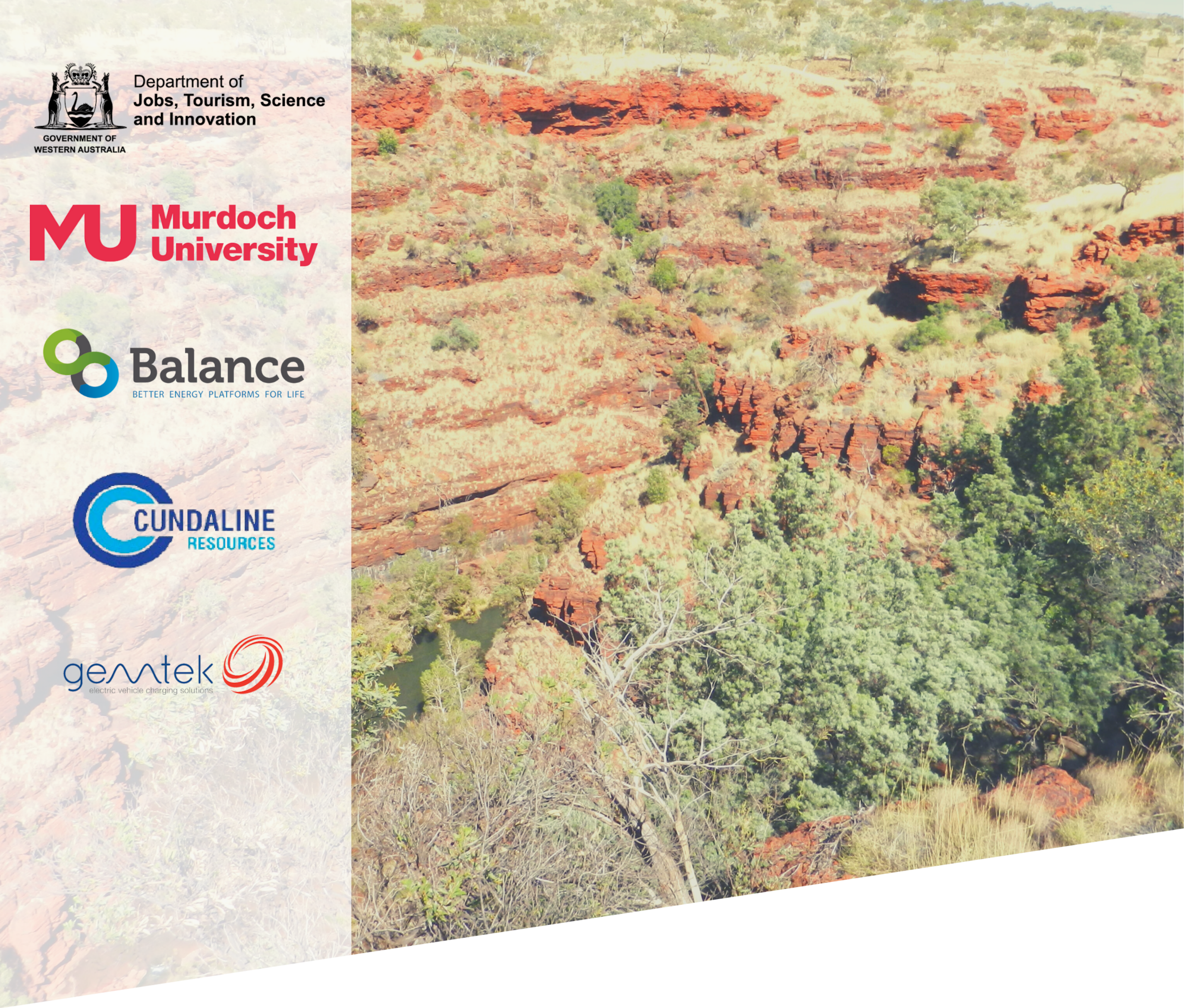

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HYBRID SOLAR PV-BATTERY-HYDROGEN SYSTEM FOR 100% RENEWABLE ENERGY STANDALONE MICROGRID DEVELOPMENT

KNOWLEDGE SHARING REPORT

JUNE 2023

Acknowledgement of CONTRIBUTION

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DISCLAIMER

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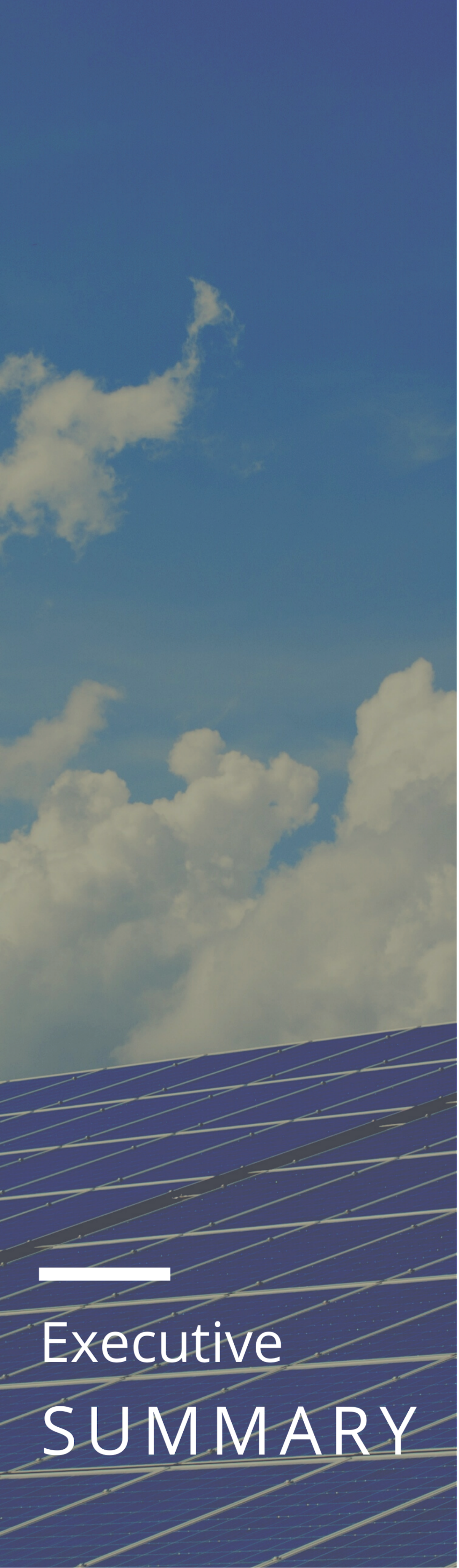

Executive SUMMARY

MURDOCH UNIVERSITY RECOMMENDS WITH A LOWER UP FRONT CAPITAL INVESTMENT 100% RENEWABLE ENERGY (RE)-BASED STAND-ALONE MICROGRIDS (SAM) WITH HYBRID BATTERY-HYDROGEN-BASED STORAGE SYSTEMS RENDER OPPORTUNITIES FOR THE COMMUNITIES TO BUILD A SMALLER SCALE PLANT, AND LEVERAGE POTENTIAL FUTURE COST REDUCTIONS OF HYDROGEN TECHNOLOGIES.

Murdoch University has undertaken a feasibility study to investigate the viability of a 100% renewable energy (RE)-based stand-alone microgrid (SAM) with a hybrid battery-hydrogen-based storage system for remote communities in the Pilbara region, considering social, economic and environmental benefits. The study aims to support an investment decision for pilot project implementation in the Pilbara. Murdoch University has partnered with indigenous mining logistics company Cundaline Resources as well as leading electrical contracting companies Balance Services Group and Gemtek Automation to deliver the study.

The study successfully developed the optimised technical designs and financial analyses from the modelling for the SAMs for the Jinparinya and Warralong Communities in the Pilbara. These serve as representative sites for other similar communities in Western Australia.

The first site was the small-scale grid connected Jinparinya Community, which is proposed to undergo significant expansion in electricity demand and become a hydrogen refuelling station in the future. It was modelled as a 100% RE SAM power system for its current load to become a pilot zero-emission project and provide the basis for a larger system in the future to avoid the cost of expansion of their grid-connection and remain zero net emissions. The second site was Warralong, a Remote Essential Municipal Services (REMS) community, where a medium-scale diesel-powered transition to a 100% RE SAM power system has been modelled as a pilot project also utilising a hybrid battery-hydrogen storage system.

Several scenarios were considered in the modelling at each site. Simulation analyses revealed that a larger capacity hydrogen system can add more energy autonomy but at a price. The battery bank follows the load fluctuations while the hydrogen fuel cell generator covers the baseload. The option of using one of the existing diesel generators at Warralong community for backup and autonomy was techno-economically evaluated. This model's simulation revealed a longer period of more autonomy and less cost of energy at a penalty of 98.5% instead of a 100% RE penetration.

The highly modular and expandable design supports a staged expansion of the facilities - which Murdoch University recommends taking to allow a lower up-front capital investment, an opportunity for the communities to build capability with a smaller scale plant, and the ability to leverage potential future cost reductions of hydrogen technologies.

The works performed during this study include framing and optimised systems studies for the two communities including a techno-economic analysis, business case development and risk assessment for the use of hybrid solar PV-battery-hydrogen storage system to quickly reduce fossil fuel-based generation in regional and remote WA Aboriginal homeland communities as part of the State's commitment to ramping up renewable (green) hydrogen in WA fulfills 2040 goals. There are 117 homeland communities on old technology polluting diesel power stations, which are maintained by the REMS program, Horizon Power, and the three regional service providers. The business cases were developed for the two previously modelled homeland communities, Jinparinya and Warralong Aboriginal Communities, as representative sites for the larger group of communities.

The modelling engineering work performed during this study confirms that there are no technical barriers to developing projects of this nature in Australia, and the study presents Hybrid Solar PV-Battery-Hydrogen System solutions for the two communities. These are representative of the range of grid connected and stand-alone REMS community sites in Western Australia.

The optimum scenario for each site is given below:

Jinparinya	Warralong
84kW solar	966kW solar
80KWh battery	480kWh battery
12kW electrolyser	200kW electrolyser
25kg Hydrogen storage	200kg Hydrogen storage
7kW fuel cell	60kW fuel cell
Total plant capital cost $437,105	Total plant capital cost $3,216,000
	Utilising one of the existing diesel gensets of 110kW

The payback period for Jinparinya depends on the actual costs of energy before subsidy for the Northwest Integrated System (NWIS), which was not available during this feasibility study. A comparison of a Jinparinya-like system (load size and profile) connected to a diesel mini-grid (such as Sandstone in the Midwest), with a cost of electricity generation of $2/kWh showed a simple payback of 6.75 years (discounted payback period of 8.1 years).

Warralong has a simple payback of 5.4 years (discounted payback period of 6.6 years). Compared to a 100% RE system, the cost reduction is 8.4% (COE from $0.902 to $0.827) if a diesel genset is used with RE at Warralong. These optimised modelled systems were then reality checked against the use of off-the-shelf commercial systems in which it was found that the modelled system is cost-effective than the available commercial systems.

A sensitivity analysis of key cost assumptions was undertaken to determine the range of costs that could occur and the effect of evolving (usually down) costs of key systems components, such as the solar system, the electrolyser system and the fuel cell, as well as site and installation costs and maintenance costs. The study has proven the business case for the feasibility of using Hybrid Solar PV-Battery-Hydrogen Systems to provide the lowest energy cost, over 24 hours of autonomy and reduced carbon footprint to the communities.

FINALLY, THE MODELLING AND BUSINESS CASE SUGGESTS THAT A HYBRID SOLAR PV-BATTERY-HYDROGEN SYSTEM WOULD NEED TO PLAY A MAJOR ROLE IN THIS, AND THEY ARE CURRENTLY AND WILL INCREASINGLY BE THE LOWEST COST OF THE ENERGY SOLUTIONS.

GLOSSARY

Term/Abbreviation	Definition
AC	Alternating Current
AS	Australian Standard
ASME	American Society of Mechanical Engineers
AUD	Australian Dollars
°C	Degree Celsius
CAPEX	Capital Expenditure
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
DC	Direct Current
DI	Deionisation
DWER	Department of Water and Environmental Regulation DI Deionisation
EP	Environmental Protection
ft	Feet
GST	Goods and Services Tax
H2	Hydrogen
HAZOP	Hazard and Operability Study
HMI	Human-Machine Interface
hr	Hours
ISO	International Standards Organisation

GLOSSARY

Term/Abbreviation	Definition
kg	Kilogram (mass
kJ	Kilojoule = 10 3 Joules
km	Kilometre = 10 3 metres
kW	Kilowatt = 10 3 Watts
kWh	Kilowatt per hour
L	Litres
m/s	Metres per second
m	Metres
m3	Cubic metres
MJ	Megajoule = 10 6 Joules
MPPT	Maximum Power Point Tracking
MVA	Mega Volt Amperes
MW	Megawatts = 10 6 Watts
NIOSH	National Institute for Occupational Safety and Health
NFPA	National Fire Protection Association
Nm3	Normal meter cubed
NWIS	Northwest Integrated System
O&M	Operating & Maintenance
OEM	Original Equipment Manufacturer

GLOSSARY

Term/Abbreviation	Definition
OPEX	Operational Expendicture
P2H2P	Power to Hydrogen to Power
P2H2X	Power to Hydrogen to X
PEM	Polymer Electrolyte Membrane
PLC	Programmable Logic Controller
ppm	Parts per Million
PV	Photovoltaic
REL	Recommended Exposure Limit
REMS	Remote Essential Municipal Services (WA Government funded)
RE-RHFC	Renewable Energy - Regenerative Hydrogen Fuel Cell
RES	Renewable Energy Source
RHFC	Regenerative Hydrogen Fuel Cell
SAM	Stand alone microgrid
SCADA	Supervisory Control andData Acquisition
SMEs	Small and Medium sized Enterprises
t	Metric tonne = 10 3kg
tpa	Tonnes per annum
W	Watt (electric power)
yr	year

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1

INTRODUCTION

A GREEN RENEWABLE HYDROGEN INDUSTRY IS CURRENTLY EMERGING IN AUSTRALIA AND AROUND THE WORLD WHICH HOPES TO PROVIDE A LOW CARBON FUEL REPLACEMENT FOR MANY APPLICATIONS, INCLUDING IN THE MINING, POWER, AND TRANSPORT SECTORS.

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

Australia has the potential to become a world leader in the emerging green hydrogen market which is currently being encouraged by the Western Australian and Australian governments. The Western Australian Renewable Hydrogen Strategy [1] and Roadmap [2], launched in 2019 and 2020 respectively, aim to “drive WA's position as a major producer and exporter of renewable hydrogen, and detail the WA Government’s commitment to support and facilitate industry efforts to develop a renewable hydrogen industry in WA." [3]

Decentralised, distributed power generation systems have been identified as a possible solution for the major increase in intermittent renewable energy sources (RES) based power production. It is required in the electricity supply system to meet the ambitious targets at the national [4] and state [5] levels to reduce the greenhouse gas intensity of the grid by 80% by 2030 and to achieve Net Zero emissions by 2050.

Renewable energy microgrids are a solution which create the possibility of developing smaller and flexible power grids that can operate either in complete autonomy, or even remain connected to larger central power grids, and exchange power as needed [5].

