Denham Hydrogen Demonstration Project

Construction and Commissioning Report

Version No: 1

HORIZON POWER

Acknowledgement of Country

We respectfully acknowledge Malgana people as the original custodians of the lands where the Denham Hydrogen Demonstration Plant is located.

We recognise their connection to Country as they hold the memories, the traditions and culture through the lands surrounding Denham and extend that respect to all First Nations people across our service area.

May their strength and wisdom be with us today as we walk together on our Reconciliation Journey and acknowledge the past, present and emerging leaders as we gather together on Malgana Country.

#

Table of Contents

1. PROJECT DETAILS

Recipient Name	Regional Power Corporation trading as Horizon Power (ABN 57 955 011 697)
Primary Contact Name	Renato Pascucci
Contact Email	renato.pascucci@horizonpower.com.au
Reporting Period	Milestone 3 – Construction and Commissioning (Jul 2022 – Jan 2024)

2. Project Funding

Australian Government
Australian Renewable Energy Agency

ARENA

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

Acknowledgement of Grant Funding

This Project received funding from ARENA as part of ARENAs Advancing Renewables Program and from the Renewable Hydrogen Fund as part of the Western Australian Government's Renewable Hydrogen Strategy.

Disclaimer

3. Executive Summary

Horizon Power operates remote electricity microgrids throughout Western Australia.

These microgrids use a mix of diesel, gas, solar, and wind sources for generation, and the increased use of renewable energy for these remote power stations are a priority for Horizon Power.

The use of hydrogen to capture and store excess renewable energy and then return that energy to the electricity system provides a viable alternative to the continued consumption of diesel, also provides an energy storage mechanism that may compete favourably with batteries.

The Denham Hydrogen Demonstration Project (the Project) is located at the town of Denham, approximately 800km north of Perth that is home to about 800 permanent residents plus a high volume of seasonal tourists. The power system in Denham is a remote hybrid microgrid, not connected to any other grid, and relying on diesel, wind, and solar generators plus a battery energy storage system. This Project involved the addition of a green hydrogen generation and storage system powered by a new dedicated solar array.

The main objective of this Project is to advance learning, specifically in the areas of technology, understanding costs, the regulatory requirements, and the impacts and acceptance by the community of hydrogen as a fuel source.

Horizon Power aims to enhance technology and commercial readiness for renewable hydrogen energy, fostering understanding of its application in microgrid power systems and operations. Then use this information to determine how hydrogen technology can be applied in other remote microgrids.

The unique integration of various hydrogen equipment and components within a microgrid as an energy source, sets this project apart in Australia.

A benefit of this project is also an increase in renewable energy generation in Denham, reducing diesel consumption and emissions, with renewable energy from both the dedicated solar farm and the fuel cell supplying the power system.

An EPC Contract for the Works was awarded to Hybrid Systems, in December 2020, with an initial completion date of January 2022, which was not met. But despite delays attributed to COVID-related challenges and unforeseen technical issues, including unexpected equipment reliability issues, the Project is delivering its objectives and benefits, and operational.

The Project has been a great opportunity for Horizon Power and its contractors to learn and apply those learnings and will aid future projects. A summary of some of the learnings from the construction and commissioning stages include:

- Early and collaborative engagement with regulators has proved beneficial, offering valuable lessons applicable to future hydrogen projects beyond regulatory compliance. The construction and commissioning stages, including preparation for operational readiness has involved upskilling across Horizon Power and Hybrid Systems, and the regulators.

- The development of a custom control program for the autonomous control of the plant's sub-systems and its integration with the power station control system, demanded significant effort and skilled resources. A control system with high level of maturity was a critical achievement for the success of commissioning and safety operation.

The purpose of the trial was not to produce as much renewable hydrogen as possible, or to optimise for minimal costs - instead it was to prove that hydrogen storage systems can be used as a viable means to store excess renewable energy and return that energy to a power grid, thereby 'time shifting' the renewable energy.

Future projects hold the potential to mitigate costs through scale, optimal utilisation of excess renewables, and use of combined energy sources such as wind and solar to increase the use of the electrolyser capacity across a 24hr period.

The continuous monitoring planned during the 12-month operational phase will yield comprehensive data for efficiency assessments and potential improvements.

The Project not only contributed to upskilling both Horizon Power's people and Contractors for the future hydrogen market, but also serves as a knowledge-sharing platform for the broader industry's benefit.

Horizon Power Denham Hydrogen Demonstration Plant represents a critical step toward cleaner generation, more resilient renewable energy solutions. As we pioneer this concept, we remain committed to sharing our knowledge and driving the transition to a sustainable energy future.

Denham power station and hydrogen plant with the wind and solar farms at the horizon.

4. Purpose

This report details the learning and information from the construction and commissioning phase of the Denham Hydrogen Demonstration Project.

Information in this report supplements the ARENA Funding Milestone 1 and 2 Lessons Learnt Report, with focus on the following areas relating to this project:

- Project objectives,
- Hydrogen plant technical specifications,
- Project delivery methodology,
- Design considerations,
- Key project metrics,
- Risk management,
- Project approvals,
- Construction and commissioning activities, and
- Lessons learnt and key findings.

5. Project Information

5.1 About Horizon Power

Horizon Power is responsible for generating, distributing, and retailing electricity to approximately 53,000 customer connection points in the network, including residential, business, and major industry, across regional and remote Western Australia.

Our customers live and work across 2.3 million square kilometres, stretching from Esperance in the south to Kununurra in the north and a whole list of other incredible places in between, making us responsible for the largest geographical catchment of any Australian power provider.

We operate 38 power systems, including 34 microgrids tailored to meet the unique needs of some of the most isolated and remote communities in the world. Recently, Horizon Power transferred an additional 117 microgrids from the Dept of Communities to Horizon Power, and Horizon Power is integrating these into our operational care over the 2024 – 2025 period.

Horizon Power utilises three types of energy sources; gas, diesel, and renewables such as wind, solar and hydro, and This Project has introduced hydrogen.

For more than a decade our microgrids have been the test beds for innovation in our journey towards emission reductions.

5.2 Overview

Horizon Power has several remote diesel power systems throughout Western Australia such as Denham. Alternative fuels and increased use of renewable energy for these remote power stations is a priority for Horizon Power to achieve its decarbonisation targets.

The use of hydrogen to capture and store excess renewable energy (on power systems that have a surplus) and then convert back to electricity provides a potentially viable alternative to the continued consumption of diesel, and the deployment of batteries.

The Project objective is to understand the capability of providing reliable baseload power generation by converting renewable energy to green hydrogen and then converting the hydrogen to electricity for use within the community. The Project is a pilot plant to prove a concept which may then be expanded with the learnings transferred to other sites.

In short, the Project has met its objectives, albeit with several issues that have been successfully addressed along the way.

The demonstration plant utilises solar and renewable hydrogen generation and storage to produce the equivalent energy used to power 100 homes per year (the Project). This is nominally 526 MWh per year (from solar and renewable hydrogen) of which at least 220 MWh will be provided by renewable hydrogen through a hydrogen fuel cell.

The demonstration plant has been constructed in Denham, which is located approximately 800km north of Perth in Western Australia. Denham's economy relies on tourism as it sits in the heart of Shark Bay Marine Park. As such, the tourism business (food and accommodation) drives the main power load in the town.

The Project depended on the Denham Power Station Upgrade Project. The 2.6 MW diesel power station's aged and unreliable equipment, including the switchboard, fuel system, transformer, and control system, were replaced and redundant fuel tanks removed to allow space for the demonstration plant. A new 1.5 MW / 1.7 MWh Battery Energy Storage System (BESS), separate 640 kWp DC solar farm and microgrid controller were also installed as part of this separate project to coordinate the control of the different energy sources, including the hydrogen produced electricity from this Project.

5.3 Key Benefits and Objectives

The primary objectives of this Project are about learning and sharing the knowledge with industry, specifically in the areas of technology, understanding costs, the regulatory requirements and the impacts and acceptance by the community, as further detailed below:

Technical

- Trial innovative technology,
- The installation, integration, and efficiency of hydrogen into existing energy systems,
- Level of firm capacity provided based on the renewable input,
- Ongoing maintenance and reliability, and
- Frameworks and processes to replicate this technology deployment.

Commercial

- True price point of current equipment and cost of system integration, and
- True Levelised Cost of Energy (LCOE) comparison of diesel vs hydrogen.

Regulatory

- Understanding of approvals and licences required from an operational, safety, and
- environmental and government perspective.

Community

- Creating direct jobs and indirect by contributing to the future hydrogen market,
- Community trust and social acceptance of hydrogen generation,
- A step towards decarbonisation, and
- Share knowledge and learnings with industry.

The Project delivered an end-to-end demonstration plant incorporating green hydrogen energy into a microgrid with solar, wind, battery, and diesel. The Project aims to improve both technology and commercial readiness of renewable hydrogen energy, by creating knowledge about the technology, how it can be used in a power system, and how it needs to be operated and maintained. Horizon Power will use this information to determine how this technology can be applied in other remote micro-grids.

6. Project Approach

6.1 Procurement and Project Management Methodology

Horizon Power undertook a procurement process, including an Expression of Interest and Restricted Request for Tender process, to select an Engineering, Procurement and Construction (EPC) Contractor to deliver the Hydrogen Demonstration Plant and integrate it into the Denham power station.

The EPC Contract was awarded to Hybrid Systems Pty Ltd (Hybrid Systems) in December 2020. Hybrid Systems, now a part of the Pacific Energy Group, was chosen for its broad experience base in successfully delivering and operating remote hybrid grids at sites around Western Australia. Prior to the award of the contract, an Early Works Agreement was signed with them to allow the order of the long lead time items of the electrolyser and fuel cell.

