen throughout the system

7.2.1 Photovoltaic Solar Panel System

Final Design Overview:
The solar PV power system is required to generate 29.72 exajoules annually, based on the detailed calculations in Appendix A.4. Therefore, the total annual energy required in kWh is 8.26 $* 10^{12}$ kWh. The sun peak hours in the northern and western parts of Australia (Darwin) is 5.5 hours based on the data from [19] so the required solar system size in kW can be calculated to be 4.112 $* 10^{9}$ kW.

Recommendations and Specifications:

Since the power generated by the solar farm will be directly transmitted to the PEM electrolysis hydrogen plant system, the main core components required for the solar farm will be solar panels, DC-DC converters and mounting systems.

Solar Panels

Solar panels are chosen based on many factors including the overall performance, efficiency, warranty and price. For typical solar farms with significantly high output power, the solar panels with long warranty, fairly high efficiency, and most affordable solar panel will be selected. Based on the data from [20], the Jinko Tiger Pro 78TR Monofacial is selected for this solar plant. Note this model is listed on Jinko Solar's Australian website, and for a project of this size a negotiated contract of supply would be necessary [21].

The key feature of Jinko Tiger Pro 78TR Monofacial includes:

- Half-cell technology: The current in half-cell is halved, the resistive losses are lowered so that the overall performance is increased. Half-cell also reduces mechanical stresses so that the durability of the solar panel is improved.
- Tiling ribbon (TR) technology: The cell gap is eliminated to increase solar panel's efficiency.
- Multi-busbars (MBB) technology: MBB technology decreases the distance between bus bars and the finger grid line which is beneficial to power increase.

The datasheet of Jinko Tiger Pro 78TR Monofacial is shown in Table 22 [22]. Since the total power output required by the PSPS is $4.112 * 10^9$ kW, the total number of Jinko Tiger Pro 78TR Monofacial solar panels will be $7.030 * 10^9$ panels.

Table 22: Tiger Pro 78TR Monofacial specifications, from [22]

Maximum power (Pmax)	585 W
MPP Voltage (Vmpp)	44.22 V
MPP Current (Impp)	13.23 A
Open-circuit Voltage (Voc)	53.42 V
Short-circuit Current (Isc)	13.91 A
Module Efficiency STC (%)	21.40%
Temperature coefficients of Pmax	-0.35%/℃
Temperature coefficients of Voc	-0.28%/℃
Temperature coefficients of Isc	0.048%/℃

Estimated Cost of Solar panels

The price per watt for Jinko solar panels at the moment is roughly 0.36AUD/watt and is expected to decline over the next few years. Therefore, the overall cost for the all the solar panel is $1.48 * 10^{12}$AUD.

DC-DC converters

The required input voltage for PEM Electrolysis Hydrogen Plant System is 220 MV. Therefore, the configuration of the solar panels and DC-DC converters is required to boost up the voltage to a certain level for the PEM Electrolysis Hydrogen Plant System. One of the high voltage, high power DC-DC converters available in the market is "Enclosed DC-DC converter RedPrime" with the specifications shown in Table 23:

Table 23: Specifications of Enclosed DC-DC converters RedPrime

Configuration	Enclosed, metal package
Electrical characteristics	Buck, non-isolated, regulated, power, boost, high-voltage, high-power, high power density
Applications	Industrial, for railway applications, for the automobile industry, for multi-purpose applications, for marine applications
Other characteristics	CANbus, wide input range, programmable, voltage output, with metal casing, high input voltage, Buck-Boost, configurable, Modbus, RS485, Ethernet, Battery charger
Power	200 kW
Input voltage	Min: 10V, Max: 1.15kV
Output voltage	Min: 60V, Max: 1.2 kV

The maximum input voltage of the DC-DC converter RedPrime is 1.15kV and the MPP voltage of a Tiger solar panel is 44.22V, which indicates that the maximum number of the Tiger solar panel connected in series can be 26 panels. Thus, the number of strings feeding to each DC-DC converter RedPrime can be calculated to be 13 strings due to the maximum power of the DC-DC converter RedPrime of 200 kW. Therefore, the total number of solar panels connected to one DC-DC converter is 338 solar panels. Based on the total number of solar panels required for the entire project above, which is $7.030 * 10^9$ panels, the number of DC-DC converter units will be 20,798,817 units.
Therefore, the total number of DC-DC converters connected in series to provide 220 MV for the PEM Electrolysis Hydrogen Plant System is required to be roughly 183,334 units. This indicates that the number of strings of series-connected DC-DC converters will be roughly 114.
The final configuration of the entire solar PV power system is shown in Figure 4 below:

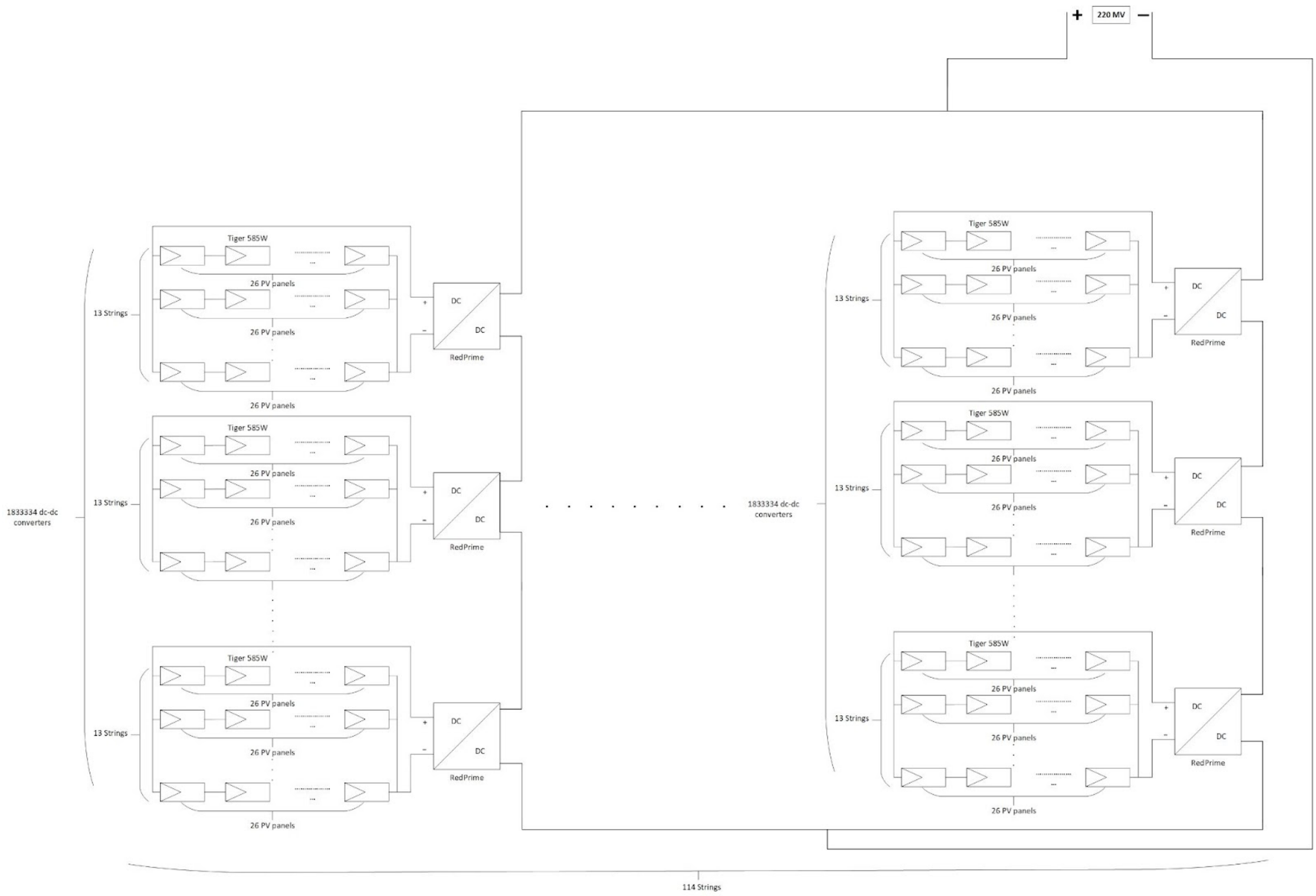


Figure 4: Single line diagram of the PV power system.

Mounting systems

The right solar mounting system will offer the structural support that a solar farm needs to safeguard it from wind-induced failure and other potential weather dangers. A mounting system can also adjust the solar system's direction and height to improve its energy efficiency. Mounting systems can be built to sit on a separate sub-frame or have tilt legs to provide the perfect inclination for a specific location.

For the location of this solar farm, the perfect inclination angle will be 12°, and the optimum orientation of the solar farm located in the southern hemisphere is north facing [23]. In the northern and western parts of Australia, there are a few times cyclones occur so that IronRidge SGA, one of the best fixed ground mounting systems in the market [24], is selected for this solar farm. This mounting system is built to hold up in extreme weather conditions. Figure 5 shows the IronRidge SGA mounting system for the solar plant.

Figure 5: IronRidge SGA mounting system.

Estimated Installation Cost of PV Solar Panel System

Based on detailed research from the International Renewable Energy Agency (IRENA) in 2019, the average cost of installing utility-scale PV systems in Australia was 1236 USD/kW, equivalent to 1688 AUD/kW based on the average currency conversion rate in 2019 [26], [27]. This figure includes the cost of the physical hardware (PV panels, mounting systems, cabling, and safety systems), the installation and inspection costs, and "soft costs" related to permits, applications, and regulatory compliance [26], [28].

Given the required solar farm size is $4.112 * 10^9$ kW, an overall estimate of the cost of the solar farm installation turns out as $6.68 trillion AUD.

A detailed cost breakdown is provided in the table below. Note the cost of the PV panels has been adjusted to match the price of Jinko Tiger panels.

Table 24: Cost estimates for PV solar panel system installation, based on 2019 research [26], [27], [28].

Category	**Component**	**Cost**	**Final Cost**	**Contribution**
		2019 AUD/kW	**AUD**	
Hardware	PV Modules/Panels	360.0	1.480E+12	22.15%
Hardware	Racking and mounting	232.0	9.543E+11	14.28%
Hardware	Grid connection	89.5	3.680E+11	5.51%
Hardware	Cabling/ wiring	81.3	3.343E+11	5.00%
Hardware	Safety and security	47.9	1.970E+11	2.95%
Hardware	Monitoring and control	59.8	2.461E+11	3.68%
Installation	Mechanical installation	268.4	1.104E+12	16.52%
Installation	Electrical installation	120.0	4.934E+11	7.38%
Installation	Inspection	11.7	4.792E+10	0.72%
Soft costs	Margin	124.7	5.129E+11	7.67%
Soft costs	Financing costs	61.9	2.544E+11	3.81%
Soft costs	System design	77.0	3.165E+11	4.74%
Soft costs	Permitting	55.0	2.260E+11	3.38%
Soft costs	Incentive application	14.7	6.034E+10	0.90%
Soft costs	Customer acquisition	21.3	8.756E+10	1.31%
Total		1625.1	6.683E+12	100%

Estimated Ongoing Costs of PV Solar Panel System

Operation and Maintenance costs (O&M) refer to the costs incurred during the operating life of the Solar Panel System, such as preventative maintenance, inspections, cleaning, and insurance [26], [28]. Based on the guidelines in the IRENA report, this can be assumed to cost about 26.3 AUD/kW/year [26].

One example of a cost-effective cleaning solution is shown below, an autonomous, waterless, self cleaning and self-powered robot that can clean panels of dust by using helical microfibre cloths and air [29]. This maximises the PV panel efficiency and eliminates the need for regular cleaning of the panels. Innovations such as this have contributed to declines in O&M costs in recent years [26].

Figure 6: Ecoppia H4 robotic solar panel cleaning system. From [30].

PV solar panels have a typical useful lifespan of 20-25 years, and Jinko guarantees their Tiger panel model will maintain at least 84.8% of its starting efficiency after 25 years [14], [22]. Based on the size of the solar farm, a total of $2.71 trillion AUD will be spent on O&M costs over a 25 year period before the PV solar panels will need replacement.

7.2.2 PEM Electrolysis Hydrogen Plant System

Final Design Overview:

The offshore electrolyser system will be powered from the 2 kilometer PV solar system located on the land to conduct the process of electrolysis to produce gaseous hydrogen that will be stored in the following storage subsystem.

According to the calculated data mentioned in the conceptual design for the PEM plant subsystem, the amount of hydrogen needed every hour is 14519 tonnes. To satisfy this demand, the PEM plant requires 782.5E+03 MW power per hour from the PV plant system. Therefore, a 785 GW PEM electrolyzer plant should be designed to reach those values.