According to Arsalis and co-authors [5]:

- Microgrids also offer higher efficiency, better utilization of resources, and operate with minimum carbon emissions.
- In addition, they offer the possibility of connecting and combining multiple loads, such as different types of buildings (residential, commercial, public, and industrial), and electric vehicles.
- As well as the benefits for the grid they can also provide higher flexibility and reduce carbon emissions in comparison to conventional fossil fuel powered (usually diesel) systems for remote applications.

Due to the intermittent nature of the RES, it is difficult to generate electricity and utilise continuously and stably, which creates spatial and temporal gaps between the available power and the power consumed by the end-users. To help resolve this issue, the integration of energy storage with RES-based power generators can greatly improve the utilization rate and stability of these systems.

One proposal is to use green hydrogen to store excess renewable energy in standalone microgrids (SAM) with the merits of longer storage periods and ease of capacity expansion compared to other storage technologies such as batteries.

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[1] Government of Western Australia (2020) “Western Australian Renewable Hydrogen Roadmap” Available from https://www.wa.gov.au/system/files/2020- 12/Western%20Australian%20Renewable%20Hydrogen%20Roadmap%20-%20November%202020.pdf.

[2] Government of Western Australia (2021) “Western Australian Renewable Hydrogen Strategy”. Available from https://www.wa.gov.au/system/files/2021-01/WA_Renewable_Hydrogen_Strategy_2021_Update.pdf

[3] Australian Labour Party (2021) “Powering Australia Labours plan to create jobs, cut power bills and reduce emissions by bosoting renewable energy”. Available from https://keystone-alp.s3-ap-southeast- 2.amazonaws.com/prod/61a9693a3f3c53001f975017-PoweringAustralia.pdf.

[4] Government of Western Australia (2022) “Ambitious interim target set for State Government emissions”. Media statement on Thursday, 23 June 2022. Available from https://www.mediastatements.wa.gov.au/Pages/McGowan/2022/06/Ambitious-interim-target-set-for-State- Government-emissions.aspx.

[5] Alexandros Arsalis, George E. Georghiou and Panos Papanastasiou (2022) “Progress in Hybrid Photovoltaic - Regenerative Hydrogen Fuel Cell Microgrid Systems”, Energies, Vol 15, pp 3512.

This so-called Power to Hydrogen to Power (P2H2P) is a promising option for storing and then regenerating the power when needed [6]. Hybrid renewable energy - regenerative hydrogen fuel cell (RE-RHFC) microgrid systems (especially using photovoltaics) are considered to have a high future potential in the effort to increase the renewable energy share in the electricity supply system, with hydrogen generation, storage, and reutilisation [5]. These systems also have the additional benefit of being used as power to hydrogen to X (P2H2X) systems, where X means different applications depending on the hydrogen utilising path or end use (for example direct heating, fuel cell vehicles) [7].

In their recent review Arsalis and colleagues [5] have proposed that hybrid PV-RHFC microgrid systems have some important advantages over conventional battery only storage systems:

- The RHFC subsystem offers medium and long-term storage (in addition to instant short-term storage offered by the batteries) helping overcome the concern that in general, batteries alone are not appropriate to overcome extended periods of windless, sunless 'dark doldrums' that persist in many locations over the course of a year.
- The added power availability and self-consumption also additionally allows less congestion of central power grids, since power generation in centralized power stations can be reduced.
- Long-term storage allows for an increase in generated power from RES and hydrogen storage offering negligible self-discharge rates.
- The high energy density of hydrogen is also important to consider in transport applications compared to batteries, and in general in applications where space and weight restrictions are unavoidable.
- Hybrid PV-RHFC microgrid systems also have the ability of combining multiple applications, i.e., servicing various types of buildings and loads (slow and fast current draw), providing electricity to battery-electric vehicles (via charging stations), hydrogen to fuel cell electric vehicles (via hydrogen refilling stations), and operating at both grid-to-vehicle and vehicle-to-grid modes. These capabilities can in turn reduce the curtailment of RES-generated power from rapid fluctuations of dynamic load profiles.

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[6] Dawood, F., Anda, M., Shafiullah, G.M. (2020) "Hydrogen Production for Energy: An overview", International Journal of Hydrogen Energy, 45,7, Pages 3847-3869.

[7] Furat Dawood, G.M. Shafiullah and Martin Anda (2020) "Stand-alone Microgrid with 100% Renewable Energy: A Case Study with Hybrid Solar PV-Battery-Hydrogen", Sustainability, vol. 12, pp 2047.

[8] Subodh Kharel and Bahman Shabani (2018) "Hydrogen as a Long-Term Large-Scale Energy Storage Solution to Support Renewables", Energies, Vol. 11, p. 2825.

[9] Fabio Serra, Marialaura Lucariello, Mario Petrollese and Giogio Cau (2020) "Optimal Integration of Hydrogen- Based Energy Storage Systems in Photovoltaic Mirdogrids: A techno-economic Assessment", Energies, Vopl. 13, p. 4149.

[10] Naoto Takatsu and Hooman Farzaneh (2020) "Techno-economic Analysis of a Novel Hydrogen-Based Hybrid Renewable Energy System for Both Grid Tied and Off-Grid Power Supply in Japan: The Case of Fukishima Prefecture", Applied Science, Vol. 10, p. 4061.

[11] Angel Xin Yee Mah, Wai Shin Ho, Mimi H. Hassim, Haslenda Hashim, Gabriel Hoh Teck Ling, Chin Siong and Zarina Ab Mui (2021) "Optimisation of a standalone photovoltaic-based microgrid with electrical and hydrogen loads", Energy, Vol 235, p. 121218.

[12] Yasuhiro Noro and Satoshi Uchiyama (2021) "Use of hydrogen storage in an off-grid system for implementing a renewable-energy system", Clean Energy pp704-712.

Several techno-economic studies of the use of RE-RHFC microgrids have been undertaken recently including grid integrated (tied) microgrids [5], [8],[9],[10] and stand-alone microgrids [10],[11],[12].

In a 2018 modelling study of the South Australian grid Kharel and Shabani [8] showed that a hybrid battery-hydrogen storage system was found to be more cost competitive with unit cost of electricity at $0.626/kWh (US dollar) compared to a battery-only energy storage system with a $2.68/kWh unit cost of electricity. This research also found that the use of excess stored hydrogen to generate extra electricity further reduced the cost to $0.494/kWh. Searra and colleagues [9] undertook a modelling study in 2020 of the optimisation of hydrogen-based storage systems in grid connected photovoltaic microgrids in facilities, such as public buildings and small- and medium-sized enterprises.

> *The results demonstrated that an efficient and cost-effective design can be obtained and that a reduction in the storage capacity to the* ***ninety eighth*** *percentile of the theoretical requirements leads to significant economic benefits without reducing the self-sufficiency of the user.*

The study concluded that the optimised configuration leads to a self-sufficiency rate of about 80% and, without public grants, a levelized cost of energy comparable with the cost of electricity in Italy could be achieved with a reduction of at least 25–40% of the current initial costs charged for the whole plant, depending on the load profile.

A techno-economic analysis of hydrogen-based hybrid renewable energy systems for both grid-tied and off-grid power supply in the Fukishima Prefecture in Japan was undertaken by Takatsu and Farzaneh [10] in 2020. This modelling study showed that the levelized cost of energy (LCOE) of the optimised systems were estimated at 55.92 JPY/kWh for the grid tied system and 56.47 JPY/kWh for the off-grid system. They concluded that while the system was technically possible the big challenge facing residential HRES is their economic viability and cost-effectiveness.

While it is not evident that currently RE-RHFC microgrid systems are yet cost competitive against existing grid electricity supply several recently published studies have shown that for stand-alone power generation systems in remote areas RE-RHFC microgrid systems are more cost-effective than the use of battery only storage and are already comparative in cost to conventional fossil fuel (diesel) based systems.

A 2021 modelling study of optimisation of a standalone photovoltaic-based microgrid with electrical and hydrogen loads by Mah and colleagues [11] showed the levelised cost of energy ranges from 0.4551 USD/kWh to 0.4572 USD/kWh for the base case scenario.

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[10] Naoto Takatsu and Hooman Farzaneh (2020) “Techno-economic Analysis of a Novel Hydrogen-Based Hybrid Renewable Energy System for Both Grid Tied and Off-Grid Power Supply in Japan: The Case of Fukishima Prefecture”, Applied Science, Vol. 10, p. 4061.

[11] Angel Xin Yee Mah, Wai Shin Ho, Mimi H. Hassim, Haslenda Hashim, Gabriel Hoh Teck Ling, Chin Siong and Zarina Ab Mui (2021) “Optimisation of a standalone photovoltaic-based microgrid with electrical and hydrogen loads”, Energy, Vol 235, p. 121218.

Sensitivity analysis results showed however that a significant cost reduction can be achieved when only 95% of loads are targeted. This suggests the use of alternative non-intermittent energy source such as biodiesel generators to cater for the remaining 5% of energy loads. In 2021 a modelling study of the use of hydrogen storage in a small scale off-grid electric power system on a remote island in Japan for implementing a renewable energy system was undertaken by Noro and Uchiyama [12]. This study showed that the initial cost of a renewable energy system in a situation like this can be reduced by ~30% when hydrogen storage is added when compared with the case in which a storage battery alone is used. The unit price of power generation using the proposed method was roughly estimated to be 42.9 JPY/kWh from the minimum initial cost obtained, which was approximately equal to the current cost of diesel power generation on remote islands.

According to Martire [13] in 2020 the State Government-owned utility Horizon Power serviced 53 of the 180 aboriginal communities in Western Australia. Of these 53, 7 large communities had solar power and 6 large Kimberley communities were to receive it in the next 2 years. The remaining 117 outstations are managed by WA's Department of Communities, *which in 2015-16 spent 16.29 million on diesel* for aboriginal communities. Diesel can cost more than $2/litre in remote areas, and the pump price doesn't include transportation to the community, via road or even air in the wet season. In an article in 2017 Parkinson [14] reported that Horizon Power paid an average of $5,000 a year for every customer to guarantee that regional and remote customers pay no more than the 26c/kW charged in Perth. This was a total of *$250 million a year*.

Most of these power generation systems were diesel. For example, to supply power to the community in the former gold rush town of Sandstone in the mid-west about 670 kilometres from Perth used to cost $2/kWh. This was subsequently reduced to 96c/kWh with the installation of a solar farm at the power station site. At Menzies at the time of the article the price was still $1.65/kWh. These are larger communities, and their power stations have size and accessibility (e.g., for maintenance and fuel delivery advantages), and therefore reduced generation costs compared to smaller remote systems.

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[13] Jodie Lea Matire (2020) "Powering indigenous communities with renewables", Renew. Technolcogy for a sustainable future magazine. Published 20 April, 2020. Available from: https://renew.org.au/renew-magazine/solar- batteries/powering-indigenous-communities-with-renewables/ .

[14] Giles Parkinson (2017) "How Horizon Power plans to remove world's biggest fossil fuel subsidy", Renew Economy, Clean Energy News and analysis, published 27 March 2017. Available from https://reneweconomy.com.au/how-horizon-power-plans-to-remove-worlds-biggest-fossil-fuel-subsidy-58724/

Given the need to significantly reduce the greenhouse gas (GHG emissions) of electricity supply to regional homeland Aboriginal communities to meet the WA State Government’s commitments to 80% GHG emissions reduction by 2030 and Net Zero by 2050 then the existing diesel power generation systems on the majority of the communities will need to be replaced by renewable energy systems. This would also be expected in many cases to result in lower generation costs, more reliable power across the year, including during cyclone season when many communities’ roads are cut off from diesel fuel delivery, and improved drinking water quality for specialist health services such as kidney dialysis [15].

The literature suggests that these systems should be RE-RHFC microgrid systems as they have both technical and economic advantages over battery only storage systems. In many cases they provide power with a similar, or lower LCOE compared to the existing diesel only systems. Horizon Power, the State-owned regional electricity supplier, is currently developing a large community sized RE-RHFC microgrid system at Denham. No analysis has been done on the use of these systems in smaller regional and remote aboriginal communities where their inherent advantages would be very beneficial.

This report presents the work done by Murdoch University, in conjunction with its industry partners, to undertake a techno-economic analysis of the feasibility of using RE-RHFC systems in regional and remote aboriginal communities, present the business case and plan for doing so and enable the systems to be rolled out to support the Western Australian Government’s emissions reduction targets.

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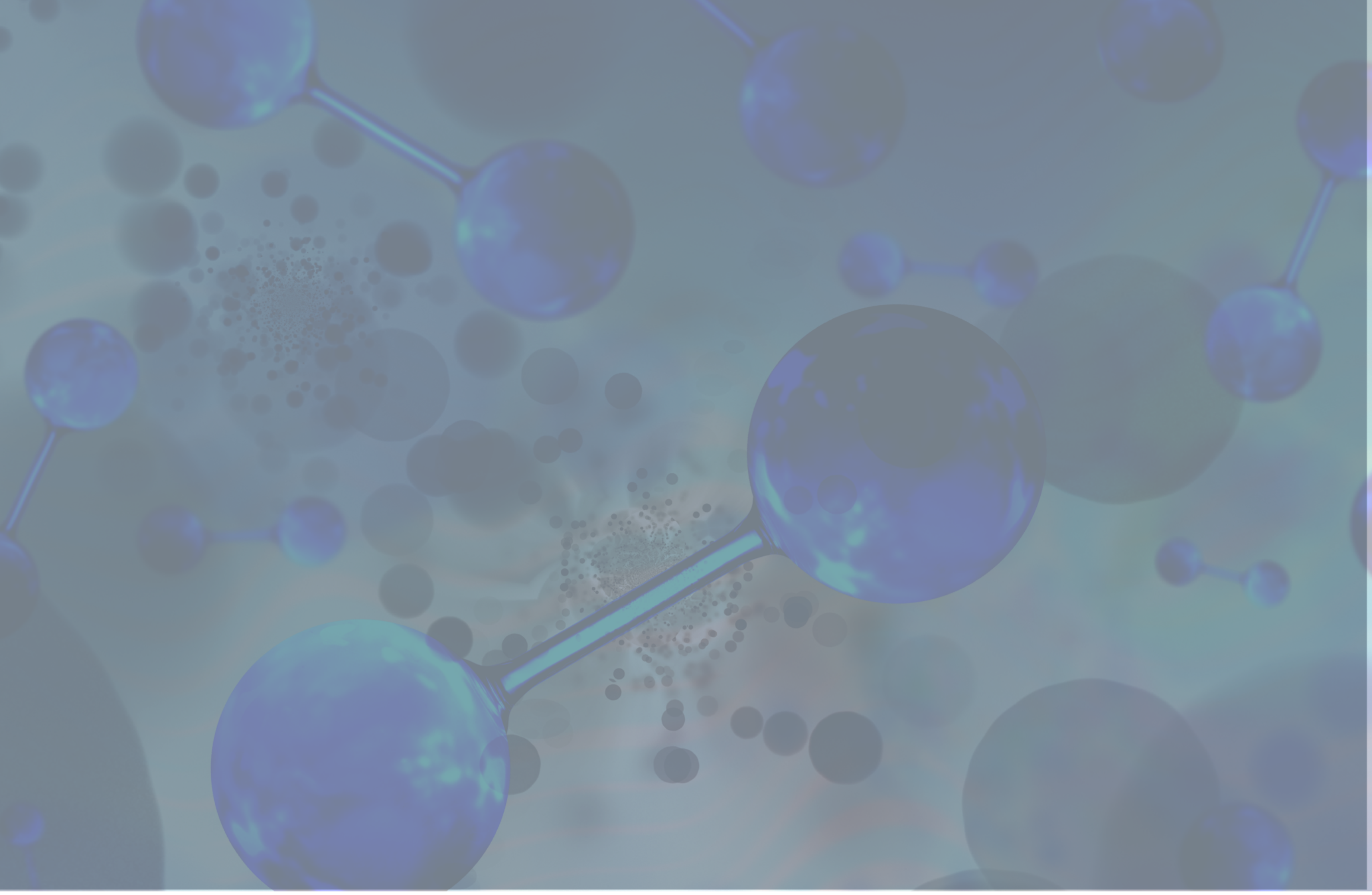
[15] Kimberley Clean Energy Roadmap, Sustainable Energy Now 2018, Rob Phillips, Ben Rose, Len Bunn https://library.sprep.org/sites/default/files/5_23.pdf



2

Background and SCOPE

The project conducted a techno-economic feasibility study to convert the current power supply system for Aboriginal homeland communities in regional and remote Western Australia to 100% RE power generation with a hybrid battery-hydrogen storage system, using the Jinparinya and Warralong Communities in the Northwest as examples. This feasibility study evaluates the Life-Cycle Cost of Energy (LCOE) and carbon footprint reduction. It also facilitates the investment decision to implement these pilot projects. Additionally, implementing these trial projects opens the gate for the transition from grid connected and diesel based off-grid (stand-alone) power systems to low-carbon RE-based power systems for the many other such communities in Western Australia.