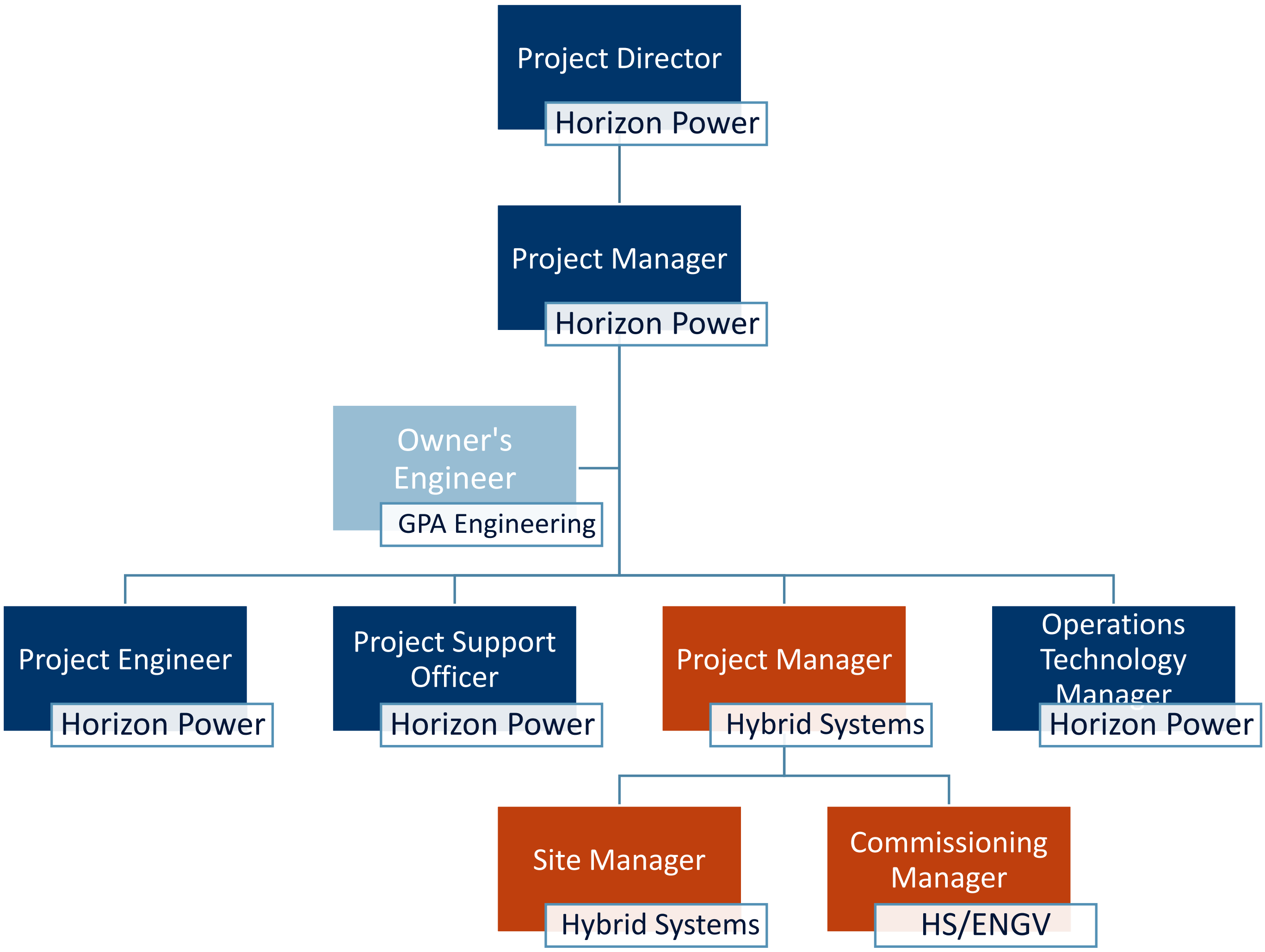
ENGV was awarded the sub-contract for supply and commissioning of hydrogen generation technology. ENGV is a nationally recognised industry partner in the integration, deployment, and maintenance of renewable and traditional gas technologies. The technology partners selected for key hydrogen generation equipment are Nel Hydrogen for electrolysis and PowerCell Group for the fuel cell.

Horizon Power engaged GPA Engineering to act as our Owners Engineer and provide the relevant experience and input into the design review process. GPA Engineering has had extensive involvement in similar hydrogen projects that have progressed through design into the construction and commissioning phases.

The Project has followed the internal Horizon Power project management methodology. A Project Board was established to provide overall direction and management of the project, with a Project Manager and Project Director responsible for the delivery of the project, working closely with Project Board members, key stakeholders, consultants, contractors, and the project team as the project progresses.

Project delivery team

The Diagram below details the delivery team roles and responsibilities.



Project team details

The Horizon Power project team mostly comprised of employees residing in Western Australia. The EPC contractor and subcontractors engaged to deliver the construction and commissioning works comprised of employees and contractors with the workforce residing in WA and interstate.

Project team	Number of Jobs	
	Horizon Power (Part-time)	EPC Contractor
Design Stage	15	12
Construction stage (including solar farm)	17	31
Commissioning and Operational Readiness stage	21	13

Resource Requirements

The table below shows the total number of hours that the Horizon Power and the EPC Contractor teams spent on the delivery of the project.

Project Stage	Approximate Work hours
Design stage	8,312
Construction stage	13,761
Commissioning and Operational Readiness stage	9,637

6.2 Project Stages

The key stages of the project delivery include:

- initiation and kick-offs with stakeholders
- detailed design and procurement including:
  15%, 50% and 85% design reviews and deliverables,
  Safety in Design risk workshops (HAZID, HAZOP, CHAZOP)[1],
  IFC drawings.
- factory acceptance testing
- construction
  Construction and commissioning risk assessment workshops,
  civil works,
  electrical and mechanical works,
  control system and communication works.
- pre-commissioning and commissioning, including connection of temporary load bank and generator,
- integration testing, including connection to the power station,
- operational handover, including training and all operational readiness documentation,
- reliability testing, and

[1] Hazard Identification (HAZID), Hazard & Operability study (HAZOP), Power & Control Systems Hazard & Operability study (CHAZOP).

- monitoring of performance over an operating period of 12 months for learning and knowledge sharing with industry.

6.3 Schedule

The EPC Contract, awarded to Hybrid Systems in December 2020, set a completion date of January 2022 and an overall project completion date of April 2022.

The project faced significant delays, attributed to a combination of COVID supply chain related delays and technical challenges, primarily due to the unprecedented nature of the project as one of the first of its kind in Australia, integrating hydrogen facilities into a microgrid.

6.3.1 Multidisciplinary Engineering Design Challenges

Hydrogen facilities require multidisciplinary engineering design, including process engineering, to enable the successful integration of different equipment packages. Gaps in experience across disciplines, both from Horizon Power and the Contractor, became evident. Addressing these gaps necessitated a strategic approach, involving upskilling initiatives and the engagement of subject matter experts (SME) to ensure a comprehensive and safe design.

6.3.2 Regulatory and Licensing Complexities

The Dangerous Goods Safety (Storage and Handling of Non-explosives) Regulations 2007 requires licence for a storage and handling facility exceeding 5,000 litres of hydrogen. The 13.23 kl of compressed hydrogen stored on site triggered the amendment of the power station's dangerous goods licence. This process took longer than normal because considerable due diligence was applied by Western Australian regulators. This process, conducted collaboratively with the regulator, ran in parallel with other project activities, mitigating its impact on overall project timelines.

6.3.3 System Integration Challenges

The inherent complexity of integrating various equipment packages, presented challenges. Noteworthy among these were:

- Integration of the fuel cell and its DC-DC converter with the grid interfacing power inverter,
- Coordination of the compressor's constant flow operation with the electrolyser's variable hydrogen production,
- Integration of forced ventilation within containers for elimination of explosive atmospheres in a windy site. Monitoring of ventilation with large natural pressure and flow fluctuations due to strong gusts proved challenging, and
- Integration of evaporative cooling loops across the site to balance heat rejection needs in a dynamic operating environment and electrical efficiency.

These system integration issues have proven to be the single biggest challenge for the project, in the main due to a lack of on-shore Australian experience installing, integrating and commissioning these types of facilities.

6.3.4 Control System and Operational Considerations

The uniqueness of the Denham Hydrogen Demonstration Project lies not only in the utilisation of individual cutting-edge technologies but in the integration of various hydrogen equipment and balance-of-plant components to function cohesively within a microgrid as an energy source, is unprecedented in Australia.

This required the development and implementation of a complex control system from scratch, which demanded considerable efforts from the EPC Contractor and Horizon Power SCADA teams. The control system had to seamlessly integrate diverse equipment packages, ensuring safe and efficient operation within the microgrid power system. Key considerations included:

- **Novel Firmware Development**: Creation of innovative firmware within the HESS master controller to govern the dispatch of each equipment within its operational requirements, manage automatic state transitions, provide secondary safety functions, integrate the plant's safety system, and actuate process valves, among other functions.
- **Solar Energy Utilisation:** Incorporation of solar energy as an intermittent power source for the electrolyser, introducing complexities in startup and operation.
- **System Stability Challenges:** Addressing system stability complexities arising from integrating a highly variable and relatively large load into a small power system with a high penetration of renewables.

6.3.5 Limited Precedent

The absence of previous project experiences in this domain required the creation of deliverables, testing procedures, and technical documentation from scratch, exceeding initial time estimates.

Another key learning is that the vendors of the equipment were also not experienced onshore with the assembly and commissioning of these systems.

6.3.6 Unconfirmed Equipment Reliability

The reliability of specific hydrogen equipment technologies remained uncertain, contingent on accruing sufficient statistical data through large-scale deployments. Technical issues during the final commissioning stage, particularly with electrolyser power modules, the fuel cell, and the reverse osmosis unit, resulted in significant project delays and necessitated equipment replacements.

The scale of equipment failures was not anticipated, and a significant amount of Original Equipment Manufacturer (OEM) subsystems have required trouble shooting, repaired and/or replaced. Each failure contributing considerable schedule shift as the cycle of technical support, root cause analysis, warranty claims, manufacturing and shipping timeframes can be consequential. This process was compounded by several key suppliers being in the Europe, China, and the United States of America.

6.3.7 Schedule Overview

The following high-level project timelines, provided below, underscore the disparities between the initially forecasted construction and testing schedule and the actual timeline required to complete these activities.

While it is difficult to attribute how much was caused by COVID related delays, such as border closures and supply chain issues, it is important to note that most delays can be attributed to unforeseen technical issues. These include unexpected equipment reliability problems, which are further elaborated upon in Section 11 - Key Learnings of this report.
Project timeline estimated at the constitution stage on 15/07/22:

Project timeline on 17/01/2024.

6.4 Technical design considerations and rationale for chosen design

The technical design of the hydrogen plant equipment was modelled during the concept design and tender stage using the information available at the time of the modelling.

The sizing of the solar PV and equipment was based on meeting the minimum specification requirements while optimising the techno-economics aspects of the project.

The plant is intended to demonstrate a hydrogen-based power plant integrated into a microgrid. Despite the seemingly modest 100 kW generation capacity, the project remains significant for Denham's power loads, ranging from approximately 400 kW to 1,600 kW peak. Consequently, the project provides valuable insights into the challenges of integrating base load green hydrogen power into a microgrid, as well as about the plant's potential capabilities to perform grid support functions for future applications.

The electrolysers, constituting a substantial electrical load in the Denham grid context, necessitate careful management. However, their operation, inherently tied to the output of the dedicated solar farm, they were modelled to have minimal impact on the grid during normal operation, this was subsequently proven during commissioning activities. Electrolysis was not nor is it intended to support the grid as a controlled load and has not been implemented as such.

Based on initial modelling, target annual energy production and power requirements for the hydrogen plant performance targets were set by the Project, as follows:

- Minimum combined annual energy output to supply the network load from hydrogen plant and dedicated solar farm is 526 MWh,
- Minimum annual energy output is 220 MWh derived from renewably sourced hydrogen delivered through the fuel cell, and
- A minimum 35kW output (in aggregate from the point of connection and the dedicated solar farm point of connection) at 415 V AC, 3 phase, 50 Hz, in each case, on a continuous basis.

The design philosophy sought to:

- Focus on the combination of solar PV and hydrogen (electrolysis) generation, hydrogen storage and fuel cell technology for the purpose of project learnings,
- Minimise ongoing water usage in the hydrogen generation, including recirculation of water produced by the fuel cell,
- Minimise electrical auxiliary load, hence the use of evaporative cooling,
- Minimise any communications and interaction with the power station control system. Aiming for a standalone, robust, and autonomous system,
- Ensure high accuracy data collection and simplicity of data collection points to develop a scalable representation of the plant operation (where practicable),
- Avoid the reliance on a battery energy storage system to test the viability of directly driven electrolysis. Use of the microgrid BESS is not included as part of the project scope,
- Ensure data collection/analysis reflects the project outcomes with a focus on implementation in micro-grids, and
- Ensure that hydrogen is produced using coincident power from the dedicated Solar Farm, as “green hydrogen”.