Typically, the principle working of the PEM plant is to split water molecules into purified hydrogen and oxygen gas. The Figure 7 below demonstrates the entire PEM system which consists of the electrolyzer stack that is the main core associated with the BOP. The BOP is also constructed further from subparts including power supply (transformer, rectifier), deionized water circulation (gas separator, circulating pump), cooling part (heat exchanger, dryer), and miscellaneous (compressor, vent). Gas reservoirs internally have demisters to free the condensation.
[33]

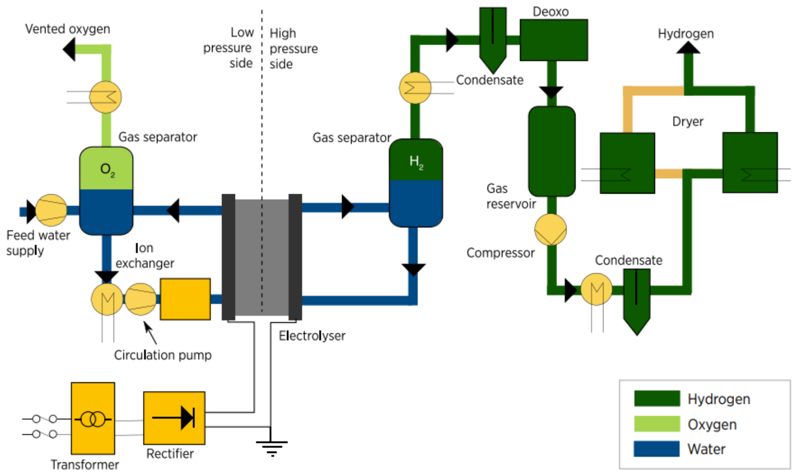


Figure 7: Schematic of the PEM electrolysis system

The sea water is used directly in the process of hydrogen production. The feed water pump firstly moves sea water to fill the water tank. The water continues to flow through the electrolyzer by the circulating pump. When the DC power from the PV system is supplied, the PEM electrolytic cell starts to electrolyze to produce oxygen and hydrogen. The produced oxygen flows back to the water tank, those oxygen and water are separated, and the oxygen is filtered via a molecular sieve before being expelled. On the other side, the hydrogen separator receives hydrogen and a small amount of water which goes back to the Electrolyzer stack, and the hydrogen gas is sent through a filter for further storage. [35].

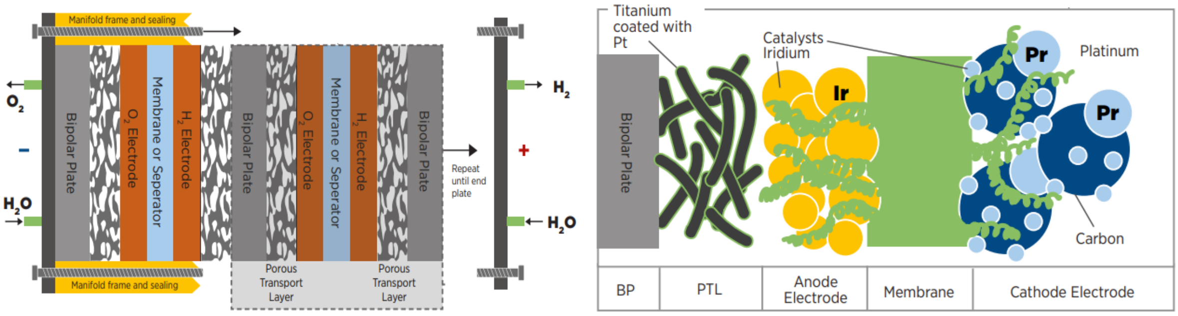


Figure 8: Internal Electrolyzer stack

Inside the PEM electrolyzer stack mentioned Figure 8 above comprises electrically connected cells in series and reactant product/gas cells connected in parallel. To structurally retain these cells inside the stack, two thick metal plates are placed from both ends. The core cell is a catalyst-coated membrane (CCM) consisting of a polymer membrane and cathode and anode catalyst layers placed at both sides of the membrane. The porous transport layer (PTL) is a layer that improves water diffusion and water splitting reactions on the membrane's surface. Bipolar plates (BL) include channels to assist with water, hydrogen, and oxygen movement inside the stack [35].

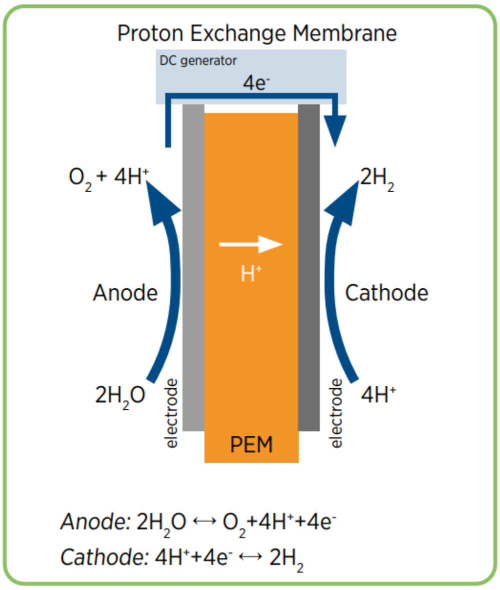


Figure 9: Principal operation of PEM electrolyzer

In the anode side, the salt water is supplied to the catalyzer where the oxygen, protons, and electrodes are oxidized. Then on the opposite side, cathode side, the conducted electrodes and protons via the membrane are combined with each other to produce gaseous hydrogen.

Design Proposal:

The scope of this technical design consists of all equipment and services required to connect to a photovoltaic Solar grid and a pure hydrogen delivery point (30 Bara). The plant includes electrical installations for transformation and rectification, electrolysis (stacks), purification, and compression.

Assumption:

The plant is designed to operate flexibly according to Australian weather conditions, yearly climates, and export geography. Furthermore, the design complies with the grid code and health, safety, and environmental requirements.

The hydrogen will be delivered at 30 Bara pressure and 99.99% purity with a maximum of 5 ppm, by volume, of both water and oxygen. The hydrogen plant will be operating at 60-80 percent efficiency.

Modular Design:

The proposed design relies on modular-design based on a 1 GW electrolyser or a stack, and scaling up to be able to output required power. The main components in the system consist of transformer-rectifiers, electrolyzer stacks, and the balance of plants. These components are grouped into independently operating modules or blocks.

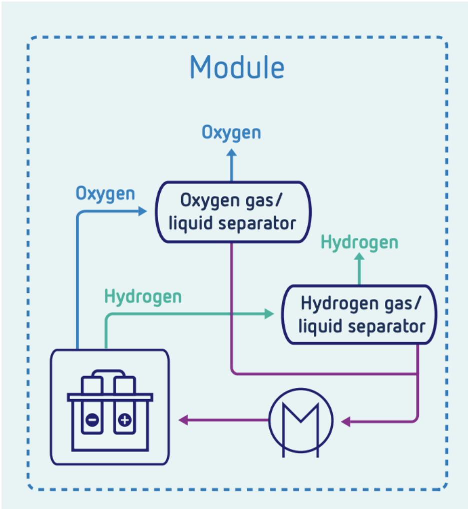


Figure 10: Modular design

Electrolyser Stack:

The 1 GW electrolyser stacks are grouped with shared transformer-rectifiers, separators, and other balance-of-plants equipment. One 40 MW transformer-rectifier power block is connected to four 10 MW stacks for PEM. Each 40 MW PEM module has one hydrogen gas-liquid separator and oxygen gas-liquid separator. This modular design enables phased development and deployment, and facilitates adaptation to newer generations of technology. Standardization, which yields cost savings, could also mean that the design can accommodate a combination of PEM technology and, potentially, different generations of stacks within the same plant.

The novel PEM electrolyzer stack is a 10 MW stack with 310 cells. It has a current density of 3.5 A cm-2, and uses improved membrane and electrode materials and low-iridium anodes. The stacks are electrically connected to rectifiers, and arranged in modules 40 MW for PEM, with improved gas-liquid separators.

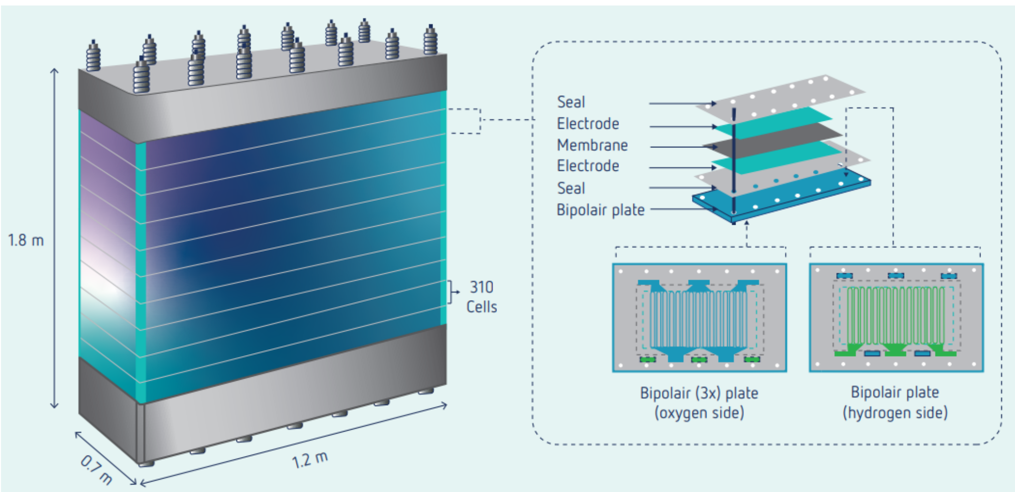


Figure 11: Stack design

As mentioned earlier, the key parts of the stack involve the CCM, PTL, BL, seal and frame. The materials used to make the stack parts need to be selected appropriately because they could reduce the electrolyzer efficiency.

Table 24: Material recommendations for stack parts

Stack parts	**Manufacturing material recommendations**
Catalyst-coated membrane (CCM)	Nafion, a perfluorosulfonic acid polymer polymer (PFSA) 0.2 millimeter in thickness, is used to make the membrane layer due to its high abilities of conductivity and chemical stability. Two sides of the membrane are covered by depositing catalyst layers to form anode and cathode. These electrode layers will face the hard challenge of chloride corrosion of seawater. The recommendation to handle this problem is the anode layer surface will be coated with other three layers. The innermost layer covered anode surface is a Ni foam in 20 µm thickness, then a 10 µm thick nickel sulfide (NiSx) layer covers Ni foam layer and the outermost layer is a nickel–iron hydroxide (NiFe) electrocatalyst layer with 200 nm thickness. To deal with the problem of unwanted chloride gas generated during the operation of the PEM plant, the basic cobalt carbonate nanoneedles are cultivated on carbon fibre fabric to form the anode. The cloth is then soaked in 2-methylimidazole, resulting in a thin layer of cobalt-imidazole metal organic framework (MOF) on the needles' exterior. The sodium ferrocyanide is added to change the layer into cobalt hexacyanoferrate, which inherited the porous nanostructure of the MOF and created 20-nm-thick catalytic shells around the conducting nanoneedles. With this coating layer on the anode surface, chloride gas will not be produced in the process.
Porous transport layer	The PTL layer can be formed by sintered titanium created from the process of powder metallurgy or common carbon cloth that have a high corrosion resistance to the seawater.
Bipolar plate	The bipolar plates are constructed by a 5 mm thick stainless steel plate coated with a 100 nm thick gold layer to keep them away from the degradation process of corrosion.
Frame/Seal	The frame is made by resin combined by polyphenylene sulfide (PPS) and 40% glass fiber.

Power Block:

Each power block consists of transformer-rectifiers and stacks, while each module consists of stacks, gas-liquid separators, and associated equipment. This combination of transformer-rectifier and stacks is defined as a power block, which is 40 MW for both PEM (refer to power block figure).

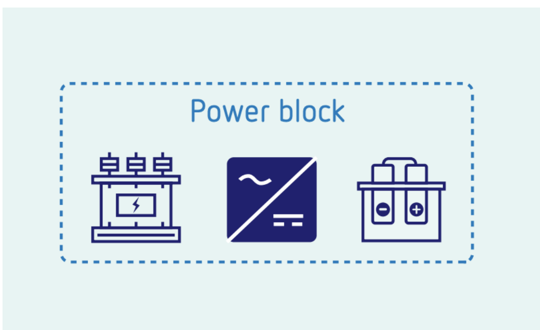


Figure 12: Power module design

Modular Specifications

Module:

The nominal hydrogen output capacity will be 19 tonnes per hour (210,000 Nm3/hr). The hydrogen will be delivered at 30 Bara pressure and 99.99% purity with a maximum of 5 ppm, by volume, of both water and oxygen.

Table 25: Modular Specifications

Specifications	Description
Electrical system	380 kV AC ~ 270 kV DC
Current density PEM	2 A/cm^2
Number of stack PEM	96
Output capacity	19 tonnes per hour (210,000 Nm3/hr)
Plot size	10 ha

Estimate Cost:

The present the technical design and the associated total investment costs of a 1-GW green-hydrogen plant that would be built, and up and running, in Australia. This project shows that anticipated total investment cost levels of 1,471.60 AUD/kW or 1,293.87 AUD/(kg/d) for PEM are within reach.

Total Installed Cost:

1,471.60 AUD/kW

Table 26: Total installed cost

Cost contributors	Percentages
Indirect cost	12%
Owner cost	9%
Contingency Cost	26%
Direct Cost	54%

Estimated Direct Cost:

1,293.87 AUD/(kg/d)

Table 27: Estimated direct cost

Cost contributors	Percentages
Balance of plants	5%
Civil, structural and architectural works	6%
Utilities and automation	7%
Power supply and electronics	17%
Stacks (electrolysers)	19%

Scalability:

From the 1 GW electrolyzer modular design mentioned earlier, the design for 785 GW PEM electrolyzer system will be scaled up based on the modular specifications.

Table 28: Scale-up 785 GW electrolyzer specifications

Specifications	Description
Electrical system	220 MV
Current density PEM	2 A/cm^2
Number of stack PEM	75360
Output capacity	14519 ton/h
Plot size	7850 ha

Cost

Table 29: Scale-up 785GW electrolyzer cost

Cost Contributors	Cost
Total installed cost	1155 billion AUD

Layout:

A four 10 MW-stack group will be coupled to a 40 MW transformer-rectifier power block. One hydrogen gas-liquid separator and one oxygen gas-liquid separator are included in each 40 MW PEM module. For the 785 GW PEM electrolyzer system, it needs 19625 modules of 40 MW PEM, 19625 power blocks of transformer-rectifier units, 39250 gaseous separators and 39250 heat exchangers. The Figure 13 below is to show the layout of the whole system of PEM electrolyzer including power blocks, stack modules, separations, and heat exchanges.