2.1 Project Team

Murdoch University Hydrogen Research team (present as ‘the Team’ throughout the report) has partnered with Cundaline Resources, Balance Group and Gemtek Automation to conduct feasibility study for this project. Cundaline Resources is an indigenous-owned mining logistics company based in Port Hedland, Western Australia (WA). Balance Group and Gemtek Automation are the industry partners with Murdoch University.

2.2 Purpose of this Report

This report summarises the outcomes of Murdoch University’s study to investigate the viability of a 100% renewable energy-based SAM with a hybrid Solar PV-Battery-Hydrogen system for the Pilbara region, considering social, economic and environmental benefits.

The key components of the study were to:

1. Design a hybrid PV-battery-hydrogen-based SAM system with the aim to achieve 100% renewable energy supply in regional and remote Western Australia.
2. Identify the most optimum solution for SAM based on technical, economic and environmental perspectives.
3. Identify the preferred ultimate configuration of equipment, sizes and timing to achieve the project objective.
4. Identification and analysis of a potential commercial demonstration project with Cundaline Resources that leads to an investment decision for pilot project implementation in the Pilbara.
5. Identify the possibility of future extension of SAM to provide hydrogen for transport, particularly regional heavy haulage transport.
6. Prepare a business case and business plan for the implementation of hybrid PV-battery-hydrogen-based SAM systems at the two sites, and then by extension to the other regional and remote aboriginal communities in Western Australia.

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

2.3 Scope & Limitations

This report has been prepared by Murdoch University for Cundaline Resources and the two communities studied, and may only be used and relied on by those entities for the purpose agreed between Murdoch University and these entities, as set out in this section.

Murdoch University otherwise disclaims responsibility to any person other than Cundaline Resources and the two communities studied arising in connection with this report. Murdoch University also excludes implied warranties and conditions, to the extent legally permissible.
The services undertaken by Murdoch University in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope and limitations set out in this report.

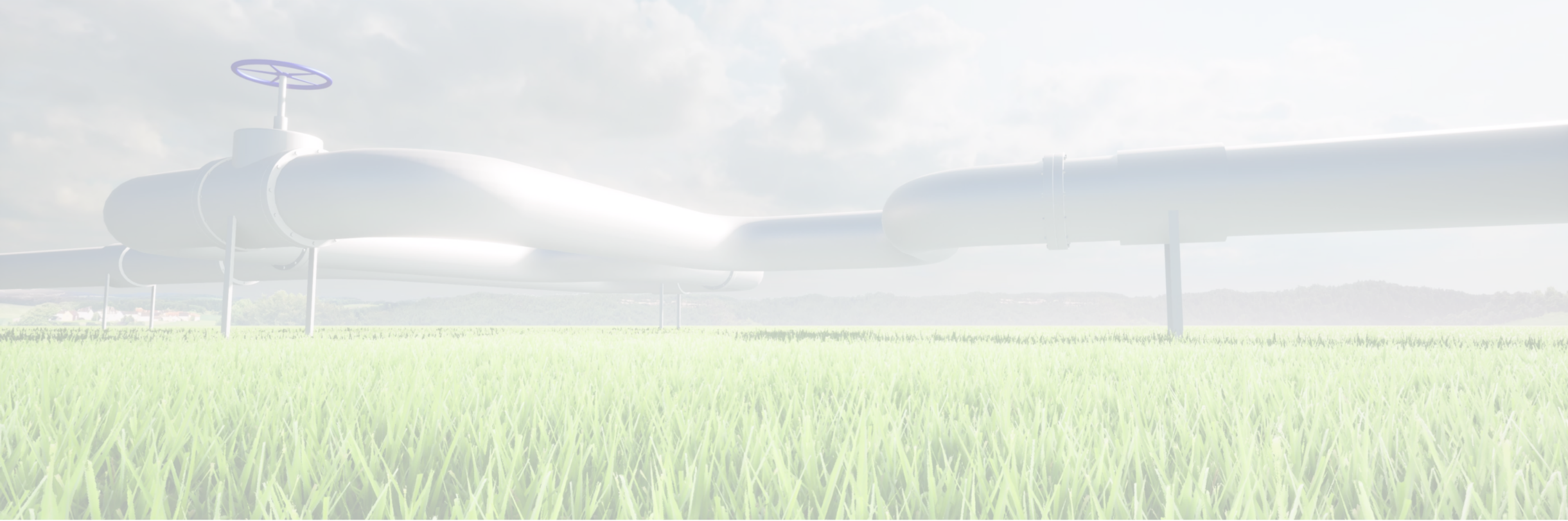
The services undertaken by Murdoch University in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in this report.

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

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

Murdoch University has prepared the preliminary cost estimates set out in Section 5 of this report ("Cost Estimates") using information reasonably available to the Murdoch University employee(s) who prepared this report; and based on assumptions and judgments made by Murdoch University as set out in this report.

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



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

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

2.4 Exclusions from Study Scope

The study only covered the current systems and power needs at the Jinparinya and Warralong Communities and not those needed for any future proposed commercial activities such as those proposed by the Jinparinya Community. The study is a high-level modelling analysis, and does not include detailed systems design, site selection and associated civil and construction works. These would need to be undertaken during the specific site design process.

3 Project FRAMING

3.1 Overview

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

The overall project objective is to economically displace the high cost and GHG emitting grid or diesel standalone power systems in Aboriginal homelands in Western Australia.

Key drivers of this project include:

- reduce the community's carbon emissions
- reduce the LCOE electricity to the community
- produce an economical green energy solution (e.g., comparable costs to current diesel use)
- provide the basis for future business opportunities for some communities through the provision of green hydrogen for external sale to hydrogen trucks and light vehicles.

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

3.2 Scope Framing

Considering the previously published work relating to the technical feasibility, economic favourability, and other benefits the project investigated the viability of a 100% renewable energy-based SAM with a hybrid battery-hydrogen storage system for Aboriginal homeland communities the Pilbara region, considering social, economic and environmental benefits. Considering the findings of the investigation a business case was developed to assist in meeting the State Governments GHG and service delivery improvement targets for the power provision to these communities by the rollout of these systems.

3.3 Hydrogen Use Cases

The target areas identified for hydrogen were power generation with a hybrid battery-hydrogen storage system for two different types of regional Aboriginal homeland community:

- one which is representative of grid connected communities; and
- one which is representative of communities that have a stand-alone diesel electricity generation system.

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

3.4 Staging

A key outcome of the framing work was the confirmation that this project supports a staged approach, starting with full replacement of the existing grid connected system and replacement of most of the diesel stand-alone system. The analysis showed that for the stand-alone system it was initially most cost effective to retain one of the diesel generators to provide contingency backup allowing a smaller hydrogen storage system and a smaller battery bank – the latter reduction also reduces *fire risks* if lithium-ion is the battery of choice. As system prices drop, and the Net Zero by 2050 target needs to be achieved, the system can easily be upgraded to become a fully renewable energy system.

Both the solar field and hydrogen plant components are highly modular and expandable, and this supports a staged expansion of the renewable power and hydrogen production facilities as required, either as the load of the community increases (e.g., electric vehicles) or commercial opportunities arise to provide hydrogen as a commercial transport fuel (part of the strategic plan for the Jinparinya community). The options developed during the scope framing step identified that limited to no opportunity would be lost in pursuing a staged approach to the project, and in *some cases* it would be beneficial. The work confirmed that staging, in some cases provides the lowest up-front capital, the ability to leverage potential future cost reduction of hydrogen technologies and provides an opportunity for the communities and utility providers to be able to incrementally build their understanding and capability in hydrogen.

3.5 Framing Outcomes

The framing outcomes were:

- Techno-economic feasibility study focussed on the use of a hybrid PV-battery-hydrogen-based SAM system with the aim to achieve maximum level of RE supply in the two representative aboriginal communities.
- Identification of the preferred ultimate configuration of equipment, sizes and timing to achieve the project objective of maximum RE for lowest LCOE.
- Preparation of a business case and business plan for the implementation of hybrid PV-battery-hydrogen-based SAM systems at the two sites, and then by extension to the other regional and remote aboriginal communities in Western Australia.

4

Project OVERVIEW

THE PROJECT CONSISTS OF THE ANALYSIS OF TWO REMOTE REGIONAL ABORIGINAL COMMUNITIES IN THE PILBARA REGION TO DETERMINE THE TECHNO-ECONOMIC FEASIBILITY AND BUSINESS CASE FOR REPLACING THE EXISTING CONVENTIONAL (GRID CONNECTED OR DIESEL STAND-ALONE POWER SUPPLY) WITH A HYBRID SOLAR PV-BATTERY-HYDROGEN SYSTEM.

The Jinparinya indigenous community was selected as the first suitable site for the proposed feasibility study after visiting a few suitable sites, consulting with project partners and the local stakeholders. Later, the project Team also considered the Warralong Aboriginal Community as the second suitable site.

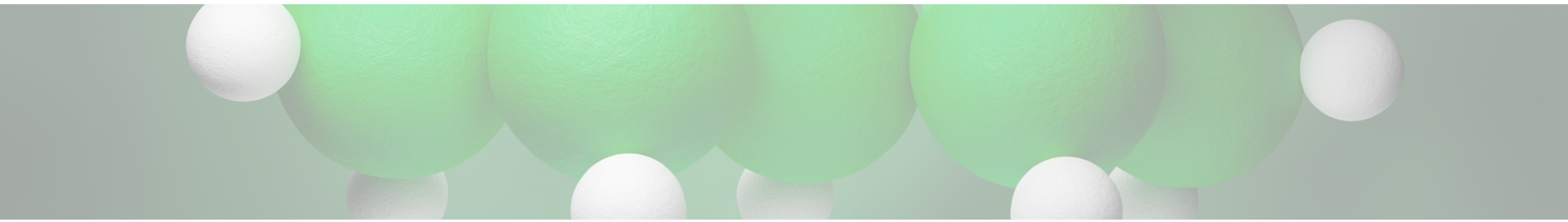
Jinparinya Aboriginal Community, a small-sized community located about 1,320km north-northeast of Perth and about 22 kilometres west of Port Hedland, just off the Great Northern Highway, as illustrated in Fig. 1. Jinparinya is located just off the Petermarer Creek near the Indian Ocean about 19m above sea level, West of the nearest population centre of Port Hedland. The current Jinparinya population of 35 people are living in seven houses. The community power system is a grid-connected system via the underground cable provided by Horizon Power the utility company that services remote and regional WA. This community site was selected because of their plan to expand their load to a proposed business of a roadhouse, caravan park and a fuel service station with hydrogen fuelling dispenser and an EV charging station.

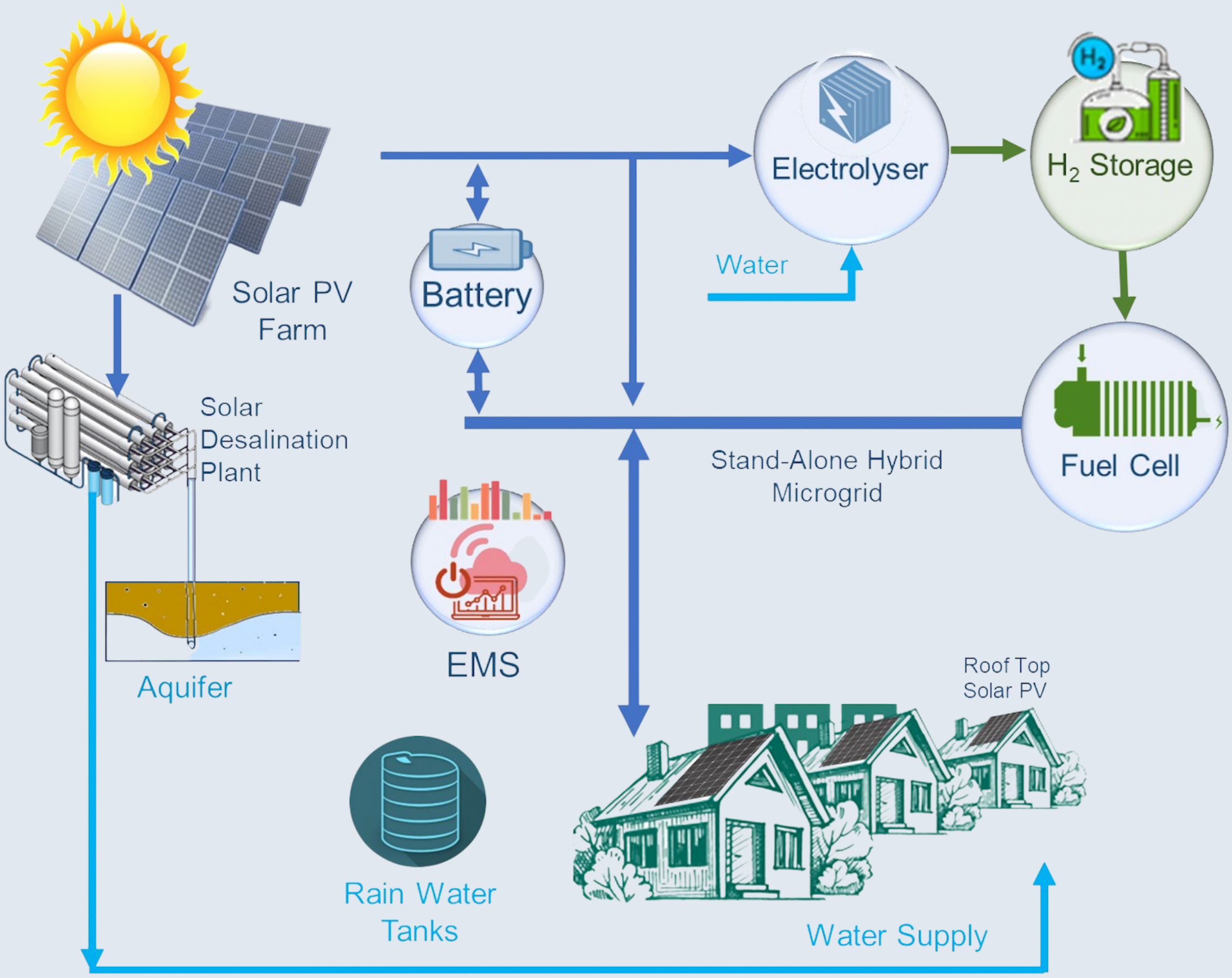
Figure 1: Jinparinya and Warralong Communities East of Port Hedland

Therefore, converting their power system to 100% RE will reduce the carbon footprint and provide experience with RE powered hydrogen generation and storage systems and evaluate the cost of expanding the grid connection (i.e., the cost of energy – LCOE) in future years to accommodate the planned commercial activity. Essential data was collected during the visit and follow-up meetings for the preliminary system design and arrangements made for future developments.