The detailed mechanical design considered:

- Containerised packages (Wind Region C),
- Adequate material selection (hydrogen embrittlement),
- Mechanical protection of piping,
- Provision of adequate isolation valves, visual inspection locations, fail safe air actuated valves, test points.

The detailed electrical design considered:

- Hazardous Area (HA) requirements:

Installation compliance with AS/NZS60079, Part 14 Design selection, erection, and initial inspection,

Hazardous area report and drawings for HA zones for delineation,

Adequately selected and certified HA equipment,

Competent and qualified Electrical Equipment for Hazardous Areas (EEHA) technician installs as per OEM and EEHA compliance requirements,

Earthing – All piping and structure are earthed,

Signage in place. i.e. non-intrinsically safe device prohibited, non-smoking.

- A single point of connection to each Package,
- Separate balance of plant control system and Safety Instrumented System (SIS) with SIS design hardwired using Safety Relays.

6.5 Technical details

The Project, a 100% renewably powered hydrogen production facility, involves the installation and operation of the major equipment in the table below.

Equipment	Manufacturer / Model	Further Info
Renewables – Solar	LONGi Solar Panels (LR4-72HBD 445 M) With 6 x FIMER Inverters (PVS100)	Total AC Capacity = 600 kW @ 50 deg C Total DC Capacity = 705 kWp
Water Treatment	ELGA / Veolia Centra R120 DI/RO	Delivery flow rate: 10 l/min @ 22 psi (1-5 bar) Feedstock water supplied from the town potable water scheme.
Electrolyser	Nel 2 x C30	Proton Exchange Membrane (PEM) – nominal 348 kW AC. Caustic Free Nominal Production Rate (60 Nm3/h (5.4 kg/h) -2 x C30 units) – nominal 64.5 kWh/kg H_2
Compressor	PDC-4 2500-6000-150	Diaphragm Compressor Suction Pressure – 30 bar Discharge Pressure – 300 bar
Storage	EKC	60 x 210 l Storage Cylinders (12,600l total) Storage capacity is 260 kg of gaseous H2 at 300 Bar pressure – 25° C
Pressure Reduction	Cryoquip	Inlet Pressure – 300 bar Outlet Pressure – 8-12 bar
Fuel Cell	PowerCellution PS-100 with ABB PCS100 Inverter (97kVA)	Max power = 100 kW 7.2 kg/hr (max) with 16.67 kWh/kg H2 (min)
Evaporative Cooling Tower	Wanxiang Refrigeration Co Ltd WXC-052 Closed Circuit Cooling	330 kWr via Evaporative Cooler Air flow rate up to 30,000 m3/h Inlet / Outlet temperature: 40 deg C/30 deg C

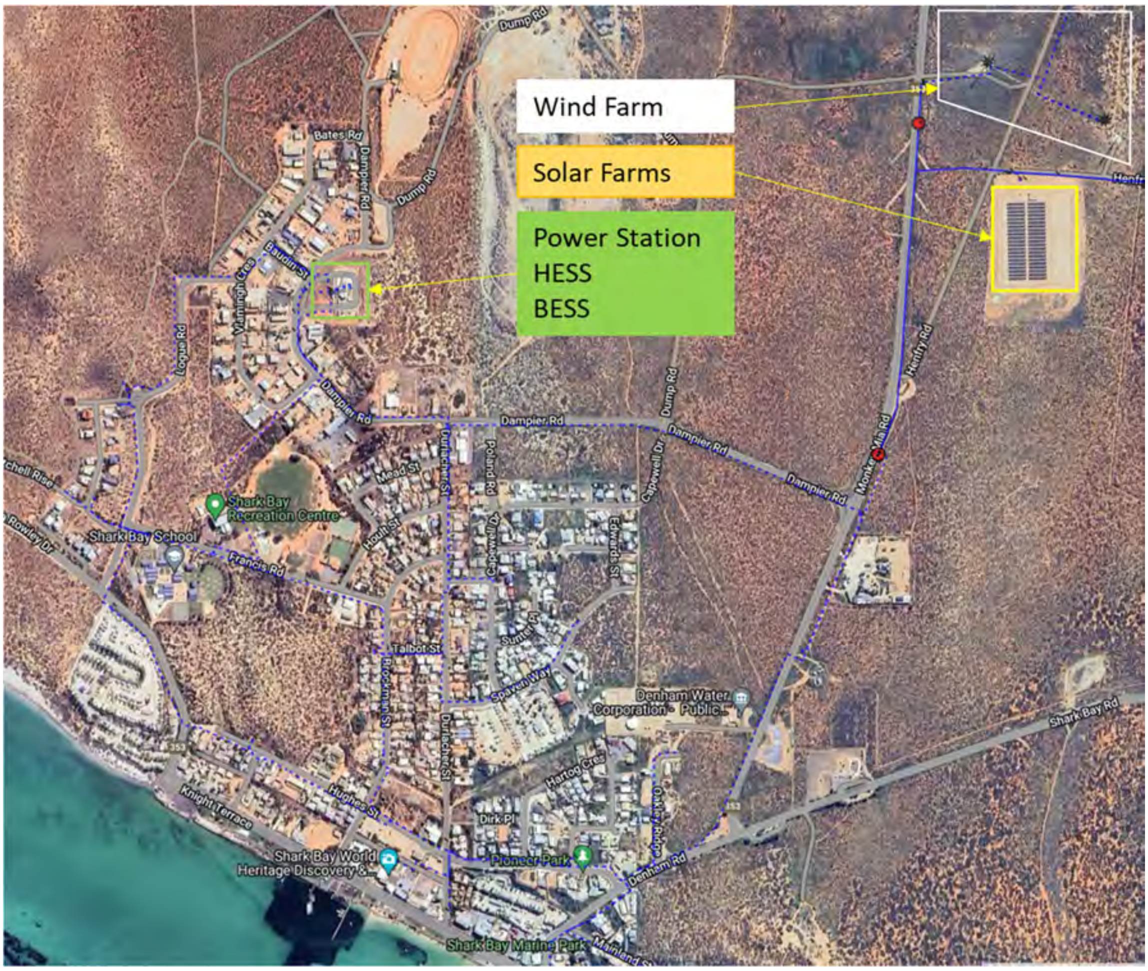
Additionally, the system required control systems and balance of plant; including safety system, outdoor main switchboard, water storage facilities, and metering to track the hydrogen and energy production.

6.6 Denham Power System

Denham, a remote community, relies on an isolated power system that operates independently from any other grid. With a population of approximately 800 residents, Denham also serves as a major tourist destination, experiencing significant seasonal influx and energy demand. Denham's annual electricity consumption stands at 5 GWh, with peak demands reaching 1.7 MW. The power system in Denham operates as a hybrid microgrid, integrating various energy sources and storage solutions. The facilities described in the table below contribute to this system.

Facility	Capacity	Further Information
Distribution Network	3 x 11 kV / 415 V Feeders 1.7 MW Peak Load	Underground and overhead network
Solar Farm	640kWp / 500kVA	Located at a remote site. Supplies energy to the grid offsetting the use of baseload diesel generation.
Wind Farm	1 x 330 kW Enercon turbines. 2 x 230 kW Enercon turbines	Located at a remote site. Supplies energy to the grid offsetting the use of baseload diesel generation.
Battery Energy Storage System (BESS)	1.5 MW / 1.7 MWh	Located in the power station. Provides increased system strength and greater utilisation of renewable generation.
Microgrid controllers and wireless communication system	N/A	Enable the effective coordination of microgrid components such as diesel gensets, renewable energy sources, energy storage systems, and loads
Diesel Generators	7 x gensets - 2.6MW total	Supplies energy to the grid Diesel generation is the lower priority in Denham energy dispatch logic.
Components added as part of this project:		
Hydrogen Dedicated Solar Farm	705kWp / 600kVA	Located at a remote site. Supplies energy to the grid used to power the hydrogen plant
Hydrogen Energy Storage System (HESS)	348 kW electrolysers 100 kW Fuel Cell 12,600 l H2 storage up to 300 bar	Located in the power station. Produces and stores H2 from renewable energy and return that energy to the grid

The images below show the location of the main power generation facilities and Denham's electrical network.



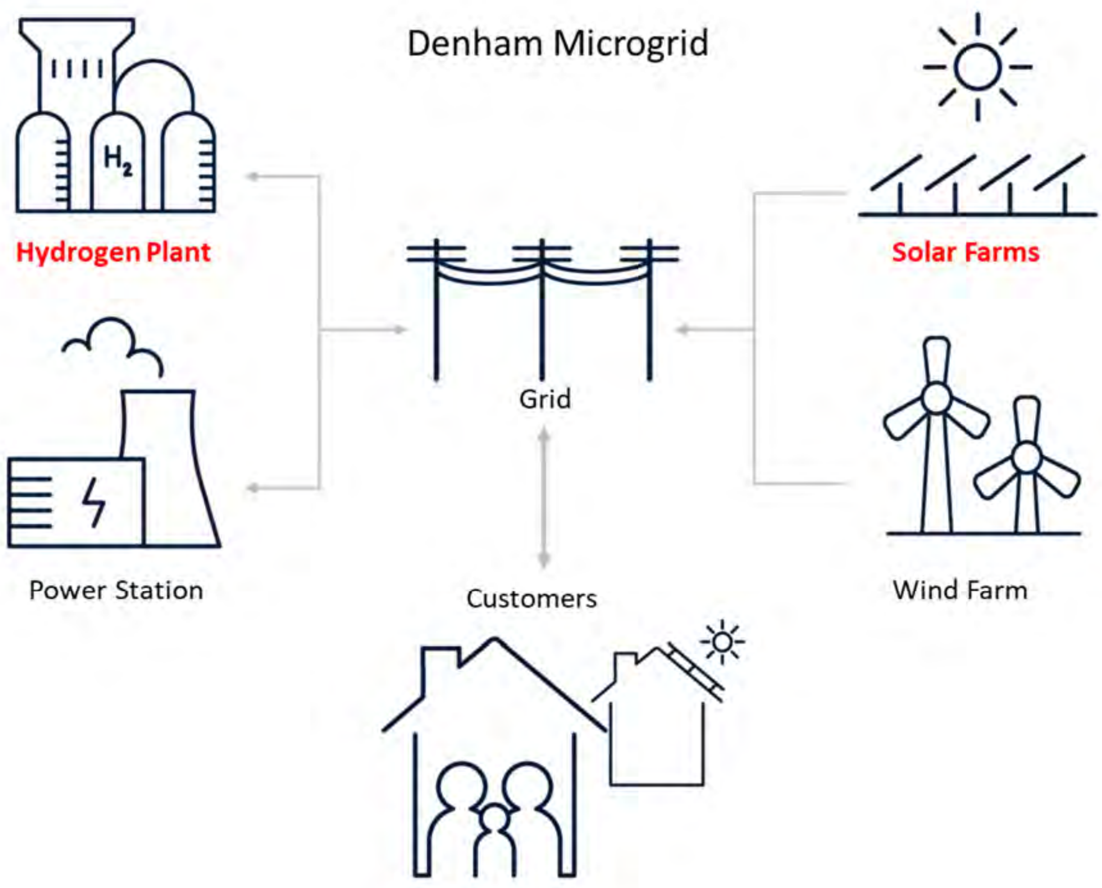
6.7 Interface into the microgrid

The hydrogen demonstration plant is composed of two distinct facilities , which are connected to the Denham power system at separate locations. This section details the technical aspects and configuration of these facilities.