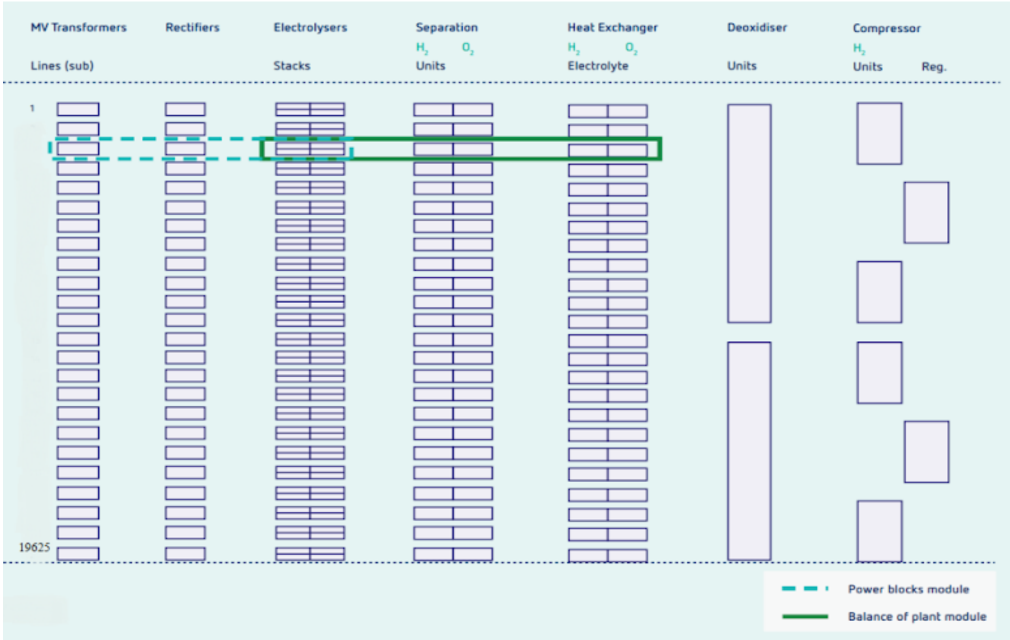


Figure 13: 875 GW PEM Stack and balance of plant layout

7.2.3 Hydrogen Storage System

Final Design Overview:

The final design of the hydrogen storage system will be performed through liquid formation. Hydrogen storage systems are commonly stored in conventional hydrocarbonfueled automobiles. Hydrogen storage through liquid is highly used for transportation. As seen in Figure 14, liquid hydrogen is supplied through a high pressure pump that travels into an evaporator followed by high pressure buffer storage where it is maintained at 950 bar then distributed into pre-cooling units at -40 degrees celsius before being dispensed onto tanks. Through cryogenic liquid storage tanks they hold on to liquid hydrogen at -252.8 degrees celsius as boiling point of hydrogen is at one atmospheric pressure and density about 71 kg/m³ which equates to about 5 kg of hydrogen kpet in a 75 L tank. In this procedure, high volumes of hydrogen are stored rather than compressed gas and less amounts of evaporation loss compared to compressive machines. Materials used in hydrogen storage systems are chemically reacted with water based materials, known as chemical hydrogen storage which allows hydrogen to be stored in large quantities at low temperatures and pressures.

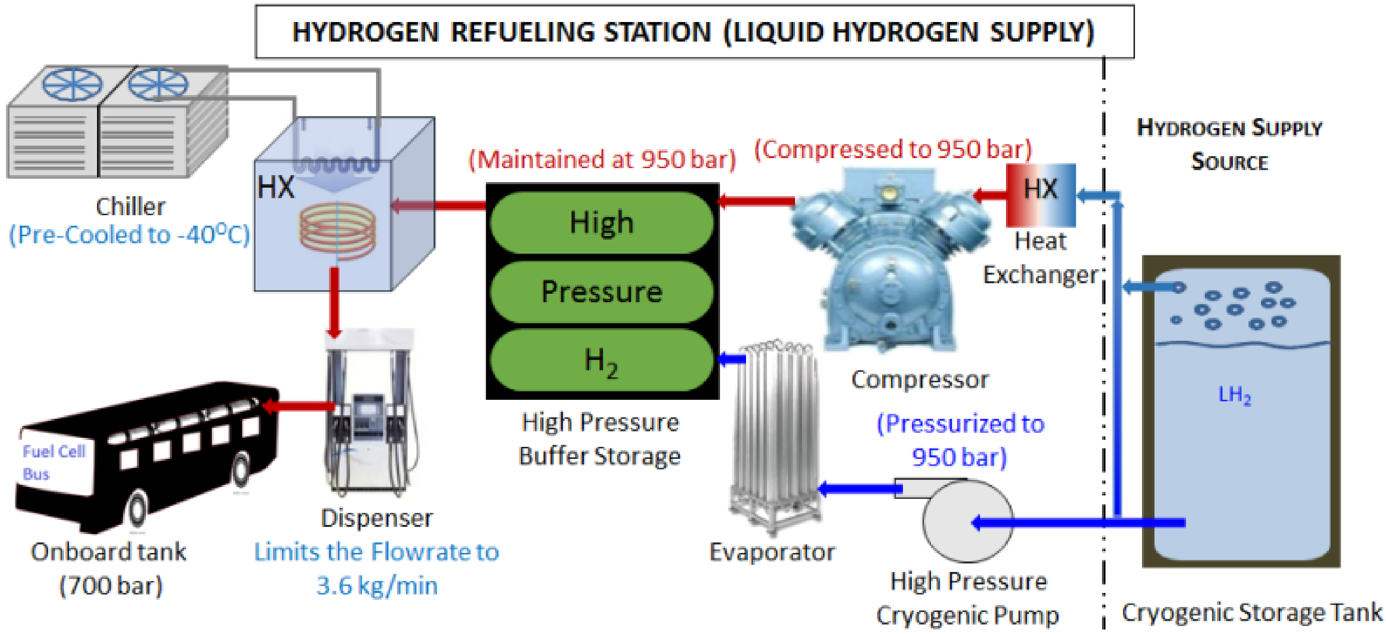


Figure 14: Hydrogen Refueling Liquid Station

Design Application

Hydrogen storage systems via liquefaction are high in expenses and provide low energy efficiency hence utilised on vehicles or space operations. As the hydrogen are transported through tanks on a fuel cell bus, there are possible risks that may take place such as air leakage in tanks can lead to fires in doing so, the tanks must be kept greater than the atmospheric pressure from air penetrating in to the tanks.

Recommendations and Specifications:

Table 30: Cost of Hydrogen Storage System

Description	Cost	No of Units
Storage Area	$2.70kg	180kg/day
High Pressure Compressor	$36500	1

High Pressure Buffer Storage	$1400	1
Cooling Unit	$3000 - $5000	2
High Pressure Pump	$5000	1
Cryogenic Pump	$2600 - $2800	1
Evaporator	$600 - $2000	1
Fueling Dispenser	$16000 - $21000	5

7.2.4 Submarine Cable System

Final Design Overview:

The SCS supplies power generated by the PSPS to the PEHPS. The overall distance of the SCS is roughly 2 km, with transformers on either end of the SCS to convert the incoming power to allow for more efficient energy transfer. The cables will be constructed as shown in Appendix B.1.

Recommendations and Specifications:

- The cables will have a voltage rating of ±500 kV [36]
- The cables will have a capacity of 2000-3000 MW [36]

Table 31: Cost of Submarine Cable System

Description	**Cost**	**No. of Units**
HVDC Submarine Power Cable [36]	$1.5 - 2.5 million/km	2 km

7.2.5 Tracking/Ordering Management System

Final Design Overview - Customer TOMS:

The final design of the Tracking/Ordering Management System (TOMS) is split up into two main sections, the customer interface and the administration side. Starting with the customer interface referencing Figure 15, the customer will be able to access the four main components that relate to the user, the first being login and registration. Using the 'Formik' library, users will need to first log/register into their accounts before being able to access their main content which w, i.e. order forms, order history, current pricing and settings. The customers will also get updates on the current progress of their order which they will be able to view in their order history. Customers do not have the ability to change any information that already exists on the servers including profile settings and order history. When customers place orders, due to the high costs associated with hydrogen purchases, all purchases and changes to profiles have to be approved by the administration team as a method to increase customer and system security. An example of the UI layout for both 'orders' and 'order history' pages can be found in Appendix E.

Final Design Overview - Administration TOMS:

With reference to Figure 16, the administration section of the TOMS is split into two further sections, administrative functions and safety functions. The administrative functions of the system allow users to accept and manage orders that customers request as well as edit customer profiles and verify users. When orders are accepted, the system sends the order details to storage, transport and the hydrogen production centres. This way, different teams will be able to communicate with each other and on the time-frame for delivery and work out the logistics on how much hydrogen needs to be produced and the amount that will need to come out of storage in order to meet the feasible time-frame of delivery to customers.

The second section is the safety function of the system. Administrators will be able to view and manage problems within the system. For instance, the system tracks the deterioration of the cathode during the electrolysis of water and will warn the administrators if the cathode is close to being completely corroded away in order to stop corrosion from occurring in the rest of the system. The system tracks the state of solar panels and the outputting electricity levels through the use of sensors and technician reports. This means that users will be able to change production levels throughout the entire system if other subsystems become faulty or if a hydrogen production plant requires more electricity then the administrator can make those changes.