The second site considered was the Warralong Aboriginal Community, a medium-size community located about 120 kilometres southeast of Port Hedland and 50 kilometres north of Marble Bar. This community is powered by three diesel gensets as a SAM or islanded town grid. The actual data was collected remotely via teleconferences (Microsoft Teams) and e-meetings with Warralong community leaders, the WA Department of Communities REMS officers, and the power system operator.

The Warralong diesel power station is currently maintained by Pilbara Meta Maya Aboriginal Corporation (PMMAC) based in Port Hedland (Wedgefield) and with offices in Perth also (Canning Vale). PMMAC is one of three indigenous-controlled regional service providers across WA that provide power, water, and sewerage services to 140 Aboriginal communities (117 of these have diesel power stations) under the Remote Essential Municipal Services (REMS) program. REMS is funded by the WA Government through Department of Communities and REMS technical program management is by engineering consultants WSP. It is understood that REMS will transition to a new 'licensed service provider' arrangement over the coming years delivered principally by Horizon Power and Water Corporation. There is great interest in transition to renewable energy for the 117 diesel communities. This feasibility study will help inform such options.





5

SAM Model

PRELIMINARY DESIGN AND INVESTIGATION STRATEGY

The Jinparinya Community expressed their interest in transforming their grid electricity supply to a grid connected renewable energy microgrid. They also intend to start a new business on their land to be implemented in three phases and want a system that can be expanded to meet the needs of that plan as it is implemented. Warralong community's SAM system (diesel-based) is about to require retrofitting. Thus, it is an opportunity to transition to a carbon-free RE-based power supply based on Solar PV and a hybrid battery-hydrogen storage system. All the proposed projects are intended to use 100% RE power supply and show case and pilot an innovative energy supply approach that will have the potential to decarbonise the Pilbara region, regional Western Australia, and all over Australia.

5.1 Data Availability

The actual Jinparinya Community load profile was provided by Horizon Power (the current power provider). The Department of Communities provided Warralong community load profile as they are the current service providers for most of the remote Aboriginal communities. The technical data was researched and collected from the publicly available Original Equipment Manufacturers (OEM) data sheets and what is available in the academic literature. Therefore, the equipment prices are near-real but not actual.

5.1.1. Jinparinya Community

The provided aggregated interval data revealed the average daily load of 6.58 kW for the community (7 houses) during winter. The load profile follows the residential load patterns which peaking in the evenings. The daily load increases to 158 kWh/d with a peak load of 12.58 kW during summer due to more air-conditioning required because of the hot climate in Port Hedland. The proposed system must be designed to provide reliable power during the high demand. Therefore, the 10th of January interval data was taken as input data into our simulation model to ensure minimum system capacity shortage i.e., 0% unmet load. For the preliminary design, 100% RE-based power system has only been considered.

5.1.2. Warralong Community

The provided aggregated interval data revealed the average daily load of 1,385 kWh/d for the community comprises 35 houses plus a community centre and a school. The average hourly load was calculated as an average between the middle of winter and summer with a 10% daily variation. The load profile follows a residential load pattern. Currently, three diesel generators at 110 kW capacity each provide power to the power system.

5.2 Investigation Strategy

Homer Pro [16] simulation software was used to integrate the system components and simulated to optimise the sufficient sizes and capacities to meet the load (power and hydrogen) requirements. All system components were optimised for the minimum Cost of Energy (COE), resulting in a higher return on investment and minimum payback period.

The simulator calculated the balance of energy within the model to cover the load at all times of the year according to the site-specific RE resources availability and intensity. The RE resources and temperature profiles for Jinparinya and Warralong locations were extracted from NASA prediction energy resources database. The area-specific average solar energy resource in the area is 6.10 kWh/m2/day.

The simulator input parameters were collected from the publicly available, literature review, technical datasheets, and the simulation software (Homer Pro) library and incorporated any necessary modifications. The CAPEX and OPEX (all in AUD) were adjusted according to the researched information, and communications with the relevant existing plants in Australia. Additionally, some assumptions and estimations were necessary to make. The step-by-step optimisation process is illustrated in Fig. 2.

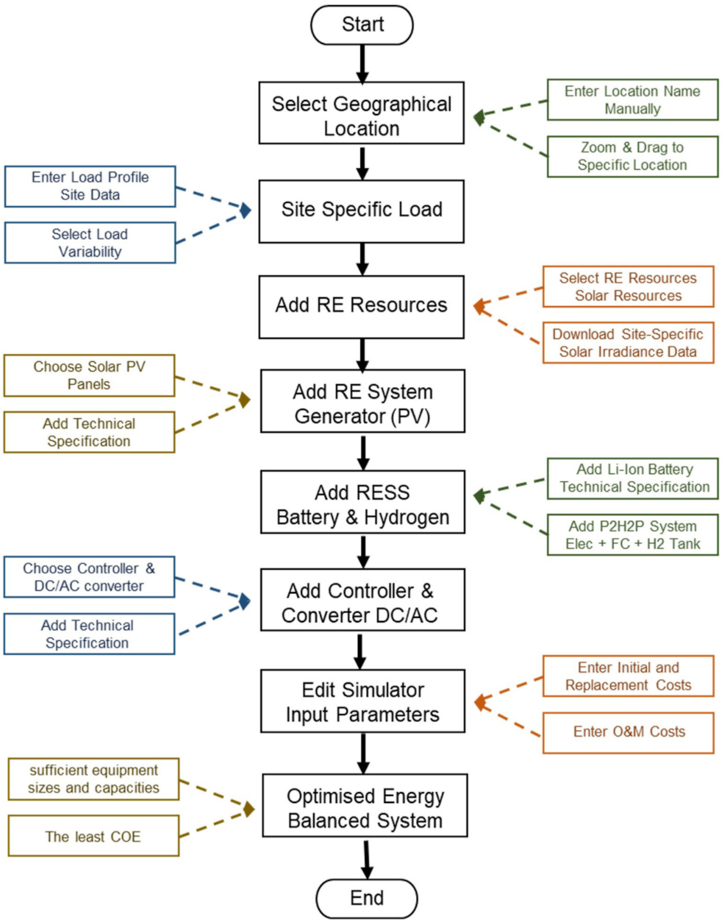


Figure 2: System investigation strategy and optimisation method

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[16] Homer Pro [Online Available} https://www.homerenergy.com/products/pro/index.html. Dated 15 January 2022

5.3 SAM - System Design and Evaluation

A 100% RE-based system with solar-PV, hybrid battery-hydrogen energy storage system was modelled to decarbonise Jinparinya and Warralong Communities power systems. The proposed system was designed according to the site-specific RE resources, climate, average and peak loads, as well as a sufficient period of autonomy, i.e., at least 24 hours (battery and hydrogen combined). The system model was simulated and analysed to techno-economically evaluate its feasibility.

5.4 Equipment Packages

This feasibility study and energy balance simulation used a high-level engineering design methodology. Therefore, equipment packages were used to assess the feasibility of the integrated system rather than technical details and specification of each part of equipment throughout the proposed integrated system. The equipment packaging allows the engineers to use a generic type of equipment as a block with a specific function, input/output (I/O) parameters, efficiency, peripherals, and control devices. Power quality will be assured by using a smart stand-alone converter/inverter, i.e., control the voltage and frequency of the system.

The CAPEX and OPEX for each block include all the additional devices to ensure the integrated systems' operability and controllability.

5.5 Solar PV System

The proposed solar PV system can be a small-scale roof-top PV system or a central PV farm. A mix of smaller roof-top PV systems with a smaller PV farm is also a viable option. However, shading from trees around the houses must be considered when designing the solar PV system.

The simulation of the proposed system was based on the following:

- the system connected to the DC Bus
- use MPPT system
- no tracking system and no shading
- facing North and using default slope and azimuth
- reflectance 20%
- a lifetime of 25 years and a derating factor of 80%.

5.6 Hydrogen Packages

The Power to Hydrogen to Power (P2H2P) system comprises three packages: electrolyser; H2 storage; and fuel cell (FC). The packages include the OEM auxiliary and control systems. The packages integration and interconnection were included as a fixed capital cost for each system depending on the size of the system.

5.6.1. Electrolyser

The electrolyser is a device that consumes electricity to split water feedstock to hydrogen and oxygen, i.e., hydrogen generator. There are many different types of electrolysers which have the similar functionality but different technology, maturity, cost, and efficiency.

The proton exchange membrane (PEM) electrolyser was adopted for these projects for the sake of its mature technology, efficiency, ramp-up and shut-down times, and life span. The generic PEM electrolyser package consists of the cell stack (the core), water treatment, hydrogen dryer, pipes and valves, safety sensors and devices, a cooling system, and a control unit. Some control and auxiliary devices are connected to the solar PV farm controller, other connections with the hydrogen storage unit, as well as the holistic integrated system's monitor and control. The water treatment (purification and deionisation) unit is included and potable water assumed to be available on site. Water and hydrogen electrolyser compressors are included in the electrolyser package to compress the hydrogen output to 30 bar.

The system controller plays an essential role in operating the electrolyser only when excess RE, H2 storage, and water feedstock are available and safe to start. Also, it shuts down and isolate safely (hydrogen venting) the electrolyser unit when RE is lost or in case of emergency. Hence, auxiliary devices require a continuous stable external power supply, which is the system battery bank.

5.6.2. Hydrogen Storage

Many hydrogen storage technologies are categorised into two main pathways: physical-based and material-based technologies. The hydrogen compressed gas storage technology (physical-based) is mature and cost-effective. However, the compression level is determined by the trade-off between the tank volume (footprint) and the cost-effectiveness. The design team adopted 30 bar compressed gas tank i.e., approximately 2.4 kgH2/m3, to reduce the high-pressure associated risk, cost of the compressor package and the use of specially designed high-pressure cylinders. The low-pressure tank requires pneumatic operating and safety valves; thus, an adequate air compressor unit is included in this package.

5.6.3. Fuel Cell

Fuel Cell (FC) consumes hydrogen to generate electrical power by redox chemical reaction. There are many types of FCs that are different in technology, maturity, efficiency, and cost. The Team adopted the PEMFC technology for the merits of its maturity, response time, and cost- effectiveness.

The PEMFC works on a range of 8-12 bar of compressed hydrogen at the input, thus it is required a pressure reduction skid (pressure regulator) between the storage tank and the FC. Also, the voltage output varies due to many parameters such as the supplied hydrogen pressure, liquid water accumulation, electrical current, and airflow which requires a DC/DC converter to stabilise the DC voltage output. Additionally, safety and control sensors and transducers are essential to ensure safe, steady, and reliable operations. All these devices are included in the FC package. A continuous and stable power supply is essential to the operation of all peripherals and auxiliary devices, and this function is performed by the system battery bank.

5.6.4. Battery Bank

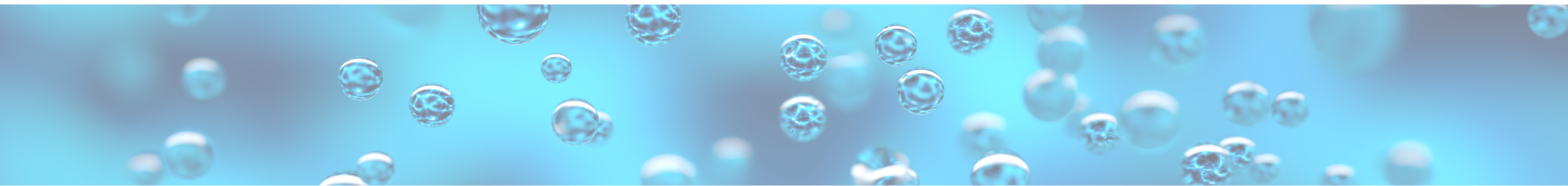
The battery bank consists of the Li-Ion cells (the core), auxiliary devices, cooling system, metering, safety sensors, monitoring and control system are all considered a battery package. Generic Li-Ion battery cells were adopted for this system as it is a mature technology, as well as having high efficiency and lifetime. The project Team adopted the central battery bank for the sake of ease to access and maintain and cost-effectiveness.

The battery bank is designed to absorb the load fluctuations above or under the FC operation limits, i.e., over the FC full load or less than the minimum allowed partial load. Also, it keeps the voltage and frequency controlled by supplying continuous and steady power to the DC/AC inverter and the integrated system controls.

5.6.5 Cooling System

The proposed cooling system is an air cooled (closed-loop coolant) chiller. The size of the cooling system is directly proportional to the size of the integrated system capacity. The cooling requirement is to keep the system equipment within its operation temperature, especially in the very hot and dry conditions experienced in the north of Western Australia. The cooling package was added to the fixed capital and yearly operational costs.

It is worth mentioning that excess thermal energy from the fuel cell can be utilised to supply hot water to the community, which will reduce the energy consumption and the cooling system size and cost. However, this is out of the scope of this feasibility study.



5.7 Fixed CAPEX and OPEX

Hydrogen-based power systems are new to the electricity industry, regulatory bodies, Governments, and communities. Therefore, it is expected that the approval process will be long and costly, and installation can cost more than conventional power systems. However, civil work and other electrical connections outside the Hydrogen power plant is the same as conventional power systems. These costs were estimated to the best knowledge of the researchers and added as a fixed initial cost to the system economic evaluation. The modelling assumed that there will be a fixed monitoring and operating cost associated with all systems. However, more cost was added both as fixed CAPEX and OPEX for the bigger systems while the Jinparinya community is considered a small-scale system which incurs less fixed costs.