- **The Hydrogen Energy Storage System (HESS)** is situated at the Denham power station site with the BESS, diesel generators, fuel storage and control room, located within an industrial area proximate to the town of Denham. The physical connection of the HESS to the power station's infrastructure is established through the 415 V main switchboard. Operational autonomy is achieved through direct control by the HESS's master controller, facilitating remote operation and monitoring. This functionality is made possible via integration into the Denham Power Station control system.

- The solar farms, encompassing the power station solar farm and the **dedicated solar farm**, are located on a remote site along Monkey Mia Road, adjacent to the existing wind turbines. The solar farms are electrically connected to the network via a 415 V/11 kV step-up transformer, and remotely controlled by the power station's microgrid controller via a wireless communication system to allow remote operation and monitoring via Denham Power Station control system.

The diagram below provides a simplified overview of the plant interface into Denham microgrid.



6.8 Control System Overview

The HESS relies on autonomous operation, managed by a dedicated master industrial Programmable Logic Controller (PLC). Specifically tailored firmware has been developed for HESS to facilitate seamless unmanned operation.

The HESS control system is integrated with Horizon Power's control system to allow remote operation and monitoring.

6.8.1 Operational States

Under normal unmanned conditions in AUTO Mode, the HESS transitions through predefined states, while consistently delivering a minimum baseload of 35 kW to the grid, drawing power from the fuel cell, the dedicated solar farm, or a combination of both.

The dedicated solar farm output dictates transitions between operational states. Sufficient solar power triggers hydrogen production, while solar insufficiency prompts the fuel cell to generate power. Consequently, the HESS normally operates in Fuel Cell (FC) mode at night and Electrolyser (EL) mode during daylight hours.

While in AUTO Mode the HESS operates in one of five discrete states at any given point in time. The main PLC is responsible for the transitioning between these states by signalling lower-level controllers such as the electrolysers and fuel cell to change their states. These states are briefly described below.

System State	Description
Emergency Shutdown (ESD)	In response to an emergency, such as the activation of a critical alarm or the pressing of an emergency shutdown button via the control system, the following actions occur: • All process assets are promptly shut down. • Safety valves are closed to isolate the storage system. Despite the shutdown, critical assets such as cooling, and ventilation systems continue to function. These critical systems ensure that equipment remains within safe operating limits even during emergency scenarios.
OFF	Hydrogen is not being generated or consumed and all process-related equipment is either turned off or in standby. Critical assets such as the cooling and ventilation systems remain on to maintain equipment within their safe limits.
Standby	Process-related assets are in Standby State ready to start with start-up sequences complete where applicable. Critical assets remain ON
Electrolyser	Electrolysers are on and generating hydrogen with the compressor automatically cycling ON/OFF to compress hydrogen to storage. The fuel cell is OFF. Critical assets remain ON.
Fuel Cell	The fuel cell is on and generating DC power from the stored hydrogen. The inverter is on and exporting AC power to the power system.

6.8.2 Modes of Operation

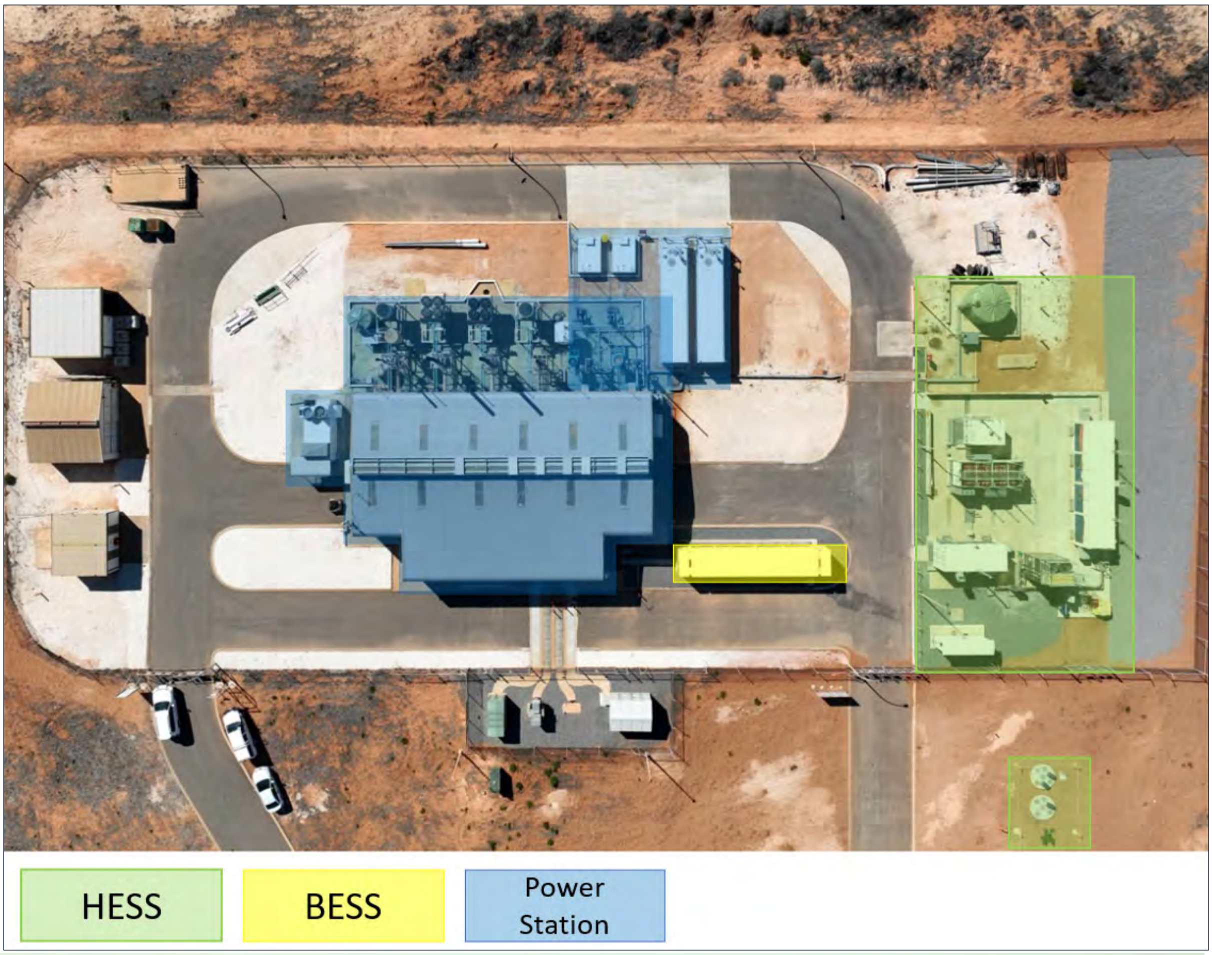
For maintenance, the HESS and its subsystems can be manually operated in Remote Manual and Local Manual Modes. In manual mode, power production aligns with operator-specified setpoints.

In summary, the intricate transitions between various operational modes and the dependency on solar farm output highlight the differentiated control mechanisms governing the HESS. The need for such complexity arises from the dual nature of the system, wherein it serves both as a consumer and a producer of power.

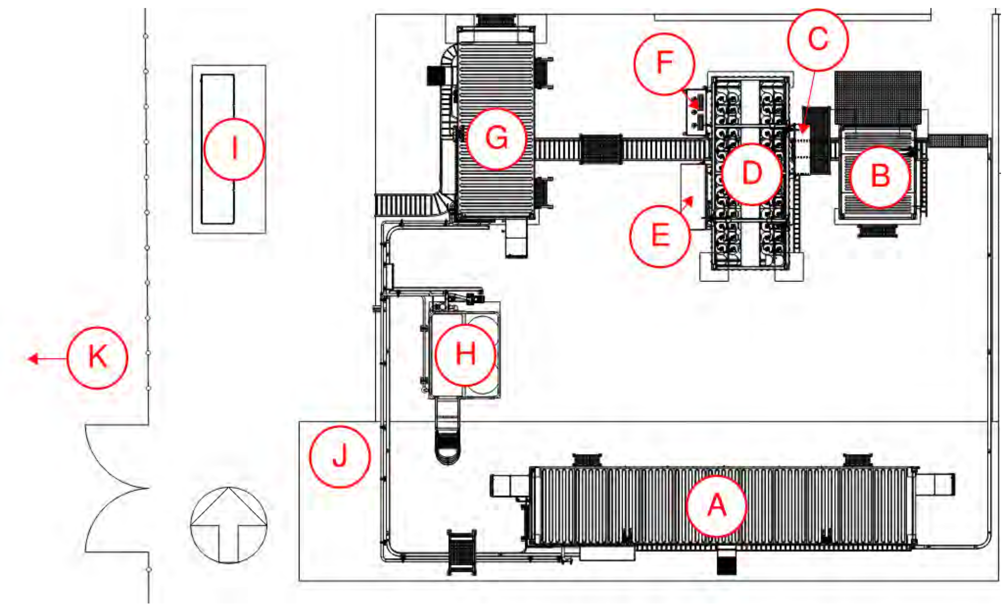
Denham Power Station with Shark Bay and Dirk Hartog Island on the horizon.

6.9 Site Layout

The figure below shows the site layout of the Denham Power Station with the HESS general Location highlighted in green. The dedicated solar farm is not shown in the site layout because it was constructed at a remote site, and it is electrically connected to the network.



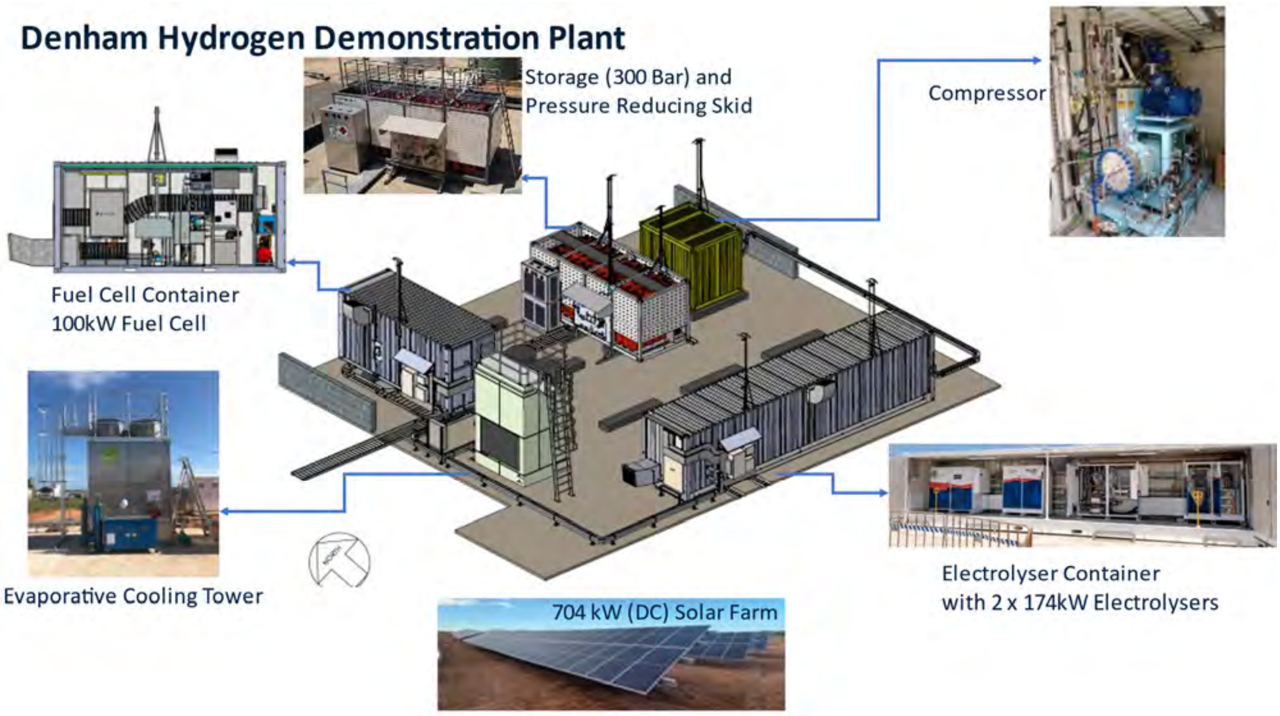
The figure below identifies the HESS major equipment general arrangement.