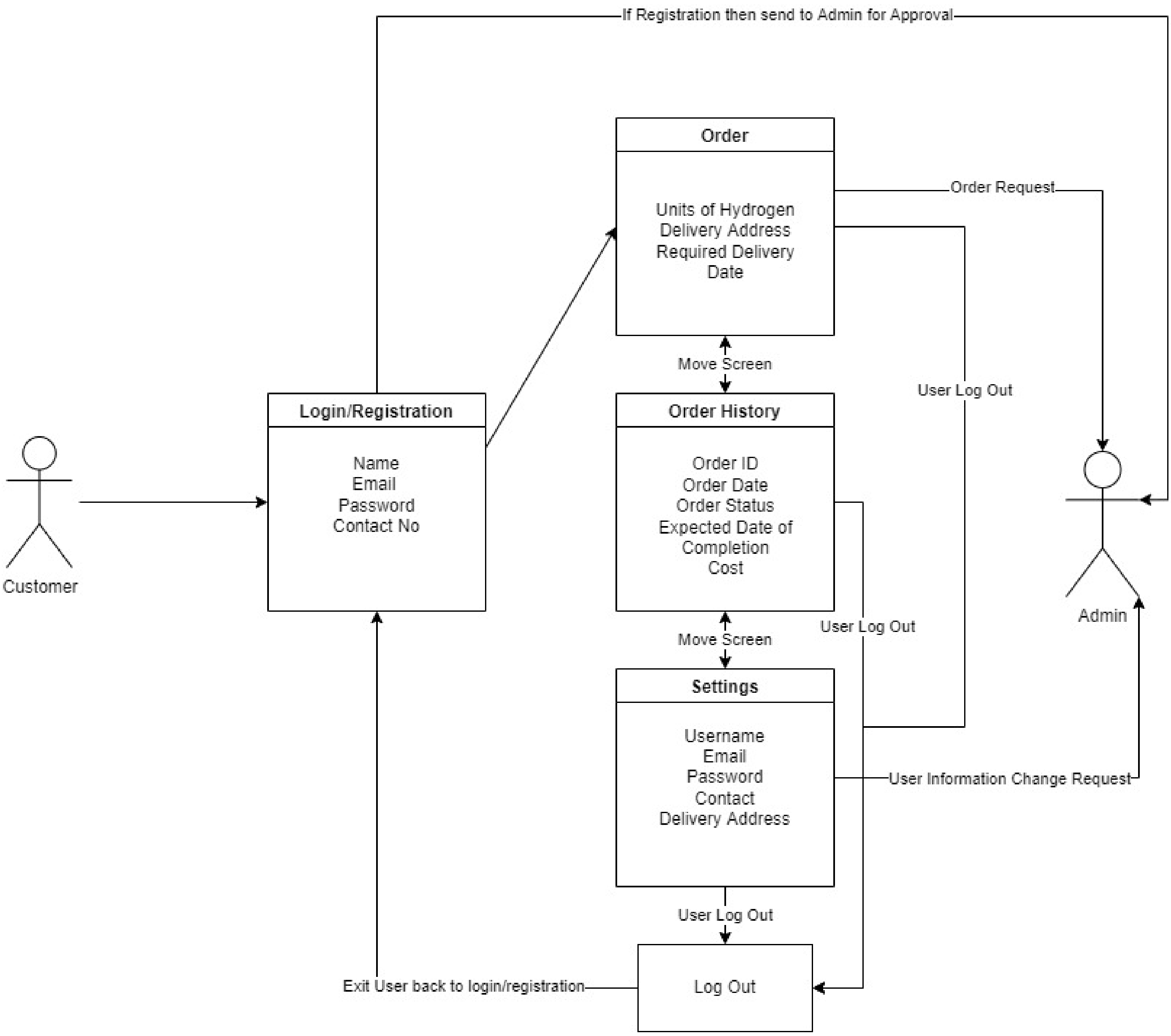


Figure 15: Customer Section of TOMS

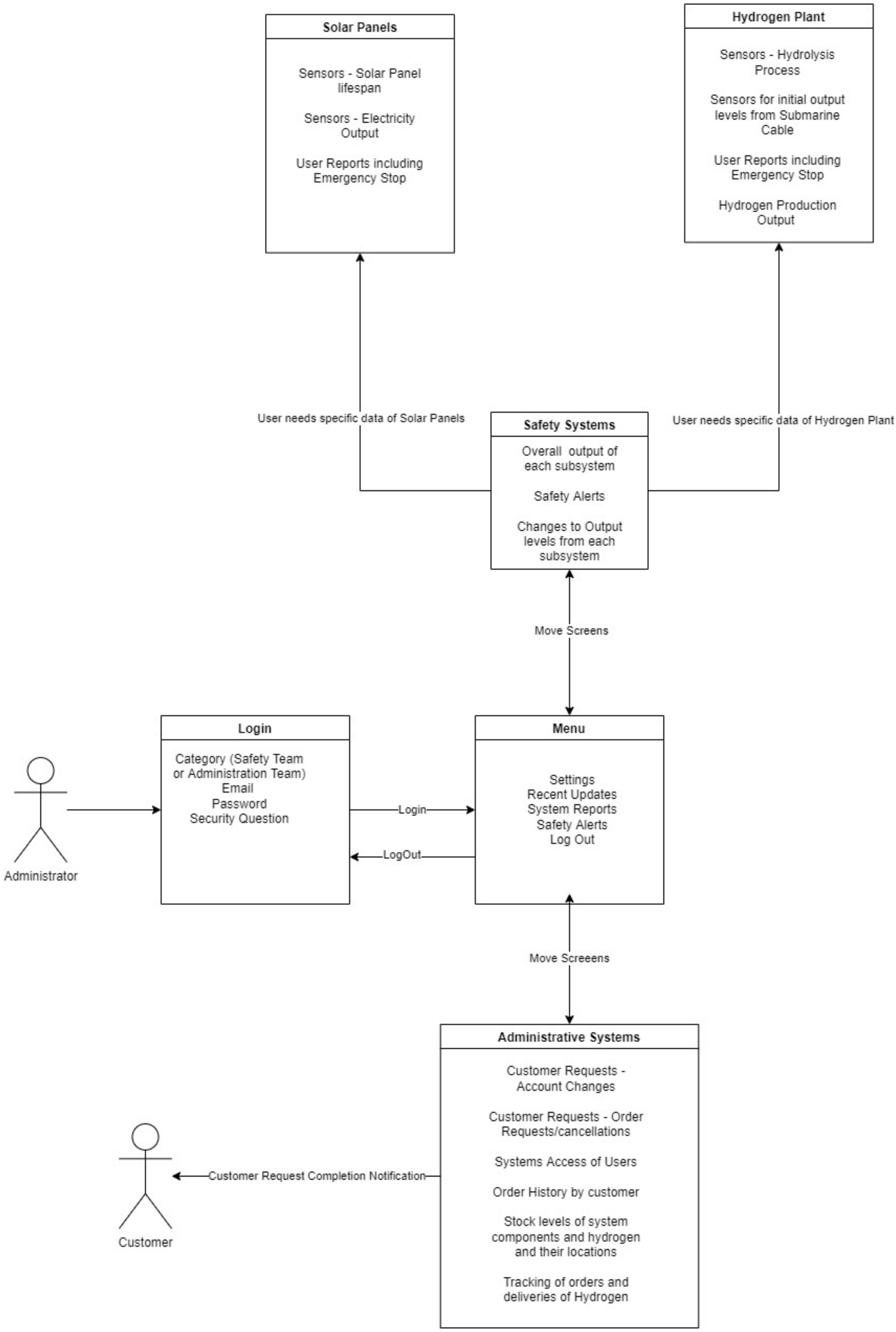


Figure 16: Administration Section of TOMS

Architecture

The choice of architecture for the TOMS will be based on the reference architecture for a retail supply chain as recommended by Amazon Web Services (AWS) Figure 17.

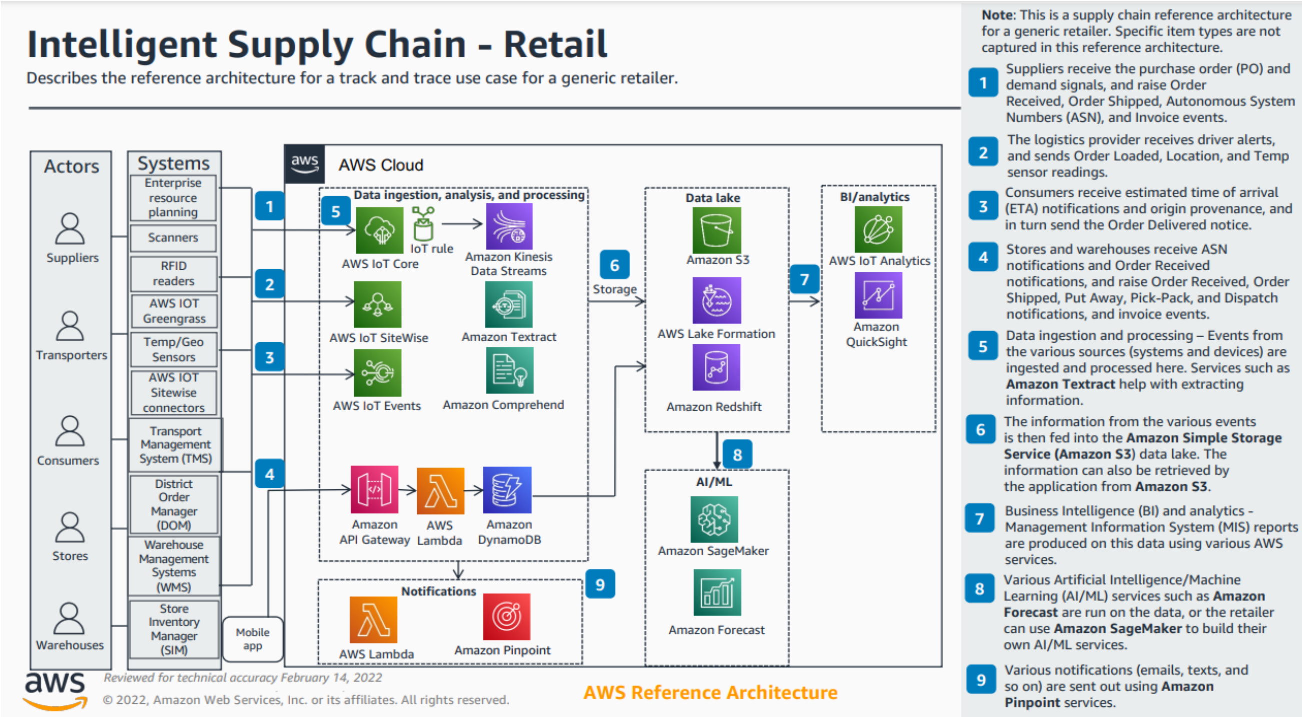


Figure 17: Reference Architecture that the TOMS is based on [37]

We have chosen to follow this format for the architecture of the TOMS due to it encapsulating the entire TOMS system with room for the system to grow into as the business cases grow into the future. The current peripherals of the system include scanners, geolocation tracking, transport management system, warehouse management system and inventory manager. Future system expansions may be able to make use of point 8 in Figure 17 to help forecast orders and point 7 may be of use to make business improvements in the future as the system grows to maturity.

Specific Technology Used

The TOMS will be based in the cloud using AWS as the cloud provider. The TOMS will have to be able to integrate with the peripheral devices used in the subsystem, host the client (ordering system) and internal facing (stock management, system management) web applications, store the data generated by the users, deliver services and notify users of order updates or system messages. For these functions we have identified the following AWS services that will be used in the initial offering of the TOMS in Table 32 below. For the specific peripheral devices identified for the TOMS, see Table 33 below.

Table 32: The list of Amazon services used for the TOMS application

Amazon Web Services Used	
Amazon Services	**Description of Service**
AWS IoT events	Amazon service to handle the events coming in from the peripheral devices.
AWS Lambda	Amazon service to run what would traditionally be the server side code for the application.
Amazon DynamoDB	Amazon database service to hold the applications data. Used for transactional reads and writes.
Amazon EC2	Amazon computing instances that will be used to host the web application.
Amazon Pinpoint	Amazon service that will be used to send out email notifications to users regarding orders and notifications to system admins regarding any action items that need responding to.
Amazon Simple Storage Service	Amazon service that will act as a secondary storage, where the data from the primary database (Amazon DynamoDB) will be migrated to.

Table 33: The list of peripheral devices used in the TOMS

Peripheral Devices for the TOMS	
Handheld Barcode Scanner	These will be used by staff to scan deliveries, register new stock and register outgoing deliveries of the hydrogen.
PCs (Desktop and Monitors)	These will be used by staff for general admin duties that are required by the TOMS such as dispatching orders, tracking orders, responding to client inquiries and general duties required to manage staff.
Tablets	These will be used by staff to use the TOMS when they need to be away from a PC. All the same functionality will be offered through the tablet.

Choice of Database

For the database component of the TOMS we will be using Amazon DynamoDB. It is a NoSQL key-value database that comes with in-built security, will be able to backup the data in a continuous fashion and will also be able to export the data to an additional data lake automatically with the data lake chosen to be the Amazon Simple Storage Service as it is easily provisioned within the AWS service infrastructure. It will be able to deliver high concurrency for our database transactions that will be needed for the ordering and tracking of the liquid hydrogen through our system and also allow for point in time recovery of up to 35 days [38]. For the code examples that will be needed to use the database and integrate it into our TOMS system which includes the create, read, update, delete operations (CRUD), please refer to Appendix D.

Estimated Costs

Table 34: List of components, number needed for TOMS, price range/estimate and total price.

Component	Number of Units	Price Range/Estimate	Total Price
Barcode Scanner	20	$62.97 - $99.00 AUD	$1,259.4 - $1,980 AUD
Tablet	15	$349-$599 AUD	$5235 - $8985 AUD
PC (desktop + monitor)	10	$1,181.64 - $1,907.64 AUD	$11,816.4 - $19,076.4 AUD
AWS (Whole Build)	1	$20,267.52 USD per year	$20,267.52 USD per year

The table 34 above provides the breakdown of components required for the TOMS and the cost estimate for each component. Please refer to Appendix section C for references to prices obtained.

Recommendations and Specifications:

- Barcode Scanners are recommended to be wireless with Bluetooth capabilities.
- Desktop: i5, 8 GB memory, 256 SSD.
- Monitor: 24 inch.
- AWS Database size: 1 TB to allow for growth.

7.2.6 Transport

Freight Estimate Costs Over Land:

Depending on the style of truck used, the costs will vary. Another factor that will alter the costs is if the delivery distance is to be within 30 km of a capital city port or whether it will be in regional areas. The two cost estimates provided here will take into consideration both of these variables [39].

The typical delivery costs associated with delivery within 30 km of a capital city port will be:

- $390 + GST for a side loader truck [39].

The typical delivery costs in a regional area are based on the following rates:

- $5.90 per kilometre + GST for a side loader truck [39].

Freight Estimate Costs Over Sea:

Shipping costs have a few different aspects to their total pricing and in addition to this, shipping containers are either charged at a full container load (FCL) or a less than container load (LCL). For this document, we will only be considering the costs of a FCL as we assume we will only be sending full containers of the liquid hydrogen when exporting. The different costs that go into calculating the total shipping cost include [40]:

- Inland Haulage: usually a lump sum that could include a fuel surcharge [40].
- UK Thermal Handling Charge: Usually a lump sum [40].
- Documentation: Usually charged as a lump sum and can be for multiple different documentation types [40].
- Customs Clearance: Usually a lump sum [40].
- Security: Usually a lump sum [40].
- Ocean Freight: Charged as a lump sum per container either $1000 for a 20’ or $2000 for a 40’ [40].
- Bunker Adjustment Factor: Charged as a lump sum per size unit. $350 for 20’ or $700 for a 40’ container [40].
- Currency Adjustment Factor: Charged as a percentage of the freight[40].

8 Design Review

8.1 Justification and Critique

Table 35: Justification and Critique

Subsystem	Justifications and Critique
Photovoltaic Solar Panel System	Requirements met: FR_PV_01, FR_PV_02, FR_PV_03, FR_PV_04, FR_PV_05, FR_PV_06, IR_PEM_03 Positives: Australia experiences the highest average solar irradiation of any continent, with large areas of land in low-populated regions that are suitable for large-scale solar farms [14]. Once installed, solar panels require minimal running costs [14]. The energy collected by the PV panels is output in the form of electricity, so it is relatively efficient to transport and deliver to the PEM plant with minimal processing. Limitation and Improvements: Solar panels are dependent on solar radiation, so weather and seasons can reduce power outputs, and they cannot produce power at night. PV panels also have a lifespan of 20-25 years [14]. The efficiency of the commercially-available PV panels specified in this report is relatively low, at around 20%. However, PV efficiency is constantly under improvement, and efficiencies of around 40% have already been achieved in lab conditions [14, p. 266].
PEM Electrolysis Hydrogen Plant System	Requirements met: FR_PEM_01, FR_PEM_02, FR_PEM_03, FR_PEM_04, FR_PEM_05, FR_PEM_06 Positives: In terms of plant location 2km offshore, the PEM plant can access to sea water source in ease, also convenient for transportation of hydrogen by ships. Space efficient for components roughly 7850 ha would be required. Flexibility in terms of phased development, with easy adaptation to newer technology generations. It enables standardisation, which saves costs. Limitation and Improvements: Technological advancements may add to upgrade cost and make current technology invalid.