5.8 Water Requirements

Typically, a quantity of 10-15 litres of raw (potable) water as an electrolyser feedstock and for cooling system is required for each kilogram of the produced hydrogen. The electrolyser's input must be a purified and de-ionised water at 9.9 litres for each kg H2. The energy requirements for
this process can be conducted during the excess RE availability (peak sunshine hours). Additionally, a water treatment unit is required, and its cost was included in the electrolyser package which is estimated at \$2-3k for 10-20 litres per hour of capacity.

5.9 Techno-economic Parameters

The techno-economic input parameters for the proposed system components as packages, i.e., including all the associated peripherals, control and auxiliary devices, are listed in Table 1.

Table 1: The RE model techno-economic input parameters

System Component	Type	CAPEX/OPEX (AUD)
Solar PV System	Generic, No Tracking (installed)	$1,000 kW / $10 kW/yr
Li-Ion Battery Bank	Generic Li-Ion Package (installed) @ eff.	$550 kWh / $5 kWh
H2 Electrolyser	Generic, PEM Package (installed) @ eff. 56%	$2,500 kW / 10 kW/yr
H2 FC	Generic PEMFC package (installed) @ eff. 50%	$3,350 kW / $1 Op hr
H2 Tank Low-Pressure	Generic package (<30 bars) Tank @ eff. 95%	$1,000 kg H2 / $5 kg H2
Converter	Generic (DC/AC Invertor) (installed) @ eff. 95%	$300 kW / 0
System Controller	Generic Load Following (Smart PLC&SCADA)	$30,000 Complete System / 0
Fixed Capital	Engineering Design, Tendering, approvals and Civil work	$220,000 (*a*) $781,000 *(b)*
Yearly Operational	Supervising and Remote Monitoring	$24,000 *(a)* $104,000 *(b)*
H2 Fuelling Station	Package (c)	$2.8 Million
Discount Rate (%)	Assumed average over the project lifetime	8
Inflation Rate (%)	Assumed average over the project lifetime	2
Project lifetime (yr)	All projects models	25

(*a*) Small-scale system for Jinparinya Community. (*b*) Medium-scale system for Warralong Community.
(*c*) Hydrogen Fuelling Station, ACT, Australia [17]

Some of the values in Table 1 are default values for key input parameters (such as price of diesel, PV panel, fuel cell, hydrogen tank etc., and cost of generating electricity at Port Hedland). In light of this, to enhance the confidence level in the business case and business plan a sensitivity analysis was undertaken for several key cost input values in order to determine the effect on the optimized system, as well as provide guidance around the optimal time (e.g., when PV prices hit trigger point $x per kw) or staging of a wider transition to this kind of system. The results from this sensitivity analysis were then used to inform and develop the business case.

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[17] Available on https://the-riotact.com/australias-first-public-hydrogen-refuelling-station-opens-in-canberra/449845

5.10 Feasibility Analysis Jinparinya Community

This section discusses and evaluates all modelled SAM systems options for the Jinparinya community.

5.10.1. Load Profile

The proposed 100% RE system comprises a sufficient solar PV generation capacity, battery bank, P2H2P system, converter, and a system controller. The site-specific collected data revealed an average load profile. The average daily load is 157.85 kWh/d, rounded to 158 kWh/d with an average of 6.58 kW and peak load of 11.06 kW. The system architecture and load profile are illustrated in Fig. 3.

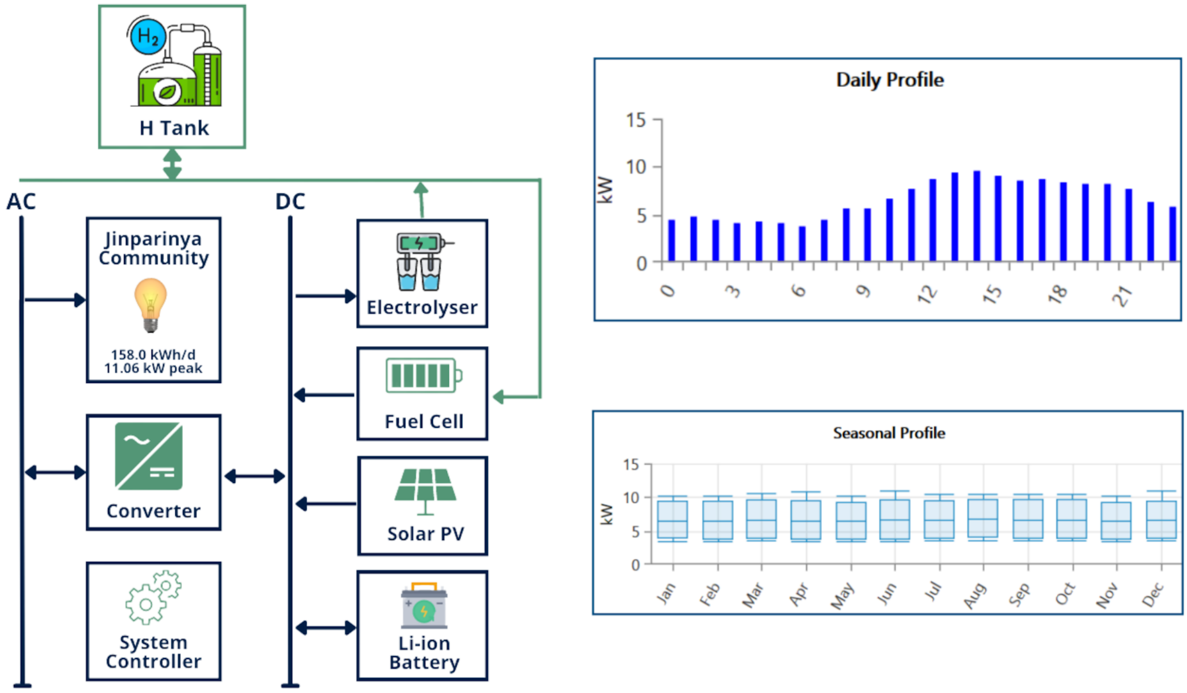

Figure 3: Jinparinya community system schematic diagram and extracted load profile

5.10.2. SAM Model Design

The 100% RE SAM system for the Jinparinya community was designed and optimised in various options. The options were based on the trade-off between the battery bank capacity and the P2H2P system capacity for the sake of minimum LCOE versus more energy autonomy in the form of stored hydrogen. The options from the range were selected to illustrate the differences of the system components and LCOE, as follows:

Option	System Specifications
Option 1	Bigger battery capacity and smaller hydrogen systems
Option 2	Middle range capacity for both battery and hydrogen systems
Option 3	Bigger hydrogen capacity with smaller battery capacity

The proposed system options optimisation results shown in Table 2 revealed that increasing the hydrogen package capacity will incur a increase in the LCOE and the system autonomy. Option 2 (the nominated system) was found to be the optimal system model, which shows that using a medium battery capacity and P2H2P system is the most cost-effective system configuration for the existing energy needs of the community and a sufficient autonomy. Despite the low amount of energy contribution by the hydrogen system it ensures over 2 full days of energy autonomy i.e., 408 kWh of usable energy at the FC output at 50% efficiency, while the battery pack has an average of 9.72 hours only. To have the same autonomy using a battery only system will require an additional 489.6 kWh battery capacity (at depth of discharge of 20%), increasing the capital cost by $269,280 (around $270,000) i.e., increasing the COE by approximately 65.8%. **Therefore, the P2H2P system Option 2 is the most cost-effective option to ensure sufficient autonomy.**

In Option 1, the P2H2P system contribution is very low for the nominated integrated system as the FC will work for an average of 209 hours per year compared to 1895 and 2580 hours per year for options 2 and 3 respectively. The recommended system (Option 2) uses an average of 7,147.5KL of potable water per year which is not much compared to about 400L water per person per day in the Pilbara region.

Table 2: Techno-economic results for the three selected options

System Component	Option 1	Option 2	Option 3
Architecture/Solar PV (kW)	58	84	104
Architecture/ Li-Ion Battery (kWh) Nominal	128	80	64
Architecture/FC Capacity (kW)	6	7	8
Architecture/Electrolyser Capacity (kW)	4	12	15
Architecture/H2 Tank Capacity (kg)	20	25	30
Architecture/Converter (kW)	14	14	14
Architecture/Dispatch Controller type	LF	LF	LF
Cost/Net Present Cost (NPC) ($)	$777,917	$968,359	$1,094,572
Cost/Cost of Energy (COE) ($)	$1,044	$1,299	$1,469
Cost/Operating cost ($/yr)	$28,547.50	$41,094.82	$48,727.70
Cost/Initial capital ($)	$408,869	$437,105	$464,644
Cost/Fuel cost ($/yr) (Hydrogen)	$0	$0	$0
Cost/O&M ($/yr)	$26,613.69	$38,750.55	$46,303.44
System/Ren Frac (%)	100	100	100
System/Excess Elec (%)	53.39	46.03	50.83
System/Total H2 Fuel Consumption (kg/yr)	53.4	452	683
System/Cap Short (%)	0.09	0.06	0.05
System/Elec Prod (kWh/yr)	109,592	165,150	207,040

Table 2: Techno-economic results for the three selected options cont.

System Component	Option 1	Option 2	Option 3
System/Elec Cons (kWh/yr)	61,209	83,789	96,924
Electrolyser/ H2 production (kg/yr)	73.4	476.5	712.7
FC/Operating Hours (hr)	209	1895	2580
FC/Production (kWh/yr)	890	7,532	11,376
FC/Hydrogen Fuel Consumption (kg)	53.39	451.93	682.55
FC/O&M Cost ($/yr)	$1,254	$13,265	$20,640
Hydrogen Tank Autonomy (kg)	20	24.5	29.7
Autonomy in a form of Stored Hydrogen (kWh)	333	408	495
Li-Ion Batt/Autonomy (hr)	15.55	9.72	7.78
Li-Ion Batt/Annual Throughput (kWh/yr)	30,212	22,404	17,929
Li-Ion Batt/Nominal Capacity (kWh)	128	80	64
Li-Ion Batt/Usable Nominal Capacity (kWh)	102	64	51
System/CO2-e (kg/yr)	0	0	0
Water requirement potable (l/yr) @ 15 l/kg H2	1,101	7,147.5	10,690.5

5.11 Feasibility Analysis: Warralong Community

This section discusses and evaluates the proposed models (options) for Warralong community SAM system.

5.11.1 Load profile

The proposed 100% RE system comprises a sufficient solar PV generation capacity, battery bank, P2H2P system, converter, and a system controller. The average daily load is 1,384.5 kWh/d, rounded to 1,385 kWh/d with an average of 57.71 kW and peak load of 122.39 kW. The system architecture and load profile are shown in Figure 5.

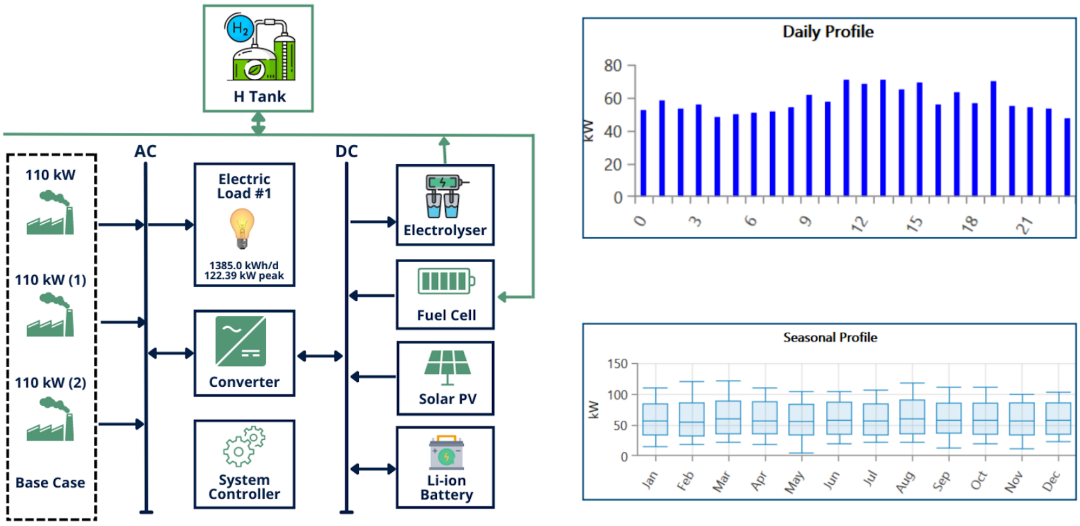

Figure 5: Warralong community system schematic diagram and extracted load profile

5.11.2 Techno-economic Design

The 100% RE SAM system for Warralong community was designed and optimised in various options. The options were based on the energy balance and the COE to replace the current power system consisting of three 110 kW diesel generators with a hybrid Solar PV-Battery-Hydrogen system. The proposed system comprises a battery bank and P2H2P system to achieve two objectives; reduce the COE and power supply carbon footprint. A range of options and different configurations were modelled and simulated to find the optimal COE by optimising the RE package (components' sizes) to its sufficient capacities to maintain the system's energy balance. Out of therange of different system component's sizes; one optimal option was selected and techno-economically evaluated to replace the base case, i.e., three diesel gensets. Both systems were simulated with the proposed CAPEX and OPEX, as listed in Table 1.

5.11.2 Techno-economic Design cont.

However, the existing diesel gensets initial cost was assumed to be null (existing) but the same fixed monitoring and operating cost was assumed for both systems. The diesel fuel and genset's replacement costs was considered as follows:

- The initial cost of diesel gensets is $0 (exist) and replacement is $1,000 per kW capacity.
- The operating and maintenance cost is $5 per operating hour.
- The diesel fuel cost is considered to be on average of $2.8 per litre, including transport to remote sites and on-site storage.
- The fixed project monitoring and operating costs are $104,000 per annum.

Additionally, a hybrid battery-hydrogen storage system with a backup genset was assessed in comparison to the nominated 100% RE system. The objectives were to evaluate keeping one of the existing diesel-gensets impact on the RE penetration, COE, and increase the whole system's resilience. The system's carbon footprint was assessed compared to the current diesel-based system to determine if it is feasible to consider this scenario.

Therefore, two options from the range of feasible equipment capacities and configurations were selected, modelled, simulated, and compared with the base case scenario and to each other, as follows:

- Base Case: three conventional diesel gensets (current power system).
- Scenario (W1): a 100% RE with battery-hydrogen storage.
- Scenario (W2): a hybrid RE with battery-hydrogen storage plus one backup genset.

The potable water consumption is comparatively low i.e., 339 L/day for W1 and 380 L/day for W2, which is comparable to the average daily water consumption per person per day in the Pilbara region.

The proposed models' simulation and calculation results in Table 3 reveal that both proposed scenarios (W1 and W2) are techno-economically feasible and will reduce the levelised (over 25 years project lifetime) COE in comparison with the base case scenario by 23.6% and 28.4% respectively.The modelling considered scenario W2 to keep one backup diesel genset within the system to make the proposed system more resilient by having a power generation redundancy and avoiding increasing the hydrogen production and storage capacities, and therefore the capital cost. However, having a backup genset within the proposed system requires frequently maintaining the genset to ensure it is ready to start (standby). Thus, the modelling considered operating the diesel genset for a few hours every week to maintain the genset standby and reduce the levelised LCOE for specifying 1.6% GHG emissions of the current power system carbon footprint.