HESS major equipment general arrangement referencing to figure above.

Ref	Description
A	40 ft electrolyser container
B	10 ft hydrogen compressor container
C	Main hydrogen panel
D	300 bar multiple element gas container (MEGC) hydrogen storage
E	Pressure reduction skid
F	30 bar buffer storage
G	20 ft fuel cell container, which also houses the water reverse osmosis (RO) and deionization (DI) unit
H	Evaporative cooling tower
I	HESS Main switchboard
J	Cooling water chemical dosing treatment plant
K	Wastewater system comprised of septic tanks and leach drains dispose wastewater from the RO/DI plant and cooling tower. (Outside boundary of Figure)

This diagram and image provide overview of the hydrogen plant:



6.10 Current Project Status

As of February 2024, the Project has achieved the following:

- Design process, including safety in design,
- Construction of the hydrogen plant,
- Commissioning of all individual hydrogen equipment packages and safety system,
- Development, implementation, and pre-commissioning of the control system,
- Commissioning of the system using a generator and load bank (i.e. disconnected from power system) to produce hydrogen and power,
- Official Opening of the Hydrogen Plant: The hydrogen plant was officially inaugurated on November 11, 2022, by the Minister for Hydrogen Industry, Alannah MacTiernan, and Energy Minister, Bill Johnston, marking a momentous occasion in the commencement of hydrogen production.
- Final Stage of Commissioning: The concluding stage of commissioning, integrating, and testing the hydrogen plant with the dedicated solar farm and the power station,
- Conducted operational readiness activities,
- Replaced and tested the equipment that had technical issues,
- Operational handover, and
- Reliability period testing.

Despite overall accomplishment, the commissioning phase experienced delays, a not uncommon occurrence in new technology projects. The extended timeline was primarily attributed to complexities in integrating equipment packages and the overarching control system. Specific challenges also arose while integrating the various stages of power conversion from the stack of the fuel cell to the grid.

Furthermore, the project encountered technical issues and equipment failures, necessitating the replacement of certain components, including pressure safety valves, electrolyser power supply modules, fuel cell, and the reverse osmosis plant. These challenges temporarily impeded the final stage of commissioning, emphasising the importance of addressing equipment issues before proceeding with the operational handover of the hydrogen plant.

The durability of hydrogen assets should be considered for any future deployments.

7. Regulatory requirements

The following sections summarise the review of regulatory approval and licensing requirements in relation to the hydrogen demonstration plant.

Hydrogen technology in the electricity industry is a new technology. Current regulations have not kept pace with the rate of development and as such, regulatory frameworks and training are being developed but still lack definition. The Department of Mining, Industry Regulation and Safety (DMIRS) is the applicable Regulator for the appliances used on this Project, with:

- The Dangerous Goods Licensing Branch responsible for the administration of requirements under the Dangerous Goods Safety (Storage and Handling of Non-explosives) Regulations 2007, and the Dangerous Goods Safety Act 2004 .
- The Building and Energy Division responsible for the administration of requirements under the Electricity Act 1945 and the Gas Standards Act 1972.

DMIRS has been progressively releasing guidelines and other publications to assist with new hydrogen projects.

The hydrogen plant consists of the following equipment, with the type of appliance from a regulation perspective given.

Equipment	Size	Appliance Type under Regulation
Electrolyser	348 kW	Electrical Appliance
Hydrogen compression and storage	13.3 kl	Dangerous Goods
Fuel cell with inverter (PowerCell MS-100)	100 kW	Type B Gas Appliance

7.1 Dangerous Goods Safety Act 2004

The threshold manifest quantity for hydrogen under the *Dangerous Goods Safety (Major Hazard Facilities) Regulations 2007* is 200 tonnes. The quantities of hydrogen produced and stored at the Denham hydrogen demonstration plant are significantly below this threshold and therefore did not trigger the requirements for Major Hazard Facility legislation.

However, the storage of Hydrogen at the site did require a Dangerous Goods Licence (DGL) amendment.

The Denham power station already had a DGL for storing up to 140 kl of diesel, which was amended to include the 13.3 kl hydrogen storage.

In February 2023, DMIRS published a Dangerous Goods Safety Guide for the Storage, handling, and production of Hydrogen, to assist industry understand what is required from a dangerous goods safety perspective. This guide is available at:

https://www.dmp.wa.gov.au/Documents/Dangerous-Goods/DGS_HydrogenGuide.pdf

Whilst this guide was not available at the time of the Licence amendment request, a similar process was followed, and the information provided aligned with that outlined in this guide.

The DGL amendment process took longer than usual, as this was the first application of its kind that DMIRS had to assess. DMIRS applied considerable due diligence and caution, as it considered the hydrogen industry as a new and novel sector that required more scrutiny than a standard DGL amendment/application. DMIRS requested information on aspects that are more relevant for a Major Hazard Facility application, such as Safety Management Systems (SMS) and hazard identification and control measures.

Horizon Power engaged with DMIRS early and collaboratively, which was beneficial for both parties. DMIRS conducted thorough documentation assessments and site inspections and provided constructive feedback to the project. This feedback helped the project to identify and mitigate potential risks and enhanced the plant's safety performance.

The outcome was not just regulatory compliance but a valuable set of lessons applicable to future hydrogen projects as described in section 11.6 - Lesson learnt No 6 Regulatory Approval Process.

7.2 Gas Standards Act 1972

The Building and Energy Division is responsible for administration of requirements under the *Electricity Act 1945* and the *Gas Standards Act 1972.*

The *Gas Standards Act 1972* (the Act) regulates gas standards, appliance safety standards and gas fitting practices. Whilst not applicable to the existing diesel-fired Denham power station, the *Gas Standards Act* is relevant to the hydrogen demonstration plant due to the introduction of hydrogen gas production and the installation of a 100 kW hydrogen fuel cell, which is classified as a Type B appliance under the Act.

Two key aspects of the Act are the requirements for approval of a hydrogen fuel cell as a Type B appliance under section 13D of the Act, and for appropriate competency and authorisation of gas fitting work under section 13A; and under the *Gas Standards (Gas fitting and Consumer Gas Installations) Regulations 1999.*

Under the regulations, for a Type B gas appliance , a 'consumer' is required to obtain approval prior to making use of a Type B gas appliance (s13D of the Gas Standards Act 1972).

Feedback was sought on the expectations and requirements of DMIRS in the absence of hydrogen specific Type B appliance regulations, accepted standards, and installation guidelines in WA (and as such suitably skilled and experienced inspectors). This is covered in more detail below.

7.2.1 Certification and Approval of Hydrogen Type B Appliances

When the project commenced, consultation with DMIRS highlighted that hydrogen fuel cells were still new to WA and, at that time, there was no framework for certification and approval of hydrogen fuel cell Type B appliances.

In the absence of hydrogen specific regulations, DMIRS indicated a Risk Based Approach and compliance with equivalent international standards was deemed to be acceptable (HAZID, HAZOP, Risk Assessment, Design Review, Risk Mitigations etc.). This has been done for the Project.

Subsequently, DMIRS has advised that in Western Australia hydrogen fuel cells are classified as a Type B gas appliance and will require approval if installed in a consumer installation. For instance, if the gas is supplied by a gas supplier.

DMIRS has produced a guideline to assist the gas industry with the minimum required technical information to be considered and included in their technical submission for the purpose of assessment and approval of a typical Hydrogen fuel cell. This can be found at the following website:

This guideline, along with a link to guidance on Hydrogen fuel cell gas safety regulation requirements in WA can be found from the following website:

https://www.commerce.wa.gov.au/building-and-energy/hydrogen-fuel-cell-developing-technical-submission-approval-western-australia

Since the Project commenced, Australian Standards for the Fuel Cell have been gazetted and are considered the minimum benchmark accepted by the Regulator, including:

- AS 62282.3.100:2021 (Australian standard),
- IEC 62282-4-101:2014 (International standard),
- IEC 62282-5-100:2018 (International Standard),
- SA TR 15916:2021 (Australian Standard).

7.2.2 Gas Consumer

In circumstances where hydrogen is produced on site using electrolysers and is not supplied by what the Gas Standards Act calls an 'undertaker' or a 'pipeline licensee', the definition of 'consumer' does not apply where a person supplies gas for their own use.

For this Project, DMIRS has confirmed that it is not classed as a consumer installation and so no Type B appliance Approval for the fuel cell is required.

Following DMIRS' recommendations, Horizon Power ensured compliance with the applicable hydrogen fuel cell standard available at that time and will maintain the compliance assessment documentation as a proactive approach.

For future projects, legislation and Australian Standards need to be reviewed to confirm compliance at the time.

7.2.3 Competencies – Installation, Commissioning and Maintenance

The regulation requires gas fitter(s) registered as WA Licensed Class I gas fitter for working on Type B gas appliances with no restrictions or an authorisation holder to carry out (or) supervise the gas fitting work. Horizon Power has adopted this requirement for the installation, commissioning, and maintenance works on the gas system of the entire plant.

All work on the hydrogen plant carried out by the Class I gas fitter must be supervised by a competent design and commissioning engineer experienced with hydrogen plants. During this project, Horizon Power's technical team did not have engineers possessing the necessary expertise; as a result, the responsibility for meeting this regulatory requirement rested with the EPC Contractor.

The engaged engineer must be onsite to carry out direct supervision and certify each stage (with records being generated and co- signed and verified by both parties on the relevant inspection test plans (ITP), inspection test reports (ITR) and service logbook.

Specific hydrogen gas training is required for personnel undertaking maintenance work on the hydrogen plant. These training sessions required physical attendance and were publicly available, delivered by multiple registered training organisations (RTOs). Horizon Power has been up skilling its operational workforce with several new skill sets, including the following training courses and respective durations:

- Basic Hydrogen Skills Set - five-day duration,
- Operate & Routine Maintenance of a Hydrogen Facility – eight-day duration,
- Hazardous Areas Awareness – one-day duration,
- Certificate IV in Hazardous Areas – Electrical – five-day duration ,
- Gas Authorisation (Category 2) Certification – ten-day duration,
- Gasfitter Supervised Certification – two-day duration.