Subsystem	Justifications and Critique
Hydrogen Storage System	Requirements met: FR_GHS_01, FR_GHS_02, FR_GHS_03, FR_GHS_04, PR_GHS_01, IR_GHS_01, IR_GHS_02, IR_GHS_03 Positives: From the storage perspective, hydrogen can be produced and stored in a large amount for a long period of time. Through the process of liquefaction, this form of energy is almost three times denser than the traditional fossil fuels. In addition, hydrogen is versatile as it can be used as fuel cells to power electric vehicles which overall contribute to the reduction of carbon footprint. Looking from the transportation perspective, since hydrogen is almost three times denser than fossil fuel, transporting it in a cryogenic tank on a cargo ship would be more efficient than the traditional energy sources because more energy is being transported. Limitation and Improvements: Producing green hydrogen requires a lot of renewable energy because of the desalination process and electrolysis. However, this can be counteracted by scaling out our PSPS to accommodate the energy needed. Another limitation is the safety risks of hydrogen storage and transportation. To help reduce this issue, STR tracks any potential energy leakage or other factors that impact the process of energy transportation.
Submarine Cable System	Requirements met: FR_PV_04, PR_SC_01, IR_GHS_02 Positives: Professionally installed cables have a benign effect on the marine environment[41]. Additionally, surface laid cables can provide substrates for marine organisms and zones created to protect submarine power cables can also act as marine sanctuaries, thus improving biodiversity and fish stocks[41]. Studies have also shown that submarine power cables have no effect on the abundance of types of sediment-dwelling animals, both near and distant from cables[41]. Limitation and Improvements: The repairing of damaged submarine power cables require specialised ships and cable jointing experts to replace the damaged segment with new cable [41]. Completion of such a repair can take anywhere between a few days to a few weeks, depending on the extent of the damage, location of the fault, and time it takes to mobilise a suitably equipped vessel [41].

Subsystem	Justifications and Critique
Tracking/Ordering Management System	Requirements met: FR_STR_01 through FR_STR_32 Positives: The system is capable of growing to meet the demands of its future user base as it is hosted on the cloud and can grow dynamically as the system increases in users or in the event that the user base decreases. It offers a simple interface for users, both internal staff and external clients to use and navigate. The cloud services can be added as the system evolves overtime to include additional things such as business analytics or machine learning to help it meet any future use cases. Limitation and Improvements: The data storage is not handled internally but instead given over to AWS to manage and secure. This is a downside to cloud based platforms and could be a problem if a natural disaster or security breach were to affect the data centre where the data is located. The system also heavily relies on stable internet connection for it to function and any interruptions could impact the critical functions that relate to emergency shut downs of the other subsystems. To prepare for this scenario it is suggested that coming up with a protocol that would alert the system user to the interruption of the internet and to bring in the use of a communication method that does not rely on the internet such as telephone or radio so that the subsystems can be shut off at the site directly.

8.2 Alternative Designs

8.2.1 Wind power as alternative to PSPS

Alternative designs from PSPS are utilizing wind turbines that are situated along the coast that will spin propeller blades around the rotor to create electricity. Although Australia is commonly known for using photovoltaic solar panels, there are a few wind farms slowly increasing around the southern parts of Australia. Similar to PSPS, wind turbines are matched with energy storage such as batteries to maintain a supply of electricity. From the efficiency factor, a wind turbine is more efficient as it can generate around 60% to 90% of energy from the wind compared to solar panels, which by the current standard, can only generate approximately 20% [43]. However, a detrimental factor of using wind energy is its consistency because the change in season can affect the amount of energy generated.

The advantage of wind turbines is that the system is functional through night or cloudy conditions, hence, it can produce more energy than solar panels. They are a clean source of energy that pumps out less carbon dioxide into the atmosphere. Although wind turbines are costly to install initially, their operating and maintaining costs are low throughout their lifetime.

Disadvantages of wind turbines is that the system is often required to be built on remote farm lands meaning losing profits for land and installation must follow certain factors before being used such as being located at least 30 feet tall than other objects to make sure there are constant wind breaks for the turbine to operate. They produce noise pollution up to 60 decibels from the generator disrupting the wildlife and landscape.

8.2.2 Using desalination plant instead of coating for anode and cathode

A design that we considered using was to use desalination plants in order to supply fresh water for electrolysis. The PEHPS requires 3.136E+09 litres of water per day to generate the required amount of hydrogen to export in order to eliminate the use of fossil fuels (see Appendix A.2). The desalination plant with the highest output in Western Australia is the Southern Seawater Desalination Plant, with an output of 300 megalitres per day (3E+08 litres)[44]. This is just under a tenth of the required daily water intake for the PEHPS.

Because of the large quantities of water required each day by the PEHPS, the challenge and cost incurred by the designing and construction of a desalination plant (or multiple if the project were to be scaled) that can output more than ten times the output of the Southern Seawater Desalination Plant renders this approach unfeasible.

8.2.3 Sand as energy storage and transportation

This alternative design looked at using thermal energy trapped in sand and then exporting the sand as the energy product to overseas clients. The system we considered, would heat up sand using solar panels to reflect the sunlight onto a metal platform that would heat up the sand which would hold the thermal energy. The heated sand would then be transferred to special purpose built containers and transported to storage facilities before being shipped off to clients using shipping containers. There would have been an electronic tracking system to facilitate orders and track the amount of product moving within the system.

The positive points for this design is that it looks to capitalise on the abundant amount of sunlight available in Australia, will utilise a clean energy source in sand that doesn't produce any by-products in its heating and is easy to track, transport and export around the world. Also in contrast to our chosen design it would have all been located on shore as opposed to having part of the system located on the coastal waters around Australia which would make it easier to secure in case of conflict with other nations.

The negative points for this design is that it would be difficult to scale up to meet production demands required of this energy product. The heating platforms that would have been used to hold the sand during heating would have a limited amount of sand that they could have held at any one time which would have made it difficult and possibly expensive to reach the required energy generation rate to meet exportation requirements. It may also have been hard to source enough good quality sand for the everyday running of the system as impurities may lower the heat capacity of the sand.

8.2.4 Buy water from other countries to do the electrolysis

As an alternative to taking sea water for use in generating hydrogen, fresh water could be imported from other countries. This would remove the need for desalination plants or special coatings in the electrolysis plants, and remove the associated maintenance costs. However, additional costs will be incurred for water production at the source country and for transportation. The environmental impacts of water production and transportation would also be harder to manage, as they would be controlled by third parties.

Because of the large quantities of water required each day by the PEM electrolysis plant(s), the cost and potential carbon emissions from the production and import of water become significant, making this approach unfeasible.

8.2.5 Full Solar Power solution with submarine cable exports

The alternative scheme considered for energy exportation is to use the submarine cables laid on the ocean floor, similar to the final solution, but the power energy produced from the PV system would transmit directly to countries via these subsea cables instead of converting them to hydrogen form and then exporting. Although, this scheme is quite feasible since it can transfer a large amount of power rapidly to the desired countries. Also, many studies in England and the United Kingdom stated that cable installation, maintenance, Electromagnetic Fields and temperature increases have insignificant effects on the environment or sea life.
However, the inevitable problem of submarine power transmission is the high-power loss since the transmission lines are extremely long enough about more than thousands kilometers to reach the country ends from Australia territory, leading the power loss to be high significantly. Additionally, this solution clearly lacked the flexibility of transportation and installation in case the energy required to be exported to other countries, then the different lines needed to be installed. Therefore, with these reasons mentioned above this idea for energy exportation was eliminated.

References

[1] “Fossil fuels and climate change: the facts”. [Online]. Available: https://www.clientearth.org/latest/latest-updates/stories/fossil-fuels-and-climate-change-the-facts/ [Accessed Mar. 17, 2022].

[2] “Australia’s fossil fuel exports”, *World Energy Data*. [Online]. Available: https://www.worldenergydata.org/australias-fossil-fuel-exports/ [Accessed Mar. 17, 2022].

[3] “Australia’s plan to reach our net zero target by 2050 | Ministers for the Department of Industry, Science, Energy and Resources”. [Online]. Available: https://www.minister.industry.gov.au/ministers/taylor/media-releases/australias-plan-reach-our-net-zero-target-2050 [Accessed Mar. 17, 2022].

[4] A. Taylor, "Australia's plan to reach our net zero target by 2050," Australian Government, 21 October 2021. [Online]. Available: https://www.minister.industry.gov.au/ministers/taylor/media-releases/australias-plan-reach-our-net-zero-target-2050. [Accessed 15 March 2022].

[5] T. Kjølberg, "World’s Longest Undersea Power Cable Linking Norway And UK," Daily Scandinavian, 4 November 2021. [Online]. Available: https://www.dailyscandinavian.com/worlds-longest-undersea-power-cable-linking-norway-and-uk/. [Accessed 16 March 2022].

[6] Victorian Government Department of Environment, Land, Water and Planning, Melbourne, "Fact-sheet-project-costs-March-2015," Unknown March 2015. [Online]. Available: https://www.water.vic.gov.au/__data/assets/pdf_file/0013/54202/Fact-sheet-project-costs-March-2015.pdf. [Accessed 29 March 2022].

[7] Belmont Metals, "Galvanic and Electrolytic Corrosion: Reducing Damage with Zinc Anode," Belmont Metals, 21 March 2018. [Online]. Available: https://www.belmontmetals.com/galvanic-and-electrolytic-corrosion-reducing-damage-with-zinc-anodes/. [Accessed 29 March 2022].

[8] Fact Check, "Fact check: Is Australia the sunniest continent on Earth?," ABC News, 10 August 2015. [Online]. Available: https://www.abc.net.au/news/2015-08-10/solar-coverage-fact-check-is-australia-sunniest-continent/6659316. [Accessed 16 March 2022].

[9] 19. P.Y.Parra, B. Hare, , U.F. Hutfilter, N. Roming, *Evaluating the significance of Australia’s global fossil fuel carbon footprint*: CLIMATE ANALYTICS, 2019.

[10] “*Climate change impacts on storms and floods,”* .Accessed on 23-Mar-2022. [Online]. Available: https://www.climatechange.environment.nsw.gov.au/storms-and-floods.

[11] CSIRO, "National Hydrogen Roadmap", CSIRO, 2018. [Online]. Available: https://static1.squarespace.com/static/58e8f58d20099ea6eb9ab918/t/5e965cdbf01cf06d99b46750/1586912484503/18-00314_EN_NationalHydrogenRoadmap_WEB_180823.pdf. [Accessed: 17- Mar- 2022].

[12] J. Verne, *AUSTRALIA'S NATIONAL HYDROGEN STRATEGY:* COAG Energy Council, 2019.

[13] S. Percy, “ Green hydrogen is coming - and these Australian regions are well placed to build our new export industry”, The Conversation, 2022. [Online]. Available: https://theconversation.com/green-hydrogen-is-coming-and-these-australian-regions-are-well-placed-to-build-our-new-export-industry-174466. [Accessed on: 22-Mar-2022].

[14] Geoscience Australia and BREE, 2014, Australian Energy Resource Assessment. 2nd Ed. Geoscience Australia, Canberra. Available: https://arena.gov.au/assets/2018/08/australian-energy-resource-assessment.pdf.

[15] Shiva Kumar, S. and Himabindu, V., 2019. Hydrogen production by PEM water electrolysis – A review. Materials Science for Energy Technologies, [online] 2(3), pp.442-454. Available: https://www.sciencedirect.com/science/article/pii/S2589299119300035.

[16] Y. Kuang et al., "Solar-driven, highly sustained splitting of seawater into hydrogen and oxygen fuels", Proceedings of the National Academy of Sciences, vol. 116, no. 14, pp. 6624-6629, 2019. Available: https://www.pnas.org/doi/10.1073/pnas.1900556116. [Accessed 30 March 2022].

[17] E. Garcia de Jesús, "Stanford researchers create hydrogen fuel from seawater", Stanford News, 2019. [Online]. Available: https://news.stanford.edu/2019/03/18/new-way-generate-hydrogen-fuel-seawater/. [Accessed: 30- Mar- 2022].

[18] Air Liquide. 2022. How is hydrogen stored ?. [online] Available: https://energies.airliquide.com/resources-planet-hydrogen/how-hydrogen-stored. [Accessed 16 March 2022].

[19] “*Average peak sun hours (Australia)"* [Online] Available: https://climatebiz.com/average-peak-sun-hours-australia/. [Accessed: 17/05/2022].

[20] “*The 6 best commercial solar panels for businesses in 2021"* [Online] Available: https://lightningsolar.com.au/best-commercial-solar-panels-for-businesses/. [Accessed: 17/05/2022].

[21] "Products - Jinko Solar", Jinko Solar. [Online]. Available: http://jinkosolar.com.au/products-new/. [Accessed: 03- Jun- 2022].

[22] “*TR 78M 565-585 Watt Mono-facial Tiger Pro*” [Online] Available: http://solarpart.vn/wp-content/uploads/2020/12/TR-JKM565-585M-7RL4-V-A1-EN.pdf. [Accessed: 17/05/2022].

[23] “*Solar Panel Angle Affects Performance*”, [Online] Available: https://solarcalculator.com.au/solar-panel-angle/. [Accessed: 17/05/2022]

[24] “*Solar Racking: Best Solar Panel Mounts In 2021”*, [Online] Available: https://unboundsolar.com/blog/best-solar-panel-mounts. [Accessed: 17/05/2022]

[25] FG Advisory Pty Ltd., "Large Scale Solar Feasibility Study", 2017. [Online] Available: https://www.naga.org.au/large-scale-solar-feasibility-study.html. [Accessed: 18/05/2022]

[26] IRENA, "Renewable Power Generation Costs in 2019", International Renewable Energy Agency, Abu Dhabi, 2020.

[27] "US Dollar to Australian Dollar Spot Exchange Rates for 2019", Exchangerates.org.uk. [Online]. Available: https://www.exchangerates.org.uk/USD-AUD-spot-exchange-rates-history-2019.html. [Accessed: 25- May- 2022].

[28] Rodríguez, L., 2021. Breaking down solar farm costs: Free template inside. [Blog] Rated Power, Available: https://ratedpower.com/blog/solar-farm-costs/ [Accessed 25 May 2022].

[29] Ecoppia, "Ecoppia H4 Datasheet", Ecoppia. [Online]. Available: https://www.ecoppia.com/warehouse/temp/ecoppia/h4_datasheet2.pdf [Accessed 25 May 2022].