5.11.2 Techno-economic Design cont.

From Table 3 it can be noted that a diesel genset with RE (Scenario W2) compared to a 100% RE, i.e., no diesel genset (Scenario W1) add following in the system:

- The COE reduction is 8.4% (from $0.902 down to $0.827).
- Diesel consumption increased (from 0 litres to 2,590.9 litres).
- The annual Diesel cost is $7,254.52

On the other hand, a diesel genset with RE (Scenario W2) compared to a 100% Diesel-based power system (Base Case) add the following in the system:

- The COE reduction is 30% (from $1.18/kWh down to $0.827/kWh).
- Diesel consumption reduction of 98.4% (from 155,001.5 litres to 2,590.9 litres), i.e. saving 152,410.6 litres of Diesel per year.
- The annual cost of Diesel fuel reduction by 98.4% (from $434,094.20 down to $7,254.52).

Table 3: Techno-economic results for the three selected options

System Component	Base Case	Option (W1)	Option (W2)
Architecture/Genset 1 (kW)	110	0	0
Architecture/Genset 2 (kW)	110	0	0
Architecture/Genset 3 (kW)	110	0	110
Architecture/Genset Working Hours (hr)	8,802	0	220
Architecture/Solar PV (kW)	0	966	966
Architecture/ Li-Ion Battery (kWh)	0	600	480
Nominal Architecture/FC Capacity (kW)	0	70	60
Architecture/Electrolyser Capacity (kW)	0	300	200
Architecture/H2 Tank Capacity (kg)	0	300	200
Architecture/Converter (kW)	0	150	150
Architecture/Dispatch Controller type	LF	LF	LF
Cost/Net Present Cost (NPC) ($)	$7,702,048	$5,869,335	$5,402,124
Cost/Cost of Energy (COE) ($)	$1.18	$0.902	$0.827

5.11.2 Techno-economic Design cont.

Table 3: Techno-economic results for the three selected options (cont.)

System Component	Base Case	Option (W1)	Option (W2)
Cost/Operating cost ($/yr)	$593,467	$168,968	$169,106
Cost/Initial capital ($)	$30,000	$3,712,000	$3,216,000
Cost/Fuel cost ($/yr) (Hydrogen)	0	0	0
Cost/Fuel cost ($/yr) (Diesel)	$434,094.2	0	$7,254.52
Compare Economics/IRR (%)	Base case	14.5	17.7
Compare Return on Investment (%)	Base case	10.5	13.5
Compare Economics/Simple Payback (yr)	Base case	6.3	5.4
Compare Economics/Discounted Payback (yr)	Base case	8.2	6.6
System/Ren Frac (%)	0	100	98.50
System/Excess Elec (%)	0	42.4	38.9
System/Cap Short (%)	0	0	0
System/Elec Prod (kWh/yr)	505,626	1,797,167	1,968,298
System/Elec Cons (kWh/yr)	505,525	1,281,839	1,165,995
Electrolyser/ H2 production (kg/yr)	0	8,260	9,259.2
FC/Operating Hours (hr)	0	2,106	2,718
FC/Production (kWh/yr)	0	132,874	153,454
FC/Hydrogen Fuel Consumption (kg)	0	7,972	9,207.21
FC/O&M Cost ($/yr)	0	$14,742	$16,308

5.11.2 Techno-economic Design cont.

Table 3: Techno-economic results for the three selected options (cont.)

System Component	Base Case	Option (W1)	Option (W2)
Hydrogen Tank Autonomy (kg)	0	288	52.2
Autonomy in a form of Stored Hydrogen (kWh)	0	4,800	870
Li-Ion Batt/Autonomy (hr)	0	8.32	6.65
Li-Ion Batt/Annual Throughput (kWh/yr)	0	131,338	102,795
Li-Ion Batt/Nominal Capacity (kWh)	0	600	480
Li-Ion Batt/Usable Nominal Capacity (kWh)	0	480	384
System/CO2-e (kg/yr)	405,503.1	0	6,776.7
Water requirement potable (Kl/yr) @ 15 l/kg H2	Cooling top-up	123.90	138.89

6 Business CASES

6.1 Financial Business Case

BOTH THE LITERATURE AND THE SIMULATION STUDIES UNDERTAKEN IN THIS WORK SHOW THERE IS A VERY COMPELLING BUSINESS CASE FOR THE USE OF HYBRID SOLAR PV-BATTERY-HYDROGEN SAM SYSTEMS, ESPECIALLY IN REGIONAL AND REMOTE AREAS.

It shows that the use of these systems to meet the GHG, and generation cost reduction aims of the Western Australian Government warrants the development of a carefully designed set of demonstration systems, including ones at each of the two sites, and the development and implementation of a full transition program for the other ~120 regional and remote aboriginal communities and homelands in Western Australia. The business cases for the two sites studied are summarised in this section.

6.1.1 Jinparinya Community

The optimal configuration for the Jinparinya system has an initial total plant capital cost of $AU 437,105 and an annual operating cost of $AU 41,094.82. The net present cost for the system is $AU $968,359 with a LCOE of $AU $1.299/kWh and a simple payback of 6.75 years (discounted payback period of 8.1 years) compared to a conventional diesel-powered mini grid or grid COE at $AU 2 before subsidy. The LCOE $AU 1.299 per kWh (unit) price of electricity for the hybrid hydrogen system is less than an all-battery system and is also less than typical generation costs from diesel only mini-grid systems such as Menzies (>$AU 1.65/kWh) [14].

6.1.2 Warralong Community

The proposed model's simulation and calculation for the Warralong community revealed that both proposed scenarios (W1 and W2) are techno-economically feasible and will reduce the LCOE (over 25 years project lifetime) in comparison with the base case scenario by 23.6% and 28.4% respectively. The optimal configuration for the Warralong system, W2, has an initial total plant capital cost of $AU 3,216,000and an annual operating cost of $AU 169,106 (retaining one of the existing diesel gensets of 110 kW). The net present cost for the system is $AU 5,402124with a LCOE of $AU 0.827/kWh and a simple payback of 5.4 years (discounted payback period of 6.6 years) compared with the existing (diesel genset) base case. The LCOE price of electricity for the hybrid hydrogen system is less than typical generation costs from diesel only systems (>$AU1.65/kWh) [14].

6.2. Non-Financial Business Case for Regional and Remote Communities

Apart from the positiveness of the financial business case the use of the hybrid PV-battery-hydrogen- based SAM system has many non-financial co-benefits for the community.

According to Mah et al. [11], for regional and remote stand-alone systems, apart from the reduction of total investment cost the main advantages of using hybrid PV-battery-hydrogen-based SAM systems include improvement of system efficiency, and enhancement of system lifetime. For instance, battery is efficient for short-term energy storage but inappropriate for long-term energy storage with its low energy density and non-negligible self-discharge rate. On the other hand, hydrogen has high power rates and is suitable for long-term energy storage. Thus, a hybrid battery- hydrogen storage system is usually more cost-effective than a single battery or hydrogen storage system. Hydrogen storage technology has the advantages of long lifetime, high-density energy storage, environmental protection, and lower maintenance cost. Therefore, hydrogen energy storage is the best choice to integrate with RES for standalone applications where remote regions are difficult to reach.

The advantages of hydrogen storage-based electricity over traditional chemical or mechanical-based energy storage technologies include their ability to provide vast volumes of clean and very dense energy without the complication of space, maintenance, and money that conventional high- capacity energy storage demands. Additionally, it is 'greener' and more robust in the maintenance cost, environmental impact, and storage requirements (it can be placed underground in sealed containers). On the other hand, traditional energy storage is poor and ineffective; Battery production consumes rare, vital minerals, alongside the ample physical space it requires; also, there's a constant deterioration in performance over time and has a short service life, with expensive recycling operations.

In the case of RES, ‘Green Hydrogen’ can be used as energy storage to buffer electrical gaps when high demand is needed, but renewable energy sources aren’t sufficient for the loads (night for solar, summer for wind turbines), or as a backup for micro-grid power plants that experience grid-tied shutdowns or poor supply.

The non-financial benefits of using hybrid PV-battery-hydrogen-based SAM systems include [18]:

- the potential thermal energy of the hydrogen energy lasts significantly longer than standard industrial batteries.
- it may be utilized (‘discharged’) at a higher rating and capacity (discharge rate or ‘depth of discharge’-in chemical battery terms).
- green hydrogen can be stored in sealed or inflated containers and cylinders above or underground.
- hydrogen fuel cells are a more power-dense source than fossil fuels and existing solid-state batteries, which can only use a portion of the potential energy per unit within.
- can be made to a small residence or industrials application.
- long service life up to 30 years.
- self-dependent power source without any ongoing fuel cost or shortages.
- simple maintenance.
- high reliability and safety.
- filling the cells may take few minutes while charging batteries might last several hours.
- can operate safely in extreme weather’
- the hydrogen can last a long time in storage without power reduction.
- the source material (water) is widely available in nature, not vital, and rare minerals are necessary for the operation.
- the system components don’t emit greenhouse gases; and
- hydrogen is a fuel twice dense as traditional fossil fuel.

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[18] Eilat-Eilot Renewable Energy “Green Hydrogen energy storage source for off-grid applications” Available fromhttps://www.eilateilot.org/database/green-hydrogen-energy-storage-source-for-off-grid-applications/ 4/5. – Accessed 25/09/2022.

Apart from the techno-economic benefits on the previous page, Mah et al. [11], have highlighted other potential benefits renewable fuel cell systems present for regional and remote communities, ranging from:

- improving public health and environmental quality.
- creating jobs and other economic benefits.
- providing combined heat and power.
- providing affordable energy prices.
- allowing capacity building and community empowerment; and
- allowing innovation in products, practices and policies.

The versatility of the P2H2P systems also being able to be used as a P2H2X system and provide hydrogen for other purposes sch as direct heating or hydrogen vehicles (which can have longer ranges than battery electric vehicles – important in remote areas) is another benefit for regional and remote areas.

A key benefit of a transition to hybrid PV-battery-hydrogen-based SA systems across the regional and remote aboriginal communities is the development of world-leading, best practice knowledge, capability and experience that will enable Western Australia to develop a new industry opportunity meeting the rapidly growing, massive need for such systems in regional and remote areas in the rest of Australia and worldwide. This includes not just systems design, construction and operation but also skills training and capacity building.

7

Hydrogen PLANT DESIGNS

As this project was a techno-economic feasibility study there was no detailed systems design done. The HOMER [16] modelling provided optimised system component/package sizings, which would need to be turned into detailed designs in the next stage. This section discusses some of the key design requirements needed during that design phase.

7.1 Scope Packages

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

7.2 Power Sources

7.2.1 Jinparinya Community

The optimal power source configuration for the Jinparinya system consists of a 84kW solar array system. The solar package incorporates all civil and structural requirements of the battery system requirements (including containerisation, temperature and humidity control, protection, cabling, wiring, and instrumentation, communications, monitoring, and control systems).

The optimal battery storage configuration for the Jinparinya system consists of a 80kWh Lithium- ion battery pack.

7.2.2 Warralong Community

The optimal power source configuration for the Warralong system consists of a 966kW solar array system. The solar package incorporates all civil and structural requirements of the battery system, and other requirements (including containerisation, temperature and humidity control, protection, cabling, wiring, and instrumentation, communications, monitoring, and control systems).

The optimal battery storage configuration for the Warralong system consists of a 480kWh Lithium- ion battery pack.

7.3 Water Treatment

The water treatment package supplies water to all users at the facility, including as feed to the water deionisation unit and subsequent electrolyser, as cooling water makeup, fire water, and occasional wash water. Water is supplied to the hydrogen plant from an on-site water source, in both community cases via an existing, or new bore. Once entering the water treatment plant, the raw water is filtered and routed to a reverse osmosis unit to deliver water to a treated water quality. Water suitable for human contact at a safety shower and an eye wash station is also supplied. The water treatment package also incorporates all required pumping, piping and valving, wastewater storage and pumps, backwash and/or cleaning equipment, chemical storage and dosing facilities as required, instrumentation and control system, and electrical equipment. Further water treatment to the purity required for the electrolyser will be done by a water treatment component within the electrolyser package – this is usually deionisation by ion exchange. The source of drinking water in most communities will be a community bore and this groundwater supply is not usually demineralised in the treatment process for drinking purposes. A co-benefit of the proposed hydrogen system is that firstly, treated wastewater can be used, and secondly or alternatively, a better-quality drinking water becomes available from the groundwater for higher order uses, for example, kidney dialysis at the health clinic. For the latter, patients are normally required to be flown to Perth and thus significant cost savings could potentially be available to the WA Government.

7.4 Hydrogen Production, Storage and Power Provision

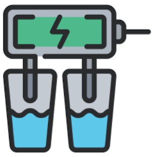
The hydrogen production, storage and regeneration equipment will be provided as a complete modular package, consisting of several containers or skids. The equipment consists of water deionisation (DI), hydrogen generation unit (electrolyser) and supporting equipment, hydrogen storage system, and fuel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

The hydrogen production and power system can be purchased as an already integrated pre-packaged unit (such as those provided by LAVO or GKN Tempo) or as individual component packages (electrolyser, storage system and fuel cell) and integrated together. This latter approach allows better tailoring to the specific community's needs and make it more flexible and easier to upgrade the system subsequently as the power needs of the community change. For example, the system can be changed to a P2H2X system to provide more hydrogen for direct heating or refuelling H2 FCEV vehicles by increasing the size of the electrolyser and the storage without needing to change the fuel cell system. This approach however has the disadvantage of needing extra work for design and optimal integration of the component systems and a more complex control system.

The optimal hydrogen production, storage and power provision component sizing for the two community power systems is described in the following sections.

7.4.1 Jinparinya Community

The optimal hydrogen production, storage and power provision configuration for the Jinparinya system consists of:



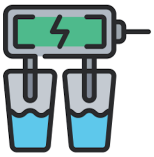
12 kW electrolyser

25 kg Hydrogen storage system

7kW fuel cell

7.4.2 Warralong Community

The optimal hydrogen production, storage, and power provision configuration for the Warralong system consists of:



200 kW electrolyser

200 kg Hydrogen storage system

60kW fuel cell

7.5 Balance of Plant

All remaining works required for the project will be sourced separately, including civils, piping and pumping outside of the vendor packages, cabling, fencing, lighting, etc. Utilities, including instrument air and nitrogen for purging, will be supplied externally. A fire water system is also included in the balance of plant - primarily intended to cool down walls and areas where hydrogen fire may impinge and cause integrity failure, not to extinguish the hydrogen fire. A deluge system will be installed for enclosed containers of equipment.

7.6 Telecommunications and Remote-Control System

Due to the regional and remote nature of most of the communities being serviced the energy systems will need to be unmanned operated and remotely monitored. As well as the central power station other smart grid elements, such as appropriate, robust, communications and networking infrastructure, load measurement and management of sensors and devices, and smart controls to form a smart grid will also need to be included as part of the design and installation of the systems.