7.3 Hazardous Area Classification

A hazardous area classification and ventilation system-related assessment were undertaken in association with the site installation of the hydrogen equipment in accordance with the relevant Standards. The hazardous area classification enabled the proper selection, installation, inspection, and maintenance of electrical equipment for use in the hydrogen explosive hazardous area.

Hazardous Area (HA) requirements:

- Installation compliance with AS/NZS60079, Part 14 Design selection, erection, and initial inspection,
- Hazardous area report and drawings for HA zones for delineation,
- Adequately selected and certified HA equipment,
- Competent and qualified EEHA electrician installs as per OEM and EEHA compliance requirements,
- Earthing – All piping and structure are earthed,
- Signage in place. i.e. non-intrinsically safe devices prohibited, non-smoking.

7.4 Aboriginal Heritage Act 1979

The development and construction of the solar farm at the greenfield location required compliance with the requirements under the Aboriginal Heritage Act 1979. An archaeological and ethnographic site avoidance heritage survey was completed prior to the construction of solar farm development.

During the solar farm construction, local heritage monitors were engaged to perform archaeological site monitoring of the earthwork activities carried out to ensure preventing harm to any archaeological resources which may have been discovered during the works. No archaeological artifacts were uncovered during the works.

7.5 Energy (Licensing) Regulations 1991

Under the Energy (Licensing) Regulations 1991, all electrical design and installation must comply with the WA Electrical Requirements (WAER)1. Under the WAER, all electrical work must be completed by a licenced electrical contractor, and a notice of work submitted to the network operator (in this case, to Horizon Power).

8. Construction and Commissioning Approach

8.1 Construction and Commissioning Management Methodology

Horizon Power engaged Hybrid Systems Pty Ltd (Hybrid Systems) as the Engineering, Procurement, and Construction (EPC) Contractor for the Denham Hydrogen Demonstration Plant, integrating it into an existing power station and microgrid.

The EPC Contractor was responsible for all aspects of the project delivery, from design and engineering to procurement and logistics to construction and commissioning. ENGV, a specialised firm in hydrogen technologies, was subcontracted for supply, installation, and commissioning of the hydrogen equipment sub-package. This section details the construction and commissioning management methodology employed, including stages, activities, and key results.

The EPC Contractor developed a comprehensive Commissioning Plan for the works, covering the commissioning stages, objectives, procedures, tests, acceptance criteria, roles and responsibilities, and safety measures required for the successful implementation of the plan.

The project team, consisting of Horizon Power’s project manager, engineers, and Operations representatives, were present on-site over the course of the construction and commissioning activities, ensuring that the respective contractors were complying with the requirements of the specifications and design, as well as confirming that the overall coordination of Site activities was effective and safe.

At the end of each stage, the EPC Contractor conducted walkdowns and maintained a punch list to identify critical defects or major outstanding items. The ITPs and ITRs were completed and signed off by competent contractor personnel before being submitted to Horizon Power for review and acceptance before the works moved on to the next stage.

The key stages of the construction and commissioning were:

8.1.1 Stage 1 – Factory Acceptance Testing (FAT)

During Stage 1, FAT activities associated with the containerisation of electrolysers and the Fuel Cell, the H2 main switchboard and some aspects of the control system were carried out by ENGV and Hybrid Systems. As many systems were delivered to site pre-installed in containers many activities that may otherwise be considered construction verification were performed at this stage.

Following a desktop review of all equipment manufacturer FAT results, the EPC Contractor carried out testing activities on the electrical and mechanical installations of the equipment containerisation undertaken by the vendors. This phase included the following activities:

- Assembly, construction verification, pre-energisation checks,
- Electrical tests, including compliance verification against AS/NZS3000,
- Mechanical integrity checks, and
- Tests of hydrogen equipment containers ventilation.

This stage included the low voltage switch boards, control equipment and PLCs such as bench testing some aspects of the controls system, including validation of Modbus points between the power station and hydrogen plant controllers.

Additionally, a significant FAT activity was the development of a software representation of the HESS within the master controller's integrated design environment (IDE). The model was developed in parallel with the custom firmware development then used to test each function at the FAT stage. That is an embedded model of each generating device and the H2 compressor was developed to mimic the expected behaviour of these devices before they were available to be electrically/mechanically connected and operational. In doing so the significant task of developing and debugging the custom master controller firmware could proceed at an earlier stage and reach a greater level of maturity before commissioning began. This significantly de-risked the commissioning process and improved the commissioning schedule. Significant algorithms and functions that were tested and debugged at this stage were:

- The HESS state machine, for expected state transitions based on simulated process variables and confirmation of no accessible null states.
- Electrolyser, H2 Compressor and Fuel cell dispatch logic. Each requiring specific sets of precedent conditions to be run safely within novel dispatch algorithms developed to run without impacting the greater power systems stability while only consuming solar power.
- Secondary safety functions. Such as monitoring key safety devices and processes for redundant shut down conditions.

This FAT activity reduced time and risk of the commissioning activities on site, as it allowed the EPC Contractor and Horizon power to verify and troubleshoot the communication and integration of the two systems in a controlled environment.

8.1.2 Stage 2 – Construction and Construction Verification

The project has applied a modular, preassembled approach as an execution strategy to minimise site construction activities as far as reasonably possible. Main components were engineered to support offsite manufacturing, preassembly into containerised packages, and FAT testing to as much of the equipment as practical prior to dispatch to site.

This approach has reduced the amount of construction activities on site to essentially civil works and mechanical, electrical and control interconnections. These included:

- preparation of hydrogen plant area,
- installation of underground services,
- concrete installation of major footing and slabs,
- construction of the wastewater treatment system,
- delivery and placement of containerised equipment into position,
- delivery, fabrication, erecting and installing of balance of plant items, and
- installation and connection of piping and cables within all major equipment and balance of plant

Construction verification was undertaken following site construction works to verify the construction works against the design drawings, equipment manuals and procedures. This included:

- verification of civil constructions works,
- mechanical installation inspections,
- hydrogen system blowdown and cleaning prior to pressurisation and leak tests to be performed during Pre-Commissioning activities,
- electrical installation tests,
- earthing system verification,
- hazardous area visual inspection and design verification, and
- communication cabling checks.

At this stage, punch list walkdowns were critical in identifying defects and critical rectifications required for initial energisation and pressure introduction into the systems.

8.1.3 Stage 3 – Pre-commissioning

The pre-commissioning activities were carried out in accordance with the relevant ITPs and ITRs and confirmed equipment readiness for commissioning. The following activities were completed at this stage:

- signal and communications checks between various subsystems including SCADA,
- verification of mechanical integrity,
- container ventilation flow rate checks,
- Instrument air system testing,
- Safety system operation testing,
- confirmation of equipment is ready for operating,
- nitrogen purging, leak testing and initial system integrity pressurisation testing,
- verification of instrumentation reading accuracy,
- confirmation of valves operation,
- Hazardous Area inspections for compliance,
- confirmation of Dangerous Goods license approval, and
- signage review in preparation for hydrogen production.

8.1.4 Stage 4 – Commissioning

This stage of testing was off-grid commissioning, where the hydrogen plant was tested as an entire system without being connected to the power station or the microgrid. The hydrogen plant was supplied by a temporary diesel generator for power and a temporary load bank for load.

In this stage, the fuel cell, electrolyser, and hydrogen compressor were tested, with the assistance of the respective manufacturer representatives. The manufacturer representatives were present on site and connected remotely via internet to verify the settings, parameters, performance, and safety operation of these key components of the hydrogen plant.

Hydrogen purity confirmation was a hold point during Stage 4 prior to hydrogen introduction to the Fuel Cell. The quality of the hydrogen produced by the electrolyser was tested in an accredited laboratory and confirmed to meet the required standards for the fuel cell. The project could not proceed to the next stage until the hydrogen purity was verified and approved by the fuel cell manufacturer. The purpose of this test was to ensure that the hydrogen was suitable for the fuel cell and did not pose any risks of contamination or damage to the fuel cell.

During this stage, the commissioning tests demonstrated the capability of the plant to operate in all modes and generated, stored, and converted hydrogen into electricity via the fuel cell, noting that this was done using thermal generation. A staged approach starting with manual operation of subsystems culminated in full automated control of the HESS. Automated control relied on the use of simulated solar power data at this stage.

This stage activities included:

- confirmation of Dangerous Goods Licence amendment approval by the DMIRS for storing hydrogen,
- electrical system commissioning,

- control system signals and human machine interface testing,
- integration testing of the fibre optical communication system,
- balance of plant equipment commissioning,
- hydrogen equipment commissioning and functional testing,
- hydrogen purge and leak tests,
- staged pressure tests,
- hydrogen purity testing (off-site in laboratory),
- testing plant operating modes of startup, steady state, transients, plant changeovers, shutdowns, and trips,
- simulation and testing of control algorithms,
- failure modes testing,
- functional verification in integrated system testing, and
- Horizon Power SCADA control testing without power station electrical connection.

8.1.5 Stage 5 – Performance Testing (Final Commissioning)

The final stage of commissioning included connecting the hydrogen plant to the power station switchboard, forming part of the microgrid, and allowing the hydrogen plant to be supplied via solar energy.

The purpose of this stage was to demonstrate that the hydrogen plant meets the design requirements, including production of hydrogen from renewable sources and a minimum net power output to the grid.

During this phase, the EPC Contractor identified opportunities to adjust the control systems parameters that resulted in an optimised performance of the plant, despite limited data from the short period of the plant in operation. The following activities were carried out this phase:

- tuning and optimisation of the driving control parameters for the dispatch of the electrolysers and fuel cell, to better achieve the targeted performance metrics,
- first fill of Hydrogen storage cylinders,
- power quality testing,
- verifying metering methodology,
- confirmation of minimum net power output is maintained,
- hydrogen equipment performance verification,
- overall plant efficiency verification,
- integration testing of the hydrogen plant with the overall power system, and
- verification of system performance to confirm compliance with performance requirements.

The performance testing stage was a hold point prior to operational handover.

8.1.6 Stage 6 – Reliability Run

Once all testing is completed and the plant is operationally handed over to Horizon Power operations, a continuous 60-day operational period is required with the aim of confirming the plant's reliability, demonstrating sustained operation without major issues. Any major failure to maintain supply will require the 60-day Reliability Period to recommence.

8.2 Performance Verification and Key Results

Testing the hydrogen equipment electrical performance, control system parameters, functional performance of the safety and control systems and Horizon Power technical rules were the most relevant tests to ensure the novelty hydrogen technology is ready to operate integrated with the microgrid. The plant has successfully satisfied all test criteria to prove the plant's readiness for operational handover.

Overall plant efficiency tests were conducted to obtain preliminary measurements and early learnings. However, given the short period of commissioning and data collection, the accuracy of these results can be improved with a greater measurement period. The commissioning test results indicate a reduction in the plant's energy performance to that initially modelled, primarily due to higher electricity consumption by the balance of plant than initially estimated.

Since the performance metrics presented here were recorded Horizon Power and the contractor have carried out optimisation works on several aspects of electrolyser, fuel cell and cooling system dispatch. The works on the use of the cooling system provided gains in efficiency of the overall plant. Continuous monitoring over the first 12 months will provide comprehensive data for further efficiency assessments and potential further performance improvements.