[30] "Ecoppia - Solutions", Ecoppia.com. [Online]. Available: https://www.ecoppia.com/solutions. [Accessed: 25- May- 2022].

[31] Australian Bureau of Statistics, "Regional Population: Population Estimates by Local Government Area, 2018 to 2019", Australian Bureau of Statistics, 2020. [Online]. Available: https://www.abs.gov.au/statistics/people/population/regional-population/2018-19#data-download [Accessed 26 May 2022].

[32] "Climate statistics for Australian locations", Bureau of Meteorology, 2022. [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_006011_All.shtml. [Accessed: 26- May- 2022].

[33] "*Green Hydrogen cost reduction: Scaling up electrolysers to meet the 1.5 degree Climate Goal*". [Online]. Available: https://www.ga.gov.au/digital-publication/aecr2021/coal. [Accessed: 17/05/2022].

[34] "*Comparison between hydrogen production by alkaline water electrolysis and hydrogen production by PEM electrolysis*". Yujing Guo. [Online]. Available: https://www.ga.gov.au/digital-publication/aecr2021/coal. [Accessed: 17/05/2022].

[35] "*Manufacturing Cost Analysis for Proton Exchange Membrance Water Electrolyzers*". Ahmad Mayyas, Mark Ruth, Bryan Pivovar, Guido Bender and Keith Wipke. [Online]. Available: https://www.ga.gov.au/digital-publication/aecr2021/coal. [Accessed: 17/05/2022].

[36] "Technical and economic demands of HVDC submarine cable technology for Global Energy Interconnection", KeAi, 2020. [Online] Available: https://www.sciencedirect.com/science/article/pii/S2096511720300463. [Accessed: 08 May 2022].

[37] "*Intelligent Supply Chain - Retail*". [Online] Available: https://d1.awsstatic.com/architecture-diagrams/ArchitectureDiagrams/intelligent-supply-chain-retail-ra.pdf?did=wp_card&trk=wp_card [Accessed on 16/05/2022]

[38] "*Fast NoSQL Key-Value Database - Amazon DynamoDB - Amazon Web Services*" [Online] Available: https://aws.amazon.com/dynamodb/?nc2=type_a [Accessed: 17/05/2022]

[39] "*Shipping Container Delivery, Delivery Trucks and Costs Involved*" [Online] Available: https://containertraders.com.au/shipping-containers-delivery [Accessed: 18/05/2022]

[40] "*How to Calculate Sea Freight Rates with FCL and LCL*" [Online] Available: https://www.mach1global.com/sea-freight-rates-with-fcl-lcl/#:~:text=Base%20rate%20for%20ocean%20freight.&text=40%E2%80%B2%20cntr%20%3D%20%242000-,Weight%20or%20Measure%20(W%2FM)%20Usually%20based%20on%20per,1.000%20M3%20whichever%20the%20greater.&text=40%E2%80%B2%20cntr%20%3D%20%24700-,Weight%20or%20Measure%20(W%2FM)%20Usually%20based%20on%20per,1.000%20M3%20whichever%20the%20greater.&text=Usually%20a%20percentage%20of%20the%20freight%20or%20sometimes%20W%2FM [Accessed: 18/05/2022]

[41] "Submarine Cables and the Oceans: Connecting the World", ISCPC, 2009. [Online] Available: https://www.iscpc.org/publications/. [Accessed: 07 May 2022].

[42] "*About Submarine Power Cables - 2011*", ISCPC, 2011. [Online] Available: https://www.iscpc.org/publications/. [Accessed: 07 May 2022].

[43] Commonwealth of Australia, 2022. Australia's National Hydrogen Strategy. [online] Commonwealth of Australia, p.xiv. Available: https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf [Accessed 16 March 2022].

[44] "*Southern Seawater Desalination Plant*". [Online] Available: https://www.watercorporation.com.au/Our-water/Desalination/Southern-Seawater-Desalination-Plant [Accessed: 16/05/2022].

[45] Geoscience Australia, "Coal", Geoscience Australia, Canberra, 2021. [Online]. Available: https://www.ga.gov.au/digital-publication/aecr2021/coal. [Accessed: 16- Mar- 2022].

[46] D. Evans, "Australia posts record LNG exports in 2021", Energy Voice, 2022. [Online]. Available: https://www.energyvoice.com/oilandgas/377058/australia-posts-record-lng-exports-in-2021/. [Accessed: 16- Mar- 2022].

[47] L. Granwal, "Export volume of liquefied petroleum gas from Australia from financial year 2011 to 2021", Statista, 2022. [Online]. Available: https://www.statista.com/statistics/674848/australia-export-volume-of-lpg/. [Accessed: 16- Mar- 2022].

[48] "LPG (propane) Gas Unit Conversion Values: Gas in Kg, Litres, MJ, kWh & m^3", ELGAS, 2021. [Online]. Available: https://www.elgas.com.au/blog/389-lpg-conversions-kg-litres-mj-kwh-and-m3/. [Accessed: 17- Mar- 2022].

[49] "LNG – Liquefied Natural Gas – Methane", ELGAS, 2021. [Online]. Available: https://www.elgas.com.au/blog/493-what-is-lng-liquefied-natural-gas-methane/. [Accessed: 17- Mar- 2022].

[50] Aziz, M., 2021. Liquid Hydrogen: A Review on Liquefaction, Storage, Transportation, and Safety. Energies, [online] 14(18), p.5917. Available: https://www.mdpi.com/1996-1073/14/18/5917/htm. [Accessed 16 March 2022].

[51] Gordonnat, J. and Hunt, J., 2020. Subsea cable key challenges of an intercontinental power link: case study of Australia–Singapore interconnector. Energy Transitions, [online] 4(2), pp.169-188. Available: https://link.springer.com/content/pdf/10.1007/s41825-020-00032-z.pdf. [Accessed 16 March 2022].

[52] Siemens Energy. n.d. HVDC Classic (LCC) – HVDC | UHVDC, Thyristor. [online] Available: https://www.siemens-energy.com/global/en/offerings/power-transmission/portfolio/high-voltage-direct-current-transmission-solutions/hvdc-classic.html. [Accessed 16 March 2022].

[53] Yamaguchi, M., 2020. High-Efficiency GaAs-Based Solar Cells. Post-Transition Metals, [online] Available: https://www.intechopen.com/chapters/73981. [Accessed 16 March 2022].

[54] Bureau of Meteorology, n.d. Average daily solar exposure. [online] Bureau of Meteorology. Available: http://www.bom.gov.au/jsp/ncc/climate_averages/solar-exposure/index.jsp [Accessed 16 March 2022].

[55] "*The Best Tablet Prices in Australia*" [Online] Available: https://www.getprice.com.au/tablet.htm?gclid=CjwKCAjw7IeUBhBbEiwADhiEMScRYbktHiOU_35sK6N0T7avMFxp3vG2BbCXa0lZdoi737Wci0wsMxoCf-oQAvD_BwE [Accessed: 17/05/2022]

[56] "*Wireless 1D Laser Bluetooth Barcode Scanner IS-5700LB (Yellow)*" [Online] Available: https://www.inkstation.com.au/wireless-1d-laser-bluetooth-barcode-scanner-is5700lb-yellow-p-18417.html?17045&gclid=Cj0KCQjwyYKUBhDJARIsAMj9lkH2W47dQQoc4cwEbr6vDGwkwWAdCXzMPv48hnY5OJgLZCxkxCptFyMaApTeEALw_wcB [Accessed: 16/05/2022].

[57] "*Motorola Handheld Barcode Scanner Kit LS2208"* [Online] Available: https://www.officeworks.com.au/shop/officeworks/p/motorola-handheld-barcode-scanner-kit-ls2208-mols2208?istCompanyId=0403b0ba-0671-498f-aeb7-e2ff71b61924&istFeedId=00ff5695-1f12-4ff3-82f4-49dd39a43a69&istItemId=wliatqmta&istBid=t&cm_mmc=Google:SEM:Always_on:RP%7CTechnology%7CMobile+Phones%7C%7CMotorola%E2%80%8B%7C%7C%7CSH%7C%7CSupplier&s_kwcid=AL!12073!3!540169777184!!!g!1448288465487!s_kwcid=AL!12073!3!540169777184!!!g!1448288465487!&gclid=Cj0KCQjwyYKUBhDJARIsAMj9lkHsPHU81g36YWQD6Wxxca8bKPwbZcEy28goao62lXi9tG5w3GRWRKMaAhA3EALw_wcB&gclsrc=aw.ds [Accessed: 17/05/2022].

[58] "*AWS Pricing Calculator"* [Online] Available: https://calculator.aws/#/estimate?id=78ad6baeca29c0bddcc91488c21718ee3adeeaeb [Accessed: 17/05/2022].

[59] "*Desktop Deals"* [Online] Available: https://www.dell.com/en-au/work/shop/deals/performance-desktop-deals/intel-core-i5?sortBy=price-ascending&appliedRefinements=402,201,101 [Accessed: 17/05/2022].

[60] "*Computer Monitors on Sale"* [Online] Available: https://deals.dell.com/en-au/work/category/monitor-deals?sortBy=price-ascending [Accessed: 17/05/2022].

[61] "*Create a DynamoDB table"* [Online] Available: https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/GettingStarted.CreateTable.html [Accessed: 18/05/2022].

[62] "*Write an item to a DynamoDB table"* [Online] Available: https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/GettingStarted.WriteItem.html [Accessed: 18/05/2022].

[63] "*Read an item from a DynamoDB table"* [Online] Available: https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/GettingStarted.ReadItem.html [Accessed: 18/05/2022].

[64] "*Update an item in a DynamoDB table"* [Online] Available: https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/GettingStarted.UpdateItem.html [Accessed: 18/05/2022].

[65] "*Delete an item in a DynamoDB table"* [Online] Available: https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/GettingStarted.DeleteItem.html [Accessed: 18/05/2022].

Appendices

Appendix A: Calculations

A.1. Annual Fossil Fuel Export Calculations

Annual Australian exports of coal and coal products is given as E_{Coal} = 11,131 petajoules [45]. This is equivalent to 11.13 exajoules.

$$E_{Coal} = 11,131\ petajoules = 1.113 * 10^{19}\ J = 11.13\ exajoules \tag{1}$$

LNG exports are around 80.9 million tonnes [46].
The energy content of LNG is between 21 and 24 megajoules/litre, while the density can range between 0.41-0.5 kg/litre [9]. Taking the average of these values, the energy content is 22.5 megajoules/litre, and the density is 0.455 kg/litre. These values can be combined to find an energy density conversion factor for LNG of EC_{LNG} = 4.945E+10 joules/tonne.

$$EC_{LNG} = \frac{22.5*10^{6}\ J/litre}{0.455*10^{-3} tonnes/litre} = 4.945 * 10^{10}\ J/tonne \tag{2}$$

Multiplying the LNG export value by the energy density shows the energy equivalent of LNG exports is E_{LNG} = 4.001 exajoules of energy:

$$E_{LNG} = 4.945 * 10^{10}\ J/tonne * 80.9 * 10^{6}\ tonnes = 4.001 * 10^{18}\ J = 4.001\ exajoules \tag{3}$$

LPG exports are about 5233.7 million litres [47].

The energy content of LPG is about 25 megajoules/litre [48]. Multiplying the LPG export figure with this conversion yields a value of 0.1308 exajoules of energy.

$$E_{LPG} = 25 * 10^{6}\ J/litre * 5233.7 * 10^{6}\ litres = 0.1308 * 10^{18}\ J = 0.1308\ exajoules \tag{4}$$

Finally, summing all the above fossil fuel exports together gives the total annual energy exports as E_{total} = 15.26 exajoules.

$$E_{total} = E_{Coal} + E_{LNG} + E_{LPG} = (11.13 + 4.001 + 0.1308)\ exajoules = 15.26\ exajoules \tag{5}$$

A.2. Green Hydrogen Calculations

The energy content of hydrogen was taken as 120 MJ/kg [43, p. xiv]. Based on this value and the required annual exports of energy of 15.26 exajoules, the annual export of green hydrogen, E_{H_2}, must be 1.272E+08 tonnes.

$$E_{H_2} = \frac{15.26*10^{18}\ J}{120*10^{6}*1000\ J/tonne} = 1.272 * 10^{8}\ tonnes \tag{6}$$

Dividing the annual export of hydrogen by 365 gives the daily production rate of hydrogen as P_{H_2} = 348,456 tonnes/day.

$$P_{H_2} = \frac{1.272*10^8\ tonnes}{365\ days} = 348,456\ tonnes/day \tag{7}$$

PEM electrolysis requires 9 litres of water to produce 1 kg of hydrogen [43, p. xiv]. Based on this value and the above value for annual hydrogen exports, the electrolysis plant needs to be supplied with 1.145E+12 litres of water annually.

$$E_{H_2O} = 1.272 * 10^8\ tonnes * 9000\ litres/tonne = 1.145 * 10^{12}\ litres \tag{8}$$

Dividing by 365 gives a supply rate of 3.136E+09 litres of water per day.

$$P_{H_2O} = \frac{1.145*10^{12}\ litres}{365\ days} = 3.136 * 10^9\ litres/day \tag{9}$$

In addition, PEM electrolysis requires a supply of electricity. The efficiency of electrolysis was taken as requiring 54 kWh of electricity to create 1 kg of hydrogen [43, pp. 14, 79]. Based on the mass of hydrogen produced each year, the electrolysers require an annual supply of E_{PEM} = 24.73 exajoules of energy.

$$E_{PEM} = 54\ kWh/kg * 1.272 * 10^8 * 1000\ kg * 3.6 * 10^6\ J/kWh = 24.73\ exajoules \tag{10}$$

Currently, liquefaction consumes 10 kWh of electricity to liquefy 1 kg of hydrogen [50, p. 15]. Based on the annual export of hydrogen found above, this will require 4.579 exajoules of energy to be supplied over a whole year.

$$E_{Liq} = 10\ kWh/kg * 1.272 * 10^8 * 1000\ kg * 3.6 * 10^6\ J/kWh = 4.579\ exajoules \tag{11}$$

Combined, the annual electrical cost of electrolysis and liquefaction is $E_{supplied}$ = 29.30 exajoules.

$$E_{supplied} = E_{PEM} + E_{Liq} = 24.73 + 4.579 = 29.30\ exajoules \tag{12}$$

A.3. Electrical Loss Calculations

The power losses of a HVDC submarine cable operating at ± 525 kV is about 3% per 1000 km [51, p. 173]. Assuming the electrolysis plant will be located 2 km offshore, the actual power loss is then η_{HVDC} = 0.006%.

$$\eta_{HVDC} = 3\% / 1000\ km * \frac{2\ km}{1000\ km} = 0.006\% / 2\ km \tag{13}$$

Given 29.30 exajoules of energy needs to be supplied to the electrolysis plant and for liquefaction, E_{HVDC} = 1.758E+15 joules of energy will be lost due to the submarine cables.

$$E_{HVDC} = \frac{29.30\ exajoules}{1-(0.006\%)} - 29.30\ exajoules = 1.758 * 10^{15}\ J \tag{14}$$

Additionally, converter losses will occur each time the voltage is stepped, once at each end of the cables. The losses will be about 0.7% for each converter station [52].