Given the needs of the water supply systems on these remote communities, which are also best operated based on smart systems it is recommended that the energy systems designers, installers, and operators of both the energy and water systems be required to work together to develop a common, simple, and robust telecommunications and smart cities infrastructure that meets the requirements of both. This will not only lead to efficiencies in operation, troubleshooting and maintenance of the energy and water supply systems but the installation, operation, and maintenance of the telecommunications systems themselves.

7.7 Basis of Operations

The following assumptions are made for the operation of the facility:

- the facility will operate on a basis of 24 hours per day and seven days per week for a nominal 365 days per annum.
- at all times, the two sites will not be manned onsite but will be operating under remote control.
- at the Jinparinya community when the system is not operating power will be provided by the solar system and the grid.
- at the Warralong community when the fuel cell system is not operating power will be provided by the solar system and the retained diesel generator. This may be at a reduced rate at times of reduces, or low sunlight (such as overnight or cloudy weather). This will require sufficient, non-essential load shedding to enable the community load to be met by the one diesel generator during these times.

7.8 Hydrogen Plant Layout

7.8.1 Overview

As this was a techno-economic feasibility study no detailed plant layout consideration and design was done. In the subsequent detailed design of the systems specifically for each site the hydrogen plant layout design would need to be done including the footprints for each of the packages and consider separation distances required for hydrogen units and storage, according to relevant Australian standards (AS 1940, AS 2022), international standards and other relevant standards such as NFPA 2. Hydrogen storage capacity is limited due to the power requirements and is likely to avoid the facility being classified as a Major Hazard Facility. Plant layout should be selected to minimise pipe runs and cabling.

7.8.2 Plant Layout Considerations

The following main items would need to be considered in the proposed plant layout design for each site:

- boundary separation distances / site boundary / future expansions.
- process blocks—area allocations / separations.
- preliminary Hazardous Areas classification.
- storage—capacity, location.
- potential future hydrogen vehicle filling (following appropriate expansion of the initial P2H2P system with addition of a hydrogen fuelling system); and
- fire protection, emergency response access/egress.

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

- adequate spacing and separation distances between plant facilities allowing for major hazard incidents, constructability, maintenance access, and isolation.
- oxygen and hydrogen vent designs and positioning to be considered carefully to allow for good dispersion of gases, and to be positioned at an adequate distance from any potential ignition sources.
- perimeter access road for emergency services access.
- appropriate road surface finishes to manage storm water run-off, traffic movements and accessibility during weather events.
- the need for enhanced security fencing and security monitoring of the plant due to the remoteness and social settings of the systems; and
- separate controlled access to the main process plant area via fenced and secured gates.

7.8.3 Proposed Location

Once the systems designs have been determined an analysis of the community will be needed to determine the best location for the power station. The recommended hydrogen plant location will be decided based on location of existing power generation plant and associated grid infrastructure, ease of vehicle access, a geotechnical investigation, and the most adherent to the siting criteria.

7.8.4 Proposed Plant Layout

The proposed plant layout features the following characteristics:

- containerised packages for water treatment, electrolysis, hydrogen compression, and hydrogen storage.
- adequate spacing around equipment for maintenance vehicle movement and access.
- fourteen-meter separation between hydrogen equipment and security fence as per NFPA 2
- requirements; and
- unused space for future expansion stages.

7.9 Process Plant Control System Architecture

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

All process equipment will be controlled via an overarching, integrating Programmable Logic based providing both automatic and local manual control, operating as a system. Normal operation of the equipment will be automatic, with monitoring and operating control from a remote control-room via a SCADA system with the capability to be controlled locally Human-Machine Interface (HMI) if needed.

8

SUSTAINABILITY

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

8.1 Emissions and Waste Streams

During operation, the solar field and hydrogen plant will produce negligible waste streams, the main effluent being oxygen gas which is not harmful to the environment. Cooling water for the electrolyser is a closed system, however it will dispose of relatively clean water during blowdown. Hydrogen gas venting to atmosphere may occur during maintenance or emergency events, as well as nitrogen gas venting during purging. The water treatment plants emit most waste products during operation, with brine wastewater being deposited into wastewater ponds. Construction activities may contribute significant solid, liquid, and gaseous waste; however, these will be once- only for the construction and installation of the initial project. Construction waste from future expansion stages will likely be considerably lower since the main infrastructure will already be in place. These are discussed in more detail in Section 11.3.

8.2 Carbon Emissions Analysis

The modelling shows that the use of the hybrid PV-battery-hydrogen-based SAM systems will result in very low, or no, operational GHG emissions. For the Jinparinya community all proposed options are zero-emission and eliminate all the current power supply emissions from the grid, i.e., Scope 2 emissions, which are 33,448.6 kg CO_2-e per year (Scope 2 emissions factor of 0.58 kg CO_2-e/kWh for the NWIS, WA) [19].The emissions savings will be even higher for similar sized communities connected to diesel generator based mini-grids. For the Warralong community the scenario W1, which is a 100% RE SAM system with a battery-hydrogen ESS has a zero-carbon footprint, while scenario W2 has 6,776.7 kg CO_2-e per annum which is 1.6% of the base case scenario. This emission is due to the RE penetration of 98.5% in comparison to the 100% RE scenario in W1.

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[19] National Greenhouse Accounts Factors, Department of Industry, Science, Energy and Resources, Available from: https://www.industry.gov.au/data-and-publications/national-greenhouse-accounts-factors-2021, Dated 5th February, 2022.

9

Construction, Transport AND LOGISTICS

9.1 Overview

All main project packages (solar, water, and hydrogen) can be delivered as highly modular packages which are transportable via standard road and sea freight. All major process plant equipment would be containerised, and the solar field configuration can also be designed for ease of transport and installation. The two analysed case study sites have good access to the port of Port Hedland, with reliable roads that enable access by the trucks required to deliver the main project packages and the equipment needed for site works and construction. Jinparinya community is about 22 kilometres west of Port Hedland, just off the Great Northern Highway.

It is to be noted that if these systems are to be extensively used amongst remote communities, then the transport and logistics will be much more difficult for some sites. While the containerisation of the plant equipment should enable it to reach these more logistically challenging communities the cost and time will be increased and needs to be accounted for in the project planning and costing.

9.2 Modular Build Strategy

The use of modular, containerised component systems which are then integrated together on-site will enable improved construction, transport, and logistics.

9.2.1 Solar

There is now significant experience with the successful use of solar systems in hybrid systems in regional and remote communities in both Western Australia and the Northern Territory. This includes regional utilities such as Horizon Power (WA) and the Power and Water Authority (NT), as well as NGO's such as the Centre for Appropriate Technology through their Bushlight program. The experience from these installations would be applied to the building of the solar generation component of the systems. The solar system components, supplied by manufacturers in China, Japan, the USA and other countries, can be sourced from local Australian agents/distributors.

9.2.2 Water Treatment

The water treatment plant would be a fully containerised system that could be installed inside the same container as the fuel cell. Also provided as a standalone item will be the safety shower and eye wash station module with local storage. All the major components of the water treatment package can be sourced from local Australian agents/distributors.

9.2.3 Hydrogen Production and Power Regeneration

All hydrogen production equipment is available in a fully containerised form.

9.2.4. Construction Resources

A suitable contractor would be engaged to install all process equipment as well as balance of plant requirements including (but not limited to) civils, piping, roads, fencing, lighting, and cabling. All materials are readily available from local suppliers. Where possible local community members would be used to undertake civil, site and other work where possible.

10

Operations and MAINTENANCE

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

10.1 Overview

As the systems will be installed and operated in regional and remote areas, usually operating under harsh conditions, with limited access to local, or nearby, timely maintenance and support, it is important that they are designed, engineered, and tested for the conditions, to ensure enhanced reliability. It is also important that the systems be as simple as possible using a standardised set of components manufactured and tested to withstand the harsh operating conditions experienced in the communities. In this way the need for maintenance and repair will be reduced. It will also be able to get the required technical support as there will be less systems and components for local maintenance and repair staff to be familiar with.

The integrated solar, hydrogen, and water plants will be designed for a high level of automation and minimal manual plant operations support. As has been discussed in Section 7 the systems would be predominantly operated remotely, with the capability to be operated locally if required due to extenuating circumstances (such as loss of, or problems with the communications system) or for onsite maintenance or repair.

10.2 Jobs

As the systems are in remote areas and operated remotely using satellite or telecommunications and can be in widely separated small communities (5 or 6 houses) there is not the need for any full-time staff. There is however the need for each community and system to have a suitably trained casual person who can undertake simple routine operational or maintenance and troubleshooting activities. The systems can also do manual operation should there be an issue with the remote-control telecommunications system. If communities are sufficiently close together one person may cover several communities. O&M activities may be undertaken by the system owner/operator (such as REMS or Horizon Power) or outsourced to specialist third party contractors.

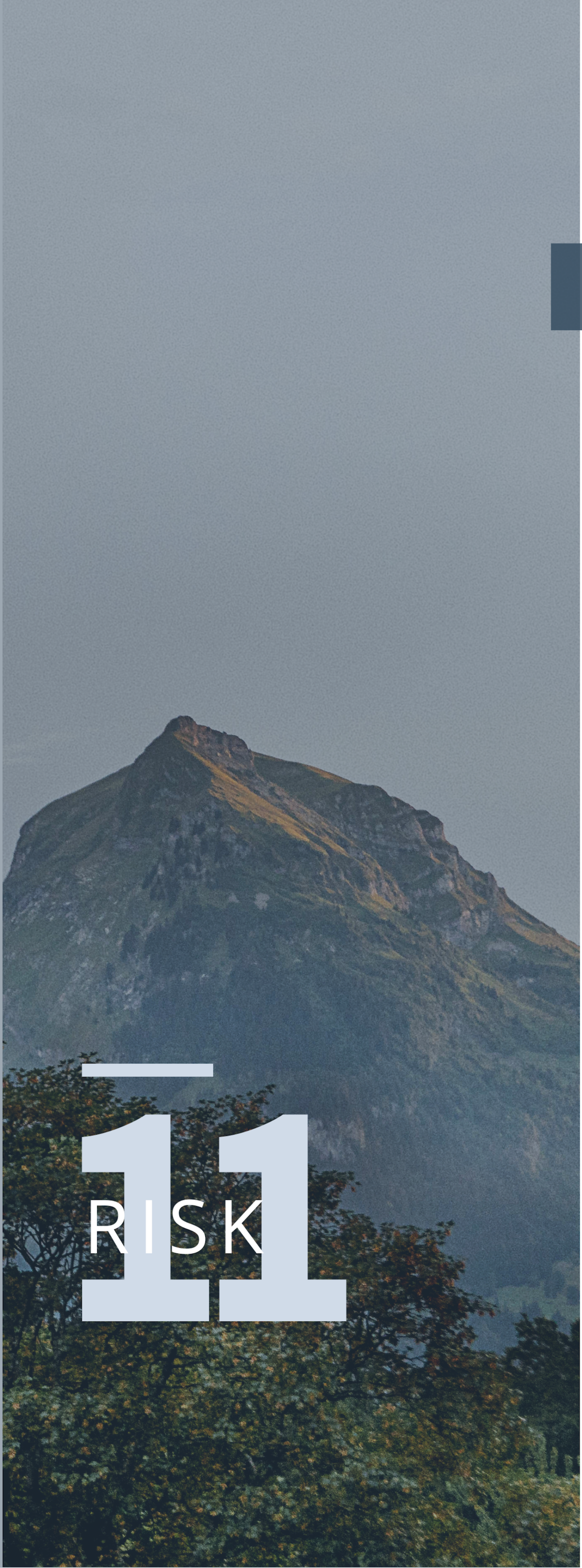
10.3 Defects Liability

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

Broadly, the following defects warranties are offered by the manufacturer:

- solar modules and DC connectors/cables normally:
  - solar panels: 10 years.
  - inverters: 5 years.
  - cables: 2-5 years.
  - solar system: 2 years.
- water treatment plant: first of 12 months from commissioning or 15 months from delivery.

Warranty agreements would be confirmed when the detailed systems design was completed.



11

RISK

11.1 Overview

Potential risks, and associated mitigation strategies need to be identified early so that they could be incorporated into the final designs. An analysis was undertaken to identify key risks which may impact on the following:

- safety
- environmental and health
- compliance
- financial and project cost
- reputation
- operations /delivery; and
- project quality.

The results of this analysis and suggested management strategies are discussed in the following sections. This analysis shows that while there are several potential risks associated with the implementation of new technology in harsh remote area conditions, previous experience with other similar rollouts of new power generation technologies, such as the hybrid PV-diesel systems rolled out by the successful Bushlight program, that these risks can be successfully managed. With the risks being able to be well managed the inherent techno-economic advantages of these systems (as discussed in the business case in Sections 6.1 and 6.2) mean that they are the best solution for meeting the power generation needs of the communities and the decarbonisation targets of the Australian and State governments.

11.2 Safety - Hazard and Operability Analysis (HAZOP)

Due to the remote locations, harsh operating environments and social settings where the systems will be implemented there is an enhanced safety risk, especially during the operational phase. Hydrogen-related policy and standards are developing quickly worldwide to overcome the barriers to adopting and implementing hydrogen-based power systems. There are existing international standards from peak organisations such as ISO for hydrogen and hydrogen-related technologies, safety and performance, such as ISO 14687- X, ISO 16110 – X, ISO/TS 19883, and ISO 22734 -X. Additionally, Australia, like many other countries, is adopting relevant existing national standards with revisions to determine the extent to which they are appropriate for use with hydrogen gas technologies, such as AS 2885, AS 4645, AS 4568, AS 4564, AS/NZS 5263.0, AS/NZS 5601.1, and AS 3814. However, the project must comply with WA State-specific regulations as well, if any. Hence, the design of all proposed systems must be assessed for hazard, safety, and handling procedure, primarily when hydrogen is in use. Standards Australia (The ME-93 Hydrogen Technologies Committee) has adopted and developed a set of hydrogen standards that will need to be met in the design, construction and operation of the systems, such as: [20]

- AS ISO 19880.8:2021, Gaseous hydrogen - Fuelling stations, Part 8: Fuel quality control
- AS 16110.1:2020, Hydrogen generators using fuel processing technologies, Part 1: Safety (ISO 16110-1:2017 MOD)
- AS ISO 16110.2:2020, Hydrogen generators using fuel processing technologies, Part 2: Test methods for performance
- AS ISO 14687:2020, Hydrogen fuel quality – Product specification
- AS 22734:2020, Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications (ISO 22734:2019, MOD)
- SA TS 19883:2020, Safety of pressure swing adsorption systems for hydrogen separation and purification (ISO/TS 19883:2017, MOD)
- AS ISO 16111:2020, Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride
- AS ISO 19881:2020, Gaseous hydrogen – Land vehicle fuel containers
- AS 19880.3:2020, Gaseous hydrogen – Fuelling stations, Part 3: Valves (ISO 19880-3:2018, MOD)
- AS 26142:2020 Hydrogen detection apparatus – stationary applications (ISO 21642:2010 Ed 1.0 MOD)
- AS-NZS 60079 - Australian Hazardous Area Standards

All relevant specific WA State and local regulations will also need to be complied with.