Key preliminary test results included:

Test	Result	Comment
Power quality and harmonics	Passed	Technical Rules criteria
Auto mode	Transitioned automatically through the operating states.	
Power input at 100% hydrogen output	369 kW at hydrogen flow 5.47kg/hr	Result not including the plant's auxiliary loads.
Fuel Cell max output	100 kW	Result not including the plants auxiliary loads.
Electrolyser load ramp rates	Ramp-up rate of 24.7 kW/s Ramp-down rate of 30.9 kW/s	
Fuel cell power ramp rates	ramp-up rate of 7.0 kW/s ramp-down rate of 4.6 kW/s	
Hydrogen purity	above 99.86%	The Fuel Cell specifications requires pure hydrogen in accordance with ISO 14687:2019 and SAE J2719_201511. The laboratory analysis specification includes purity level > 99.97%. However, upon reviewing the lab test results, the fuel cell manufacturer observed a slightly higher concentration of N2 (a

		residual from purging). As a result, the H2 purity falls below the specified requirement. Despite this, the manufacturer did not object to proceeding with the commissioning and operation
Electrolyser average performance ratio	69.64 kWh/ H_2 kg	Result including the plant's auxiliary loads
Fuel Cell hydrogen consumption	@ 50 kW – 2.83 H_2 kg/hr @ 75 kW – 4.88 H_2 kg/hr @100 kW – 6.57 H_2 kg/hr	Results not including the plants auxiliary loads.
Fuel Cell average performance ratio	12.44 kWh/H_2 kg.	Result including the plant's auxiliary loads

9. Operational Handover

Operational handover marks a critical milestone when the commissioned plant is prepared for the transition of control from the EPC Contractor to Horizon Power Operations. Horizon Power Operations assumes responsibility for the ongoing operation and maintenance activities of the plant.

Prior to the operational handover, the project executed a series of operational readiness activities, addressing technical, regulatory, and operational aspects essential for a successful transition.

9.1 Operational Readiness and Handover Deliverables

The project introduced asset classes that are new to the power utility industry. The novelty and complexity of the hydrogen technology equipment prompted a comprehensive change management process in multiple business areas, including Health and Safety Management, Asset Management, Workforce Training, Operational Management, and Power Station Control Systems. This proactive approach aimed to ensure Horizon Power's preparedness for the safe and efficient operation and maintenance of the plant.

Development of asset management plans, maintenance routines and technical maintenance guides is critical in a power utility context, where a lot of the activities and compliance requirements are subject to regulatory oversight.

An operational readiness process, initiated at the project's start and involving collaboration among the project team, Horizon Power stakeholders, and the EPC Contractor, ensured implementation of changes and completion of required deliverables, necessary for operational handover. Detailed below are some of the key deliverables that were crucial in this process:

9.1.1 Operational Readiness and Asset Handover Plan

The Operational Readiness and Asset Handover Plan is a strategic document outlining the plan agreed upon with stakeholders to ensure successful operational readiness before handover.

9.1.2 Enterprise Asset Management System

Horizon Power utilises ABB's Ellipse enterprise asset management platform. The project updated Ellipse to incorporate a new asset class and hierarchy for the plant, including operational data upload and the development of technical maintenance guides, service sheets, and maintenance schedule tasks, all based on vendor data, O&M manuals and the Scheduled Maintenance Matrix developed by the EPC Contractor.

9.1.3 Hydrogen Plant Scheduled Maintenance Matrix

The Hydrogen Plant Scheduled Maintenance Matrix is a comprehensive document detailing regular maintenance, inspection, and calibration requirements, along with skill set specifications, OEM authority, and licensing requirements.

9.1.4 Hydrogen Plant Operation and Maintenance Manual

The Hydrogen Plant Operation and Maintenance Manual, serves as a vital resource for understanding the bespoke setup of the Denham hydrogen plant. It supplements the equipment OEM manuals; and provides detailed information about the plant's custom-designed elements, including equipment containers, safety systems, control systems, gas systems, and the overall balance of the plant. This document provides the operator with essential information for the effective operation and maintenance of the plant, filling gaps that are not covered in the OEM manuals.

This manual provides the plant operator comprehensive operational and maintenance information of the plant readily accessible in a cohesive structure, covering equipment integration, subsystems, operations, maintenance, and troubleshooting.

9.1.5 Maintenance Workbooks

Supplementing the plant's manual, these workbooks provide concise summaries of specific maintenance requirements for individual equipment.

9.1.6 Safe Operating Procedures

These procedures offer detailed work instructions for routine activities, ensuring safe and effective execution.

9.1.7 Project-Specific Training for Horizon Power Operators

To enable transition to operation and effective maintenance of the hydrogen plant, the project delivered a comprehensive training program. Developed by the EPC Contractor with content specifically tailored for this plant, the training comprised of a range of documents, courseware, classes, and practical activities.

Key components of the training were:

- Classroom Training Sessions (1.5 days):
  - high-level overviews of the site and plant layouts,
  - detailed exploration of the equipment that constitutes the hydrogen plant,
  - general site safety awareness,
  - familiarization with the training courseware and O&M documentation, enabling operations and maintenance personnel to grasp essential elements,
  - guidance on utilising the documentation hierarchy for reference and guidance on permissible activities, and
  - clear delineation of responsibilities and disciplines outlined in the Schedule Maintenance Matrix.
- On-Site Practical Sessions (2 days):
  - identification and explanation of the plant's layout,
  - Hazardous Area zone drawings and safety system understanding,
  - familiarisation walkdowns, where operators engage in firsthand activities on the actual plant,
  - collaborative maintenance activities with OEM Technicians, conducted under the supervision of Subject Matter Experts (SMEs), and
  - review of on-the-job proficiency to the best extent possible.
- Assessment and Retention:
  - participants demonstrated their learnings through practical tasks,
  - a checklist questionnaire validated retention of critical information, and
  - Capability assessment on utilising the documentation structure effectively.
- Ongoing Training:
  - There is an opportunity of ongoing training following operational handover, when the EPC Contractor remains responsible for maintenance activities during the 60-day reliability testing period.
  - Horizon Power collaborated with a training provider to adapt the EPC Contractor training material and O&M documentation into a comprehensive courseware for training new operators.

9.1.8 Power Station Control System Enhancement

The introduction of the hydrogen plant posed a significant technological challenge to integrate the power station control system with the HESS control system, requiring Horizon Power to implement a series of enhancements to the power station control system, including developing new control system screens, monitoring functions, and alarms, and 24/7 SMS alerts for emergencies.

This required training for power station operators to navigate the new operator screens, controls, and included how to address alarms effectively, ensuring an appropriate system for unmanned and remote operation.

9.1.9 Manufacturer's Data Reports (MDR)

Provided by the EPC Contractor, the MDR includes a schedule of materials, equipment datasheets, OEM manuals, ITP, ITRs, test certificates, safe operating procedures, as-built drawings, engineering studies, reports, parts information, warranties, and site maintenance records/logbooks.

9.1.10 Health and Safety Management System

The introduction of hydrogen to the power station triggered revisions to the Health and Safety Management System, encompassing:

- updating the Denham Power Station Emergency Management Plan to cover safety measures related to hydrogen gas incidents, leakages, and fires. This included:
  - comprehensive protocols for handling hydrogen gas incidents,
  - measures for immediate response to gas leakages,
  - procedures for hydrogen fire events,
  - training programs for personnel to enhance emergency response capabilities,
  - regular drills and simulations to test the effectiveness of the Emergency Response Plan, and
  - continuous collaboration with regulatory bodies and emergency services for ongoing improvement and compliance.
- developing several field instructions to address plant's specific requirements to safely perform work on the hydrogen plant, for example, Performing work in and around Zone 1 and Zone 2 Hazardous Areas at Denham Power Station,
- implementing hazardous area entry procedure and hazardous area permit into Horizon Power Generation Permit to Work Standard, and
- updating Denham Power Station induction to include the relevant aspects of the hydrogen plant.

9.1.11 Hazardous Area and Dossier

The EPC Contractor developed and maintained a hazardous area verification dossier, serving as a live, legal document that verifies compliance with relevant standards and regulations. It provides a clear overview of hazardous area classification, equipment selection, installation details, and ongoing maintenance requirements.

9.1.12 Regulatory Approvals and Licences

Detailed information on regulatory approvals and licenses is provided in Section 7 of this report.

9.2 Operational Handover Process

Operational handover involves a collaborative effort between Horizon Power Operations, the EPC Contractor, and the Project team. An Operational Readiness Review was undertaken to ensure and document assurance of asset readiness for safe operation.

Operational Readiness Review activities include:

- reviewing site works for completeness,
- addressing any outstanding punch list items,
- confirming completeness of documentation deliverables, including operations manuals and maintenance instructions,
- verifying completion of operator training, and
- ensuring availability of current drawings on site and electronically.

A Handover Certificate marks the official transition of control to operations, with Horizon Power Operations taking responsibility for ongoing operations, maintenance, and fault response. Horizon Power's Generation Permit to Work System applies from Operational Handover.

9.3 Post-Operational Handover

After the handover point, the Project will continue to review performance and support Horizon Power Operations both technically and commercially through the first 12-month operation period for learnings and sharing knowledge with the industry.

The hydrogen plant operates unmanned and relies on remote monitoring and control through two primary channels:

- Horizon Power Control Centre (Perth): Using the Power on Advantage utility software, the Horizon Power Control Centre oversees the plant's operation.
- Generation Operations (Denham): Power Station operators, based in Denham, actively control, and monitor the plant utilising Citect SCADA operations control software.

Maintenance and operational responsibilities are divided as follows:

- Operator-performed tasks: On-site operators handle routine tasks related to plant operation and non-complex frequent maintenance.
- OEM and specialised technicians: These experts address specific issues, complex maintenance tasks, troubleshooting, specialised activities, and optimise plant performance.

9.4 Reliability Period

The 60-day reliability period signifies successful and continuous reliable operation without a system fault for 60 consecutive days after the Operational Handover date. In the event of any failure during this period, a subsequent 60-day Reliability Period commences after issue resolution.

9.5 Defect Liability Period

As per the EPC Contract, a defect liability period of 12 months starts from the date of completion, during which the EPC Contractor has the obligation to return to the site to remedy any defects that arise in the work they have performed. The purpose of a defect liability period is to manage the risks associated with project and to ensure that the work is completed to the required standard. It also provides Horizon Power a degree of certainty as to the process that will be followed for making good any defects that may not be apparent at the time of operation handover, and defects that present themselves over time.

10. Risk Management

A Risk Management Plan was developed to outline the process for Risk Management. As part of this plan, Project risks were identified, assessed, control measures and treatment plans identified and then risks were monitored and reviewed on a regular basis.

In addition, the project design and risk management process were underlying processes to provide confidence that the design was being undertaken in a way that ensured quality and safety. The design review process consisted of several design review workshops and corresponding design risk workshops for Safety in Design (SiD), construction, and commissioning risks.

The design review process was critical to ensuring the integrity and safety of the Denham Hydrogen Plant. Comprising several design review workshops, it included sessions dedicated to SiD process, construction, and commissioning. Collaboration between the project team, EPC Contractor, and OEM suppliers, namely NEL, PowerCell, PDC and EKC, contributed significantly to the safe integration of key components at the Denham Hydrogen Demonstration Plant.

The SiD process is implemented throughout the entire lifecycle of the plant, from the design stage to decommissioning. During the construction and commissioning stages of the hydrogen plant, the SiD registers developed during design stage were continued to be used to ensure actions were addressed and residual risks identified.

The following section outlines the SiD key activities undertaken by the project to manage risks, especially safety and environmental risks.

10.1 Safety in Design (SiD)

The project has undertaken a SiD process in alignment with the Design of Structures Code of Practice that arises out of the intent of the Work Health and Safety Act and Regulations (2012).

Specifically, that hazards associated with equipment, a facility or structure must be:

- identified,
- eliminated or managed by the design or operating and maintenance instructions,
- verified and validated that the design and final system are containing the necessary features to control the identified hazards and that these features are correctly operating, and
- that the hazards and constraints of use are documented and communicated to anyone using the subject equipment, facility, or structure or that are employed in the construction, commissioning, operation, or maintenance of the subject system.

10.1.1 SiD Planning

The SiD requirements were defined by the EPC contract technical specifications. This included the following SiD workshops, activities, and deliverables to be undertaken by the EPC:

- HAZID,
- HAZOP,
- CHAZOP,
- Construction (& Commissioning) Risk Assessment Workshop (CRAW),
- Fire hazard assessment and system design,
- Hazardous Area Classification and drawings,
- Electrical protection systems, and
- Dangerous Goods Risk Assessment (as a requirement for DG licence approvals).

Further SiD requirements were identified during delivery of the project, including:

- Type B appliance assessment for the Fuel Cell,
- Consequence analysis and Quantitative Risk Analysis (QRA) for fire and explosion, and
- Layers of Protection Analysis.

10.1.2 SiD Recording and Action Close-out

The findings of each respective SiD review were captured in a report. Action items from each SiD workshop were recorded in a register for action tracking.

Each action identified during the SiD workshops was assigned:

- An action party with responsibility for closing out the action.
- Action category or priority, indicating when the action was required to be closed out.

Residual risks for SiD action items that could not be closed out during the design, construction and commissioning phases were transferred to a residual risk register for handover to Horizon Power's Operations team.

10.1.3 Summary of SiD Actions

The quantity of actions raised in the key SiD review workshops and their close-out progress is summarised in the table below. The specific SiD workshop reports provide details of key actions raised in the workshops, and action close-out comments are included in the Residual Risk Register.

Summary of SiD Review Actions:

SiD Review	No. Actions Raised	No. Actions Closed	No. Residual Actions
HAZID	218	216	2
HAZOP	120	119	1
CHAZOP	63	62	1
Total	**401**	**397**	**4**

10.2 Key Safety Features

Technical and economic feasibility were key considerations, with specific emphasis on enhancing the safety elements . The plant's design prioritised hazard avoidance over control, focusing on core elements throughout to ensure a safer approach to plant design. The fail-safe design principles implemented by the EPC contractor for the hydrogen plant involved an automatic safety system that triggers a plant shutdown and closes all air operating valves, isolating hydrogen gas pipes in the event of any incident, malfunction, failure, or emergency. This strategy maximises the safety of the plant and its surroundings.

Multiple layers of protection were implemented, including ventilation systems to prevent hazardous areas within enclosures, mechanical protection of the pipework, inclusion of Shut off Valves (SOV), pressure and temperature monitoring and safety elements reduce fire risks. Gas, flame, and smoke detection were coupled with the hard-wired safety system to initiate controlled fast stops or emergency stops. The overall safe design includes unmanned monitoring and operations control, a robust hydrogen storage design, and various shut-off devices, covering inherent, passive, and active safety strategies at the Denham Hydrogen Demonstration Plant.

Procedural controls ensure ongoing operation, maintenance, and inspection regimes. A detailed maintenance matrix defines competence and frequency requirements, with plant access restricted via procedural authority, permits, physical delineation, signage, and external perimeter security measures such as barbed wire fences, locked gates, and CCTV surveillance.

Some of the key elements of the plant's safety system are:

- A high degree of automation of the instrumentation and control system, with remote operations, interlocks, and alarms to monitor process and environment conditions.
- Safety relays hard-wired to field instruments as a robust form of monitoring and control. Diagnostics signals from the safety relays are also hard-wired to the control system for alarms and troubleshooting purposes.
- Certified pressure relief devices, including Pressure Safety Valves (PSV) and Pressure Relief Valves (PRV) for the hydrogen piping and Pressure Rupture Disks (PRD) for the gas cylinders. The relief devices vent discharges to safe locations high above the ground.
- Instrument- air actuated SOVs that in an emergency shut down scenario "fail" to the full-close position and therefore isolating the related package.
- Container ventilation system to ensure safe operating conditions and avoid the accumulation of gas within the container and, as a result, avoid the creation of hazardous areas.
- Emergency stop buttons are provided in various easy-to-reach locations across the plant.
- Gas detectors installed close to and above equipment that have potential to leak gas inside the containers.
- Differential pressure flow sensors to monitor adequate air flow through the containers.
- Flame detector with associated beacon and siren to detect any hydrogen fire on the hydrogen bulk storage and buffer storage.
- Pressure transmitters to detect overpressure events within the hydrogen gas system.
- Instrument air differential pressure to detect a leak or line break down stream.

- Safe operating procedures and documentation to support the regular inspection, testing, and maintenance of the hydrogen plant and its components.

10.3 Department of Mining, Industry Regulation and Safety Inspection

A thorough inspection by four Dangerous Goods Officers from DMIRS, scrutinised plant facilities and audited documentation. The inspection was followed by a Remediation Notice listening measures to be taken for improving safety and ensuring compliance with the regulation.

Horizon Power's open communication and cooperative engagement with DMIRS not only addressed regulatory requirements but also demonstrated a proactive approach to risk mitigation, enhancing overall safety.

10.4 Department of Emergency Services Inspections

Collaborative engagement with the Department of Fire and Emergency Services (DFES) led to the development of an Operational Pre-Plan (OPP) on the DFES online platform, aimed at providing crucial information for emergency response.

Throughout construction and commissioning, DFES, including local volunteer firefighters, conducted inspections to verify site safety and familiarise the team with operational response requirements. Horizon Power promptly addressed recommendations from DFES site inspection reports.

10.5 Emergency Response Plan Revision

The introduction of hydrogen into the Denham power station triggered the revision of the site's Emergency Management Plan to cover safety measures related to hydrogen gas incidents, leakages, and fires. This included:

- comprehensive protocols for handling hydrogen gas incidents,
- measures for immediate response to gas leakages,
- procedures for hydrogen fire events,
- training programs for personnel to enhance emergency response capabilities,
- regular drills and simulations to test the effectiveness of the Emergency Response Plan, and
- continuous collaboration with regulatory bodies and emergency services for ongoing improvement and compliance.

11. Key Learnings

The key learnings, including challenges or technical difficulties encountered, have been documented below and categorised regarding commercial/economic, technical/safety/risk, regulatory and operational lessons learned.

11.1 Lessons Learned No 1 – Hydrogen Capability and Experience (Continuation of Lessons Learnt Report No. 2)

Category: Technical / Operational

Objective: Enhance skills, capacity, and knowledge for efficient testing and commissioning of hydrogen equipment packages and plant integration.
Details: The construction and commissioning stages revealed a significant deviation from initial time estimates. Initially, this was attributed to the EPC contractors' limited experience with hydrogen technology, considering the industry's ongoing learning phase. Later, faults with equipment (covered in Lesson Learnt No 5) further contributed to the delays. The EPC Contractor had to develop most deliverables from scratch due to the unprecedented nature of the project, including:

- drawings,
- engineering studies,
- risk registers,
- project schedule,
- commissioning plan,
- ITPs and ITRs,
- testing procedures,
- operating procedures,
- spare list,
- maintenance schedule,
- operation and maintenance manuals, and
- training courseware.

The EPC Contractor encountered challenges to produce realistic schedules due to the complexity of coordinating multi-disciplinary teams and resources on-site and remotely, involving power station operators, overseas Vendors, control system engineers from both sides, stakeholders, regulatory approvals, and unexpected aspects inherent with new-technology projects, which were frequently underestimated by the contractor's schedule.

It's important to reiterate that enhancing industry knowledge and experience in hydrogen installations remains a primary objective of this project.

Despite challenges, the EPC Contractor's construction and commissioning teams demonstrated suitable skills, qualifications, and experience from other projects, which were largely transferable to the hydrogen plant, especially in the electrical, control, and mechanical disciplines.

Effective management of concurrent subcontractors during construction marked key achievements, including a comprehensive project induction, a robust competence assurance process, cohesive project teams, and efficient implementation of the project's HSE Management Plan on-site.

The Contractor implemented an effective internal process to manage and track the completion and signoff of the ITPs/ITRs. Multiple inspections during and post-construction by Horizon Power project engineers, who were closely involved with the project, proved to be an effective quality assurance process.

Implications for Future Projects:

Future projects should consider:

- The specific challenges and scale of new technology demonstration projects, which might involve contractors with small teams and less mature engineering, construction, and project management processes (recognizing that projects like this one are rapidly advancing skills and improving local knowledge).
- The complexity of multidisciplinary projects and the availability of resources with the requisite experience and capability for efficient delivery of the works.
- The necessity of conducting multiple inspections by engineers closely engaged with the project and promptly addressing issues with the EPC Contractor.
- The importance of selecting contractors with established experience and a strong track record in on-site management and construction.
- Accounting for the complexity in planning and accurately estimating activities and timeframes acknowledging limited experience with hydrogen technology.
- Allocating sufficient time in the schedule for:
  - developing and reviewing the commissioning plan and testing documentation,
  - carrying out construction and commissioning activities,
  - conducting internal and external quality assurance processes and reviews,
  - involving the operations team for operational readiness,
  - managing change effectively, and
  - preparing for contingency in case of unexpected events.

- Allocating sufficient time in the schedule for:
  - developing and reviewing the commissioning plan and testing documentation,
  - carrying out construction and commissioning activities,
  - conducting internal and external quality assurance processes and reviews,
  - involving the operations team for operational readiness,
  - managing change effectively, and
  - preparing for contingency in case of unexpected events.

11.2 Lesson learnt No 2 - System Complexity and Power System Integration (Continuation of Lessons Learnt Report No. 5)

Category: Technical

Objective: The installation, integration, and operation of renewable hydrogen into an existing energy system, incorporating solar and diesel.

Detail: During the design phase, novel technical challenges were encountered in the integration of hydrogen equipment packages together with a solar farm to generate base load power, a task not previously undertaken. Throughout the construction and commissioning phases, the implementation and testing of the designed solutions into an integrated system has continued to pose challenges and offer valuable lessons.

For this Project, the integrated system includes:

- Hydrogen equipment,

- Enclosures/ containers,
- Ventilation system,
- Safety system,
- Pressure and flow control system.
- Overall control system,
- Cooling system,
- Water recovery system,
- Instrument air system,
- Solar generation system,
- Power conversion system, and
- Power distribution

Under normal automatic operation, the hydrogen plant will transition between a set of discrete states. The main driver for the plant to move between these is the output of the dedicated solar farm. If sufficient solar power is available, electrolysers are run and hydrogen is generated and stored, if not the fuel cell is run. At all times the plant aims to generate at least 35kW baseload supply to the power system. As such, a normal day will see the plant operating in Fuel Cell (FC) mode at night and Electrolyser (EL) mode during