Similarly to the submarine cable losses, based on the energy supply requirements, an additional 4.161E+17 joules will be wasted in converter losses.

$$E_{Stepping} = \frac{29.30\ exajoules}{1-(2*0.7\%)} - 29.30\ exajoules = 4.161 * 10^{17}\ J \quad (15)$$

A.4. Solar Power Calculations

According to Figure B.1 in the following Appendix, the northern and western areas of Australia can expect to receive 21-24 MJ/m^2 of solar energy per day. For the purpose of designing the solar farm, an average value of 22.5 MJ/m^2 was selected.

The efficiency of the Jinko Tiger Pro 78TR Monofacial PV module is 21.4% [22].

Based on the electricity requirements above in A.2 and A.3, which account for losses in the submarine cables, the total energy required to be output by the Solar Photovoltaic Power System each year is 29.72 exajoules.

$$E_{Output} = E_{supplied} + E_{HVDC} + E_{Stepping} = (29.30 * 10^{18} + 1.758 * 10^{15} + 4.161 * 10^{17})\ J = 29.72\ exajoules \quad (16)$$

Using a PV efficiency of 21.4%, a daily solar exposure of 22.5 MJ/m^2, and the required energy output above, the solar farm will need to cover an area of A_{solar} = 16,919 km^2.

$$A_{solar} = \frac{29.72*10^{18}\ J}{21.4\%*22.5*10^{6}\ J/m^{2} * 365} = 1.6919 * 10^{9} m^{2} = 16919\ km^{2} \quad (17)$$

Appendix B: Figures

B.1. Australian daily solar exposure map, averaged over a whole year.

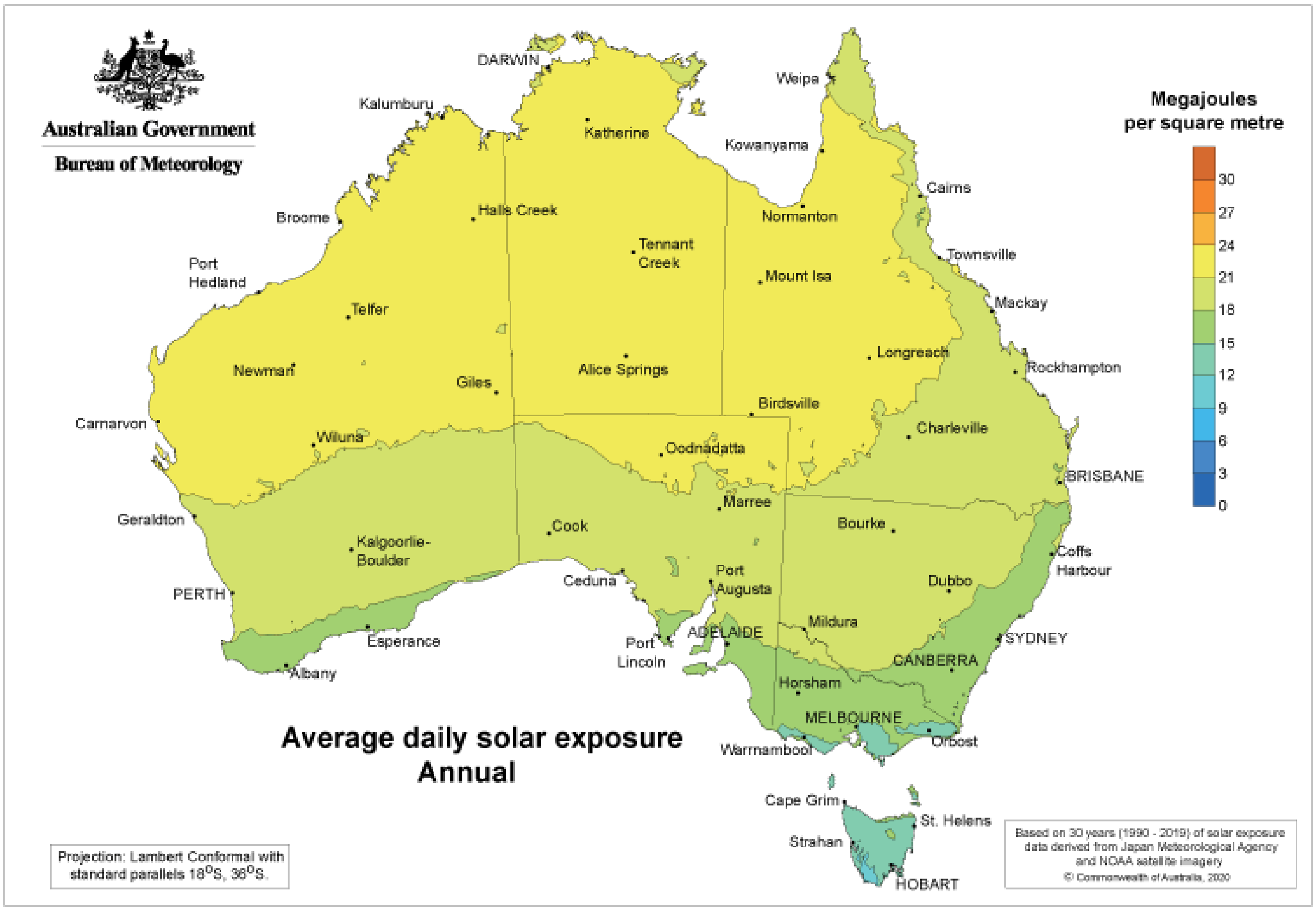
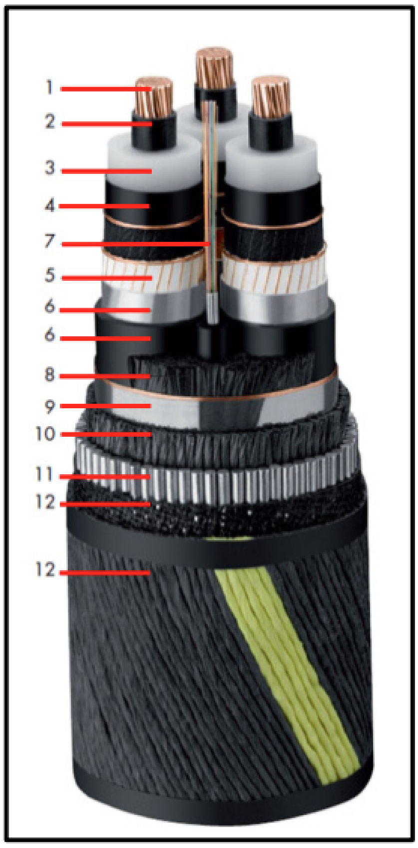


Figure B.1: Australian daily solar exposure map, averaged over a whole year [47]

B.2. Components of a typical HVDC submarine power cable



1. Conductor – usually copper
2. Conductor screening – usually extruded
3. Insulation – XLPE or EPR
4. Insulation screening – semi-conductive
5. Screen
6. Laminated sheath – aluminum tape and polyethylene
7. Optical fibres – optionally used for telecommunications
8. Fillers – as needed
9. Binder tapes
10. Armour Bedding – polypropylene strings
11. Armour – galvanized round steel wires
12. Serving – bituminous compound, hessian tape with polypropylene coloured stripe

Construction varies with manufacturer and seabed conditions, with more armour added where, for example, waves and currents are strong

Figure B.2: Components of a typical HVDC submarine power cable [41]

Appendix C: Costs

C.1. Cost for Tablet

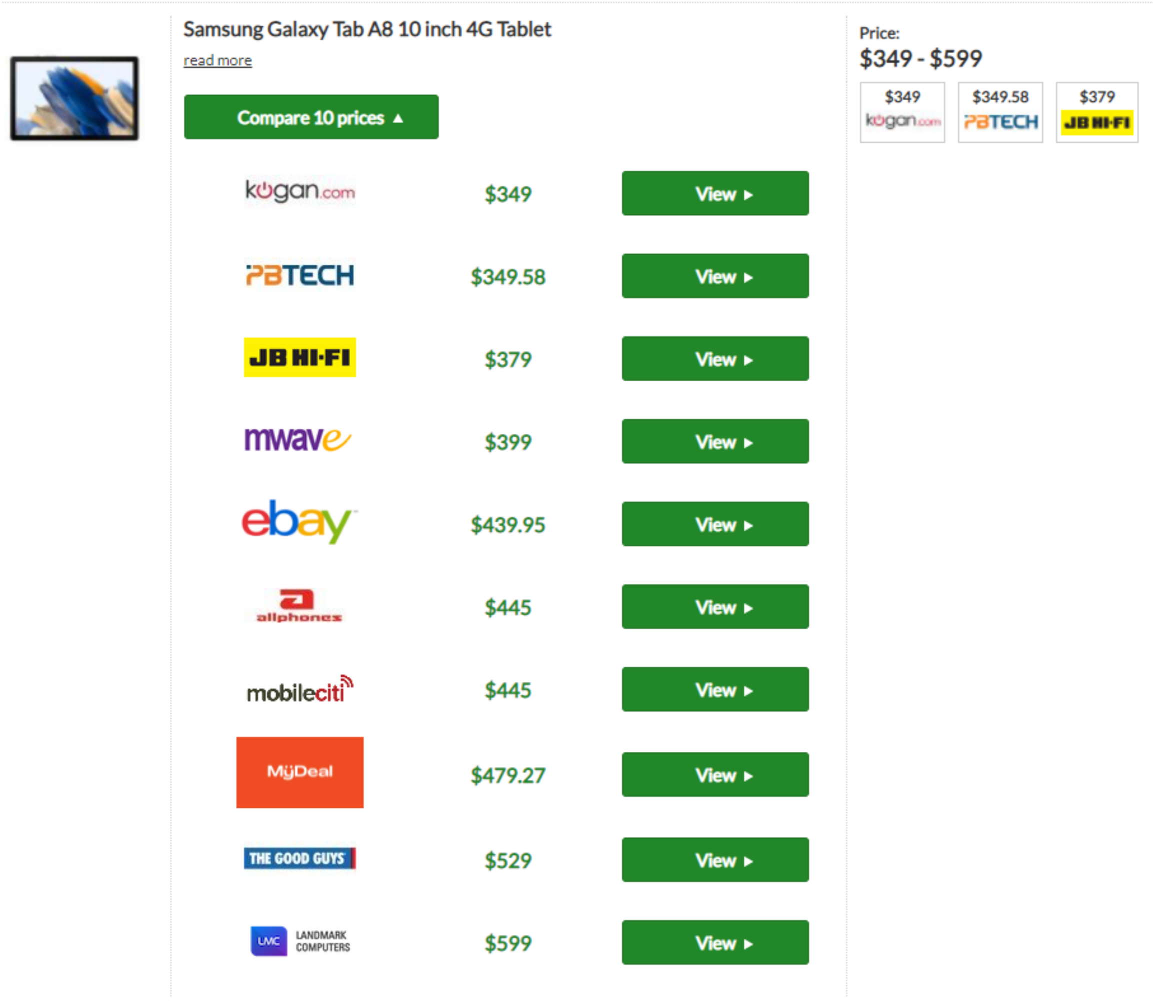


Figure C.1: Price comparisons for Samsung Galaxy Tab A8 10 inch 4G Tablet [55]

C.2. Cost for Barcode Scanner

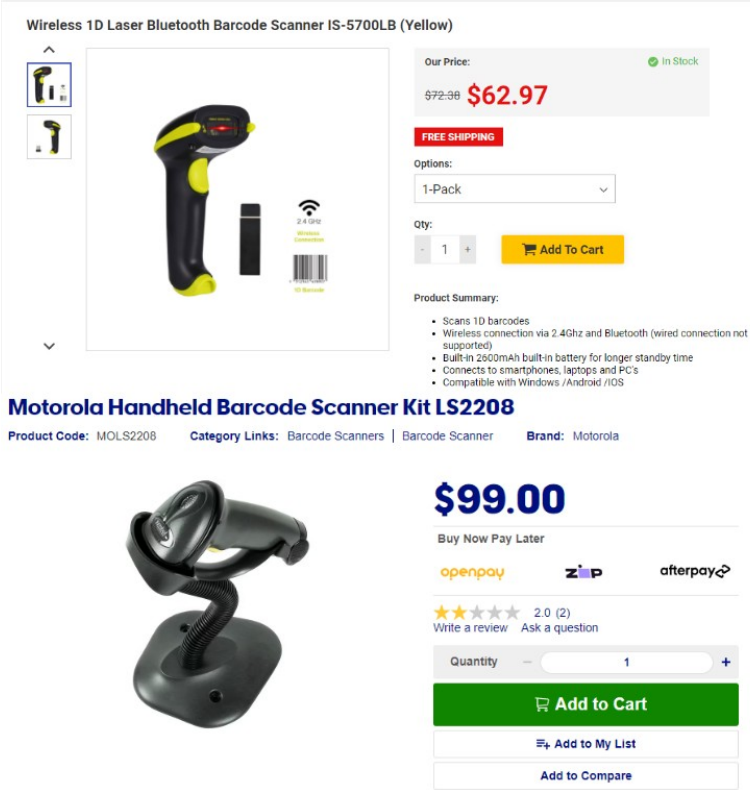


Figure C.2: Price comparisons for two different barcode scanners [56] [57]