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[20] Standards Australia website; https://www.standards.org.au/search?q=hydrogen&mode=allwords&sort=relevance

11.2 Safety - Hazard and Operability Analysis (HAZOP) (cont.)

Once the final systems designs and operating procedures are completed for each site a HAZOP analysis will need to be undertaken and the appropriate procedures and management strategies put in place. The explosive nature of the hydrogen, and unfamiliarity with the technology heighten the need for good operational procedures, risk management strategies and appropriate training of all relevant site staff. This includes not just operational and maintenance staff but emergency response staff.

Also, hydrogen systems' operability requires additional engineering controls because many different types of equipment will be delivered from different OEM companies unless integrated (ready to use) systems are proposed. Therefore, the Project Team considered the HAZOP cost in the initial fixed cost for each project.

11.3 Environmental and Health

11.3.1 Noise and Vibration

Noise and vibration are sources of emissions which can have a detrimental impact on personnel and the environment at high levels. The National Institute for Occupational Safety and Health (NIOSH) has a Recommended Exposure Limit (REL) for occupational noise exposure which has been widely referenced across the world. The NIOSH REL for occupational noise exposure is an eight-hour time-weighted average of 85 decibels [21].

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

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

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[21] U.S. Department of Health and Human Services (1998) “Criteria for Recommended Standard Occupational Noise Exposure”. Available from https://www.nonoise.org/hearing/criteria/criteria.htm. Accessed on 17/11/2022.

11.3.2 Emissions and Waste Streams

Emissions for gaseous, liquid, and solids generated as a result of the facility are summarised in Table 2.

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

The water treatment plants emit most waste products during operation, with brine wastewater being deposited into dedicated ponds.

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

Table 2: Emission type per process

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

11.4 Compliance

11.4.1 Local and State Government Approvals Plan Review

Based on the preliminary assessment of potential environmental impacts against relevant environmental legislation in other hydrogen projects it has been identified that the following may be required:

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

The requirement to meet these Government approvals should be assessed following the design (including location on site) with the submission of approvals as required.

11.4.2 *Environmental Protection Act 1986* (WA) Part V

Part V of the *Environmental Protection Act 1986* (WA) herein known as 'EP Act' enables the Department of Water and Environmental Regulation (DWER) to regulate waste, emissions, and discharges to the environment, and native vegetation clearing, with clarifications provided in the Environmental Protection Regulations 1987/Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Specified premises with potential to cause emissions and discharges to air, land, or water are known as “prescribed premises” (described in Schedule 1 of the Environmental Protection Regulations 1987 (EP Regulations) and trigger regulation under the EP Act. The EP Act requires a works approval to be obtained before constructing a prescribed premises and makes it an offence to cause an emission or discharge unless a license or registration is held for the premises. Works Approvals and Licenses are the key statutory tools the DWER use to regulate industry in WA and are intended to prevent pollution during both the construction and operational phases.

Unless a project is already assessed under Part IV of the EP Act, the clearing of native vegetation in WA requires a permit under Part V of the EP Act (except when a project is assessed under Schedule 6 of the EP Act or is prescribed by regulation in the Environmental Protection (Clearing Native Vegetation) Regulations 2004 and not in an Environmentally Sensitive Area). Permits can be granted subject to any conditions that DWER considers are necessary for controlling environmental harm or offsetting the loss of vegetation. When preparing a native vegetation clearing application an assessment of the works against the “Ten Clearing Principles” should be undertaken to determine whether this project is likely to be at variance to the principles. The Ten Clearing Principles aim to ensure that all potential impacts resulting from removal of native vegetation can be assessed in an integrated way.

11.4.3 Development Application

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

It is recommended that a development application be accompanied by a supporting report. This report should outline the proposed development, including building design and site related features, and address amenity related issues such as noise, traffic, access, dust, buffering to adjoining uses, construction works, and the operational staging.
In addition to addressing the relevant provisions of a local planning scheme or region scheme, the development application should also acknowledge relevant state and local planning policies.

11.4.4 Dangerous Goods Licensing Requirements

Dangerous goods requirements for the site will primarily be driven by the quantity of hydrogen storage and inventory on site. This will vary between communities and will be determined following system design. If the system is found to produce and stores an amount of hydrogen above one of the following thresholds, then the system will need to meet the relevant Dangerous Goods Licencing requirements.

The thresholds levels are listed below:

- Dangerous Good License: 5,000 litres hydrogen.
- Major Hazard Facility Notification Form: 5 tonnes hydrogen (threshold of 10% of 50 tonnes hydrogen major hazard facility); and
- Major Hazard Facility: 50 tonnes of hydrogen.

11.5 Financial and Project Cost Risk

Some economic/cost values in the modelling (see Table 1) were default values for key input parameters (such as price of diesel, PV panel, fuel cell, hydrogen tank etc., and cost of generating electricity at Port Hedland). These may not reflect the true values, especially for implementation in remote areas. It is also well known that implementation of projects in remote regions and sites is inevitably more expensive than originally thought. There is significant risk of financial and project cost (e.g., CAPEX for the system and site works) increases/changes when undertaking the project which could affect the viability and financial benefits of the project. To try and quantify the size of this risk the project undertook a sensitivity analysis around key financial values and assumptions used in the modelling. The variations in key economic factors for the two projects are shown in Table 3.

Table 3: Variation in the hybrid hydrogen system model techno-economic input parameters

System Component	CAPEX/OPEX (AUD)	+/- % on sensitivity
Solar PV system	$1,000 kW / $10 kW/yr	-10%, -20%, +10%, +20%
Li-Ion Battery Bank	$550 kWh / $5 kWh	-10%, -20% and -30%
H2 Electrolyser	$2,500 kW / 10 kW/yr	-50%, -20%, +20%
H2 FC	$3,350 kW / $1 Op hr	-50%, -20%, +20%
H2 Tank Low-Pressure	$1,000 kg H2 / $5 kg H2	-20%, +20%
Fixed Capital	$220,000 (a) $781,000 (b)	-20%, +20%, +50%, +100%
Yearly Operational	$24,000 (a) $104,000 (b)	-20%, +20%,+50%
Diesel price		-20%, +20%, +50%

11.5 Financial and Project Cost Risk (cont.)

From the modelling the costs that are most likely to lead to financial risk for the project are increases in:

- Fixed capital costs: Engineering design, tendering, approvals, and civil work; and
- Capital costs of the system components (e.g., Solar PV system, H2 fuel cell etc).

In the sensitivity analysis the fixed capital costs have been varied by between +20% and +100% to try and quantify the financial risk from that component. The capital cost of the system components (e.g., Solar PV system, H2 fuel cell etc) could also increase in cost (especially if there are supply and demand or supply chain issues) but the costs of these components are projected to decrease over time due to technology and mass production gains rather than increase. It is possible that the cost of some components may increase due to the need for more robust quality or environmental resilience requirements for use in remote areas. The main system components have been clumped together as one item and varied by (an average) + 20% to try and quantify the financial risk from these components. The diesel price has been varied between -20% and +50% to see the impact on the payback period, but this is not expected to be a financial risk for the project, as there is a need to rapidly transition away from diesel systems, regardless of the payback period if the decarbonisation targets are to be met.

For the optimal Jinparinya system design even with a doubling (100% increase) of the system fixed capital cost and 20% increase in capital cost of the hydrogen system the LCOE for the optimal system design only increases by 24%. This means an increase in LCOE from $1.044/kWh to $1.30/kWh, which is still below the lower range of the diesel only mini-grid price of $1.65/kWh.

For the optimal Warralong system design, assuming the base case diesel price ($2.80/litre) even with a doubling (100% increase) of the system fixed capital cost and 20% increase in capital cost of the hydrogen system the LCOE for the optimal system design only increases by 19%. This means an increase in LCOE from $0.827/kWh to 0.981/kWh which is still well below the lower range of the diesel only system price of $1.18/kWh. Even with a diesel price increase of 20% to $3.36/litre the LCOE only increases to $0.924/kWh, which will still be below the diesel only system whose LCOE will also increase.

11.5 Financial and Project Cost Risk (cont.)

It is clear from the modelling that even with significantly increased system fixed capital costs and 20% increase in the capital cost of the hydrogen system the hybrid hydrogen system is still the lowest LCOE solution, even compared to the base diesel only case. The hybrid hydrogen system has the added advantage of resulting in an ~98% reduction in GHG emissions compared to the base case.

The financial risk in the large-scale roll-out of the hybrid hydrogen systems across the ~120 Aboriginal homelands communities can be mitigated by building and trailing 2 or 3 hybrid hydrogen systems in remote aboriginal communities to test the actual fully installed system cost. The fully installed price of these systems can be compared with the corresponding PV and battery only systems also built and tested as part of the trials. In this way the true, installed cost and financial benefit of the hybrid hydrogen systems can be known prior to large scale roll-out, reducing the financial risk.

11.6 Reputation Risk

Hydrogen storage and power systems are new technologies which are not widely known or experienced, compared to diesel systems, or even now PV-diesel hybrid systems. This includes a lack of knowledge of their reliability, especially in harsh conditions and remote areas. There is also widespread uncertainty in the general community about the safety of using hydrogen considering the regularly referred Hindenburg airship disaster. Therefore, it is critically important that any hydrogen power systems installed, especially initially, are well engineered for the harsh conditions of the Pilbara and other remote areas and are reliable and safe.

If the first systems installed are not reliable, leading to prolonged or regular power failures, are complex and difficult to use and maintain, or there is a significant accident involving the hydrogen in the early systems then there is a risk of significant reputation risk. This means that other communities and potential users will be unwilling to use the technology and the roll-out of these types of systems would be delayed by many years.

11.6 Reputation Risk (cont.)

There are several things that need to be done to mitigate this risk:

- Standardised, simpler, more robust systems and components need to be used, with overengineering for safety and reliability rather than more complex innovative systems being used.
- All components, and then the whole integrated systems, need to be thoroughly tested and proven for the harsh conditions encountered in remote areas using initial component testing in a suitable standard testing lab then with demonstration systems trialled or sufficient time (at least a year) in typical remote regional sites.
- Once roll-out commences there need to be an ongoing monitoring program to measure the performance and safety of the early systems, with any remedial actions being implemented pro-actively and quickly. This includes changing the design or components of subsequent systems.
- All relevant safety and design standards need to be adhered to with reliability, and particularly safety, being the prime consideration in the systems design and implementation.
- There needs to be suitable, comprehensive training of installers, operators and maintenance staff so that they undertake their tasks to the highest standard and according to the relevant standards.
- There needs to be an established maintenance and repair network, with well- articulated preventative maintenance guidelines as well as acute repair guidelines. There needs to be sufficient suitably trained technicians and trades persons, and sufficient spare parts within suitable distances of all communities to ensure that power outages are kept to a minimum and are as short as possible.
- During the system testing and trailing stage, and in the initial stages of the rollout the existing generation systems should be retained in parallel with the hybrid hydrogen systems as emergency back-up until the reliability of the new systems has been proven and accepted by the communities.
- There need to be a very good communications and capacity building program within the communities themselves to make them familiar and comfortable with the systems prior to the installation.
- Any roll-out program should be undertaken using a co-design approach whereby Aboriginal homelands representatives and other key stakeholders are involved at every step.

11.7 Delivery and Timeline Risk

As these systems are to be installed and operated in remote areas there is a risk of delivery and operational issues and delays. The issues with delivering any kind of infrastructure in a timely manner within budget to remote communities and other sites is well known. These will need to be managed by good project management and realistic milestones and schedules. There is also the risk of delays and cost increased due to the demand for systems components and supply chain issues. These need to be managed by good procurement processes, realistic time frames and timelines, and contingency funding for cost increased. The use of local assembly and integration of the system components in containerised form will make the delivery and installation of the systems easier and reduce the risk. As discussed in the previous section there is a need to ensure that there are sufficient suitably trained technicians and trades people to build/assemble, deliver and install the systems in a high-quality manner according to the program/project schedule. The roll-out of the systems needs to be carefully project managed using companies with knowledge of the challenges of remote regions and aboriginal communities and proven experience in successfully delivering infrastructure preferably power to these communities.

11.8 Project Quality Risk

As discussed in the previous two sections it is important that the systems installed are fit for purpose, reliable, safe and built and installed with high quality. If the installed systems are not of sufficient high quality, then there is a likelihood of a higher rate of failure and an increased risk of safety issues. The risk of system and project quality issues can be managed mainly using the measures discussed in the previous two sections. This mainly involves only using a select set of standardised components and systems designs tested and proven as being fit for purpose for the operating environment. Ensuring that they are installed by suitably qualified technicians and trades people by companies who are required to meet and guarantee suitable quality standards. While this will potentially increase the initial capital cost it will result in reduced ongoing O&M and LCOE costs as well as providing more reliable and safe power delivery to the community.

11.9 Operational Risk

Due to the remote nature of the systems and the need for remote operation via telecommunications links there is a degree of operational risk, particularly if there are issues with the telecommunications systems. There are several ways to mitigate the operational risks.

- The use of standard simple systems with standard operating procedures and control systems which are designed for a high degree of autonomous operation.
- Collection and analysis of systems and component performance data to identify, and allow rectification of, any potential operational issues early.
- Capability for the system to be operated locally in isolated mode for a period if required. Someone on the community should be trained to know how to do simple operation tasks until such time as the remote operational control can be restored.

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SUMMARY

A 100% renewable energy stand-alone power system can be economically and technically achieved using a resilient hybrid battery-hydrogen storage system to provide a sufficient and stable power supply. In this feasibility study, two different sites were studied to techno-economically evaluate the transition to a 100% RE-based SAM power system utilising a hybrid battery-hydrogen storage system. The first site was the Jinparinya Community small-scale grid-connected system to be expanded to a large-scale 100% RE SAM power system to avoid the cost of expansion of their grid-connection and become a pilot zero-emission project.

The second site was Warralong, a REMS Community, where a medium-scale diesel-powered transition to a 100% RE SAM power system has been modelled as a pilot project also utilising a hybrid battery-hydrogen storage system.

To increase the robustness and identify the most optimal option for the locality in terms of cost of energy and GHG emissions several scenarios were considered in the modelling. Simulation analyses revealed that a larger capacity hydrogen system could add more energy autonomy, but at a price. The battery bank follows the load fluctuations while the hydrogen fuel cell generator covers the baseload.

The option of using one of the existing diesel generators at Warralong community for backup and autonomy was techno-economically evaluated. This model's simulation revealed a longer period of more autonomy and less energy cost at a penalty of 98.5% instead of a 100% RE penetration.

Both the literature and the simulation studies undertaken in this work show there is a very compelling business case for the use of hybrid PV-battery-hydrogen-based SAM systems, especially in regional and remote areas.

To meet the GHG, and generation cost reduction aims of the Western Australian Government a transition program should be developed and funded, starting with a carefully designed set of demonstration systems, including ones at each of the two sites, prior to implementation of a full transition program for the other ~117 regional and remote aboriginal communities and homelands in Western Australia.

The present study has demonstrated and laid out a potential transition model to sustainable energy and improved outcomes for these communities. Given the WA State Government's commitment to an 80% reduction in greenhouse gas emissions within their own operations by 2030 and Net Zero Emissions by 2050 the development and commencement of a transition program for the implementation of these types of systems should commence as a matter of priority.