C.3. Cost for AWS Setup

AWS Pricing Calculator > My Estimate

My Estimate Edit

Estimate summary Info

Upfront cost
376.20 USD

Monthly cost
1,657.61 USD

Total 12 months cost
20,267.52 USD
Includes upfront cost

Service Name	Upfront cost	Monthly cost
AWS IoT Events	0.00 USD	8.26 USD
AWS Lambda	0.00 USD	6.11 USD
Amazon DynamoDB	376.20 USD	1,386.92 USD
Amazon EC2	0.00 USD	229.02 USD
Amazon Pinpoint	0.00 USD	1.54 USD
Amazon Simple Storage Service (S3)	0.00 USD	25.76 USD

Figure C.3: Cost Estimate using the AWS Pricing Calculator based on a Database storage size of 1 TB [58]

C.4. Cost for two desktops, showing the cheapest and most expensive based on i5, 8 GB memory and 256 GB SSD

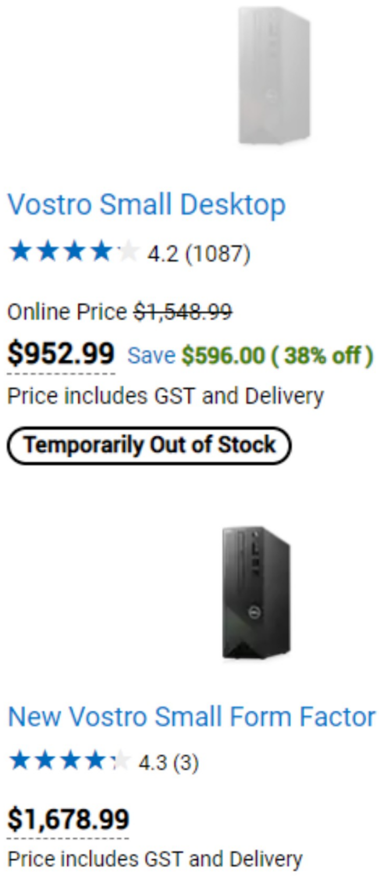


Figure C.4: Cost for two example desktops: i5, 8 GB memory and 256 SSD [59]

C.5. Cost for Monitor

Figure C.5: Cost for computer monitor [60]

Appendix D: Code For Basic CRUD Operations using DynamoDB

D.1. Code example for creating the service client module for DynamoDB (JavaScript)

```
// Create service client module using ES6 syntax.
import { DynamoDBClient } from "@aws-sdk/client-dynamodb";
// Set the AWS Region.
const REGION = "REGION"; //e.g. "us-east-1"
// Create an Amazon DynamoDB service client object.
const ddbClient = new DynamoDBClient({ region: REGION });
export { ddbClient };
```

[61]

D.2. Code example for creating a table in DynamoDB (JavaScript)

```
// Import required AWS SDK clients and commands for Node.js
import { CreateTableCommand } from "@aws-sdk/client-dynamodb";
import { ddbClient } from "./libs/ddbClient.js";

// Set the parameters
export const params = {
  AttributeDefinitions: [
    {
      AttributeName: "Season", //ATTRIBUTE_NAME_1
      AttributeType: "N", //ATTRIBUTE_TYPE
    },
    {
      AttributeName: "Episode", //ATTRIBUTE_NAME_2
      AttributeType: "N", //ATTRIBUTE_TYPE
    },
  ],
  KeySchema: [
    {
      AttributeName: "Season", //ATTRIBUTE_NAME_1
      KeyType: "HASH",
    },
    {
      AttributeName: "Episode", //ATTRIBUTE_NAME_2
      KeyType: "RANGE",
    },
  ],
  ProvisionedThroughput: {
    ReadCapacityUnits: 1,
    WriteCapacityUnits: 1,
  },
  TableName: "TEST_TABLE", //TABLE_NAME
  StreamSpecification: {
```

```
    StreamEnabled: false,
  },
};

export const run = async () => {
  try {
    const data = await ddbClient.send(new CreateTableCommand(params));
    console.log("Table Created", data);
    return data;
  } catch (err) {
    console.log("Error", err);
  }
};
run();
```

[60]

D.3. Code to create the document client in DynamoDB (JavaScript)

```
// Create a service client module using ES6 syntax.
import { DynamoDBDocumentClient } from "@aws-sdk/lib-dynamodb";
import { ddbClient } from "./ddbClient.js";
// Set the AWS Region.
const REGION = "REGION"; // For example, "us-east-1".

const marshallOptions = {
  // Whether to automatically convert empty strings, blobs, and sets to `null`.
  convertEmptyValues: false, // false, by default.
  // Whether to remove undefined values while marshalling.
  removeUndefinedValues: false, // false, by default.
  // Whether to convert typeof object to map attribute.
  convertClassInstanceToMap: false, // false, by default.
};

const unmarshallOptions = {
  // Whether to return numbers as a string instead of converting them to native
JavaScript numbers.
  wrapNumbers: false, // false, by default.
};

const translateConfig = { marshallOptions, unmarshallOptions };

// Create the DynamoDB document client.
const ddbDocClient = DynamoDBDocumentClient.from(ddbClient, translateConfig);

export { ddbDocClient };
```

[62]

D.4. Code to put an item in a table in DynamoDB (JavaScript)

```
import { PutCommand } from "@aws-sdk/lib-dynamodb";
import { ddbDocClient } from "../libs/ddbDocClient.js";

export const putItem = async () => {
  // Set the parameters.
  export const params = {
    TableName: "TABLE_NAME",
    Item: {
      primaryKey: "VALUE_1",
      sortKey: "VALUE_2",
    },
  };
  try {
    const data = await ddbDocClient.send(new PutCommand(params));
    console.log("Success - item added or updated", data);
  } catch (err) {
    console.log("Error", err.stack);
  }
};
putItem();
```

[61]

D.5. Code to get an item from a table in DynamoDB (JavaScript)

```
import { GetCommand } from "@aws-sdk/lib-dynamodb";
import { ddbDocClient } from "../libs/ddbDocClient.js";

// Set the parameters.
export const params = {
  TableName: "TABLE_NAME",
  Key: {
    primaryKey: "VALUE_1",
    sortKey: "VALUE_2",
  },
};

export const getItem = async () => {
  try {
    const data = await ddbDocClient.send(new GetCommand(params));
    console.log("Success :", data.Item);
  } catch (err) {
    console.log("Error", err);
  }
};
getItem();
```

[63]

D.6. Code to update an item in a table in DynamoDB (JavaScript)

```
import { UpdateCommand } from "@aws-sdk/lib-dynamodb";
import { ddbDocClient } from "../libs/ddbDocClient.js";

export const updateItem = async () => {
  // Set the parameters.
  const params = {
    TableName: "TABLE_NAME",
    Key: {
      title: "MOVIE_NAME",
      year: "MOVIE_YEAR",
    },
    ProjectionExpression: "#r",
    ExpressionAttributeNames: { "#r": "rank" },
    UpdateExpression: "set info.plot = :p, info.#r = :r",
    ExpressionAttributeValues: {
      ":p": "MOVIE_PLOT",
      ":r": "MOVIE_RANK",
    },
  };
  try {
    const data = await ddbDocClient.send(new UpdateCommand(params));
    console.log("Success - item added or updated", data);
    return data;
  } catch (err) {
    console.log("Error", err);
  }
};
updateItem();
```

[64]

D.7. Code to delete an item in a table in DynamoDB (JavaScript)

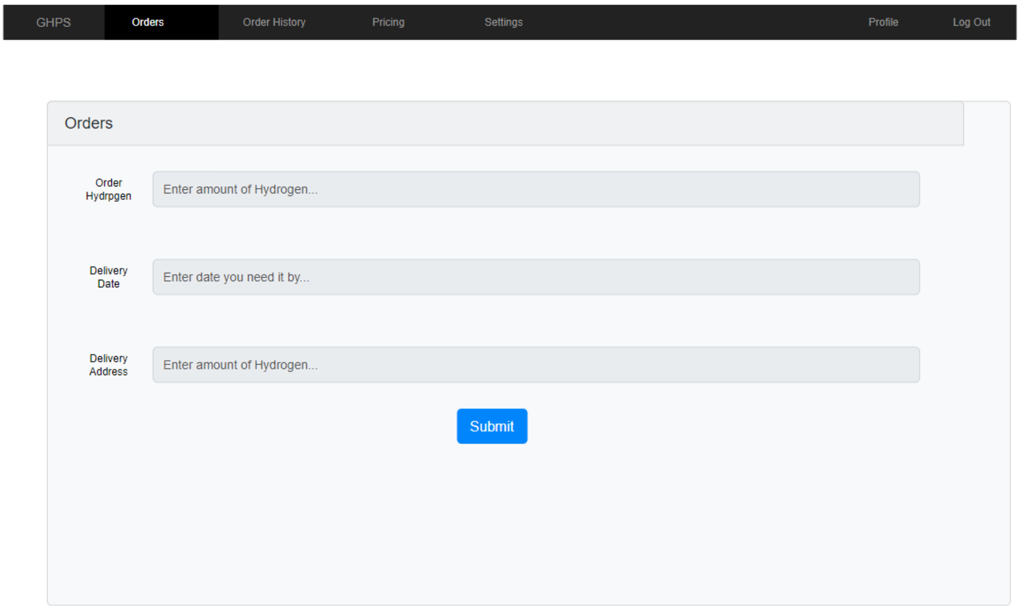
```
import { DeleteCommand } from "@aws-sdk/lib-dynamodb";
import { ddbDocClient } from "../libs/ddbDocClient.js";

// Set the parameters.
export const params = {
  TableName: "TABLE_NAME",
  Key: {
    primaryKey: "VALUE_1",
    sortKey: "VALUE_2",
  },
};
```

```
export const deleteItem = async () => {
  try {
    const data = await ddbDocClient.send(new DeleteCommand(params));
    console.log("Success - item deleted");
  } catch (err) {
    console.log("Error", err);
  }
};
deleteItem();
```

[65]

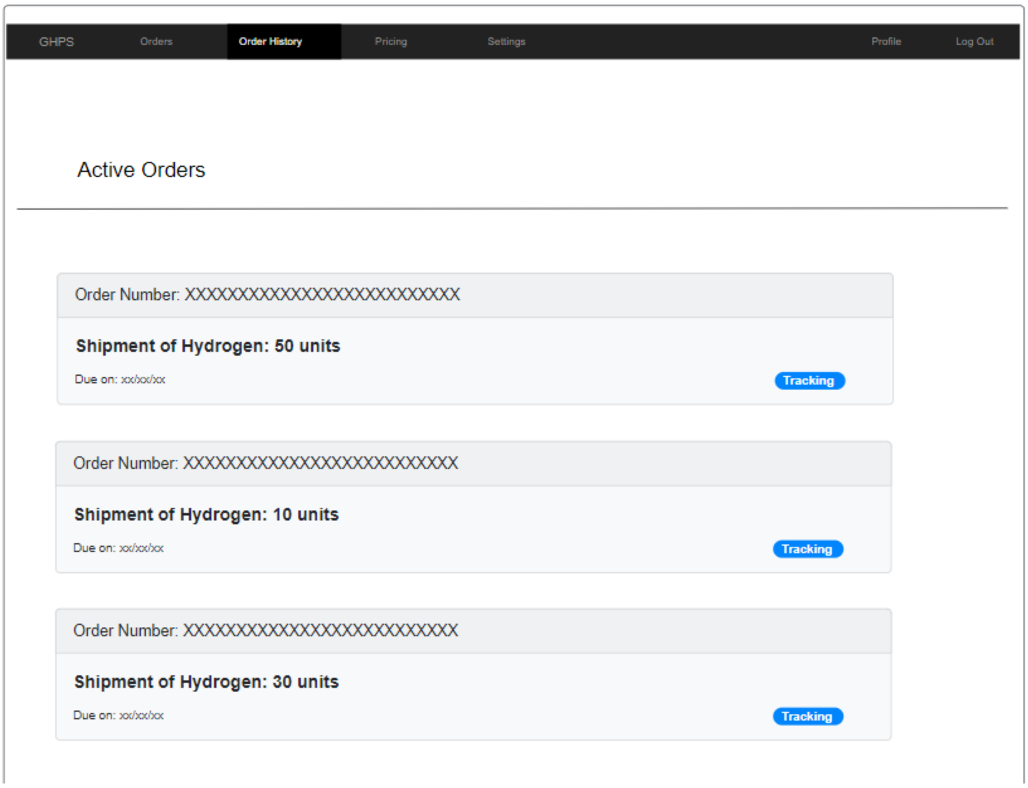
Appendix E: Example of Customer Section User Interface for TOMS

E.1 Example of Orders Page for Customers



E.1: Exemplar order page for customer

E.2 Example of Order History Page for Customers



E.2: Exemplar order history for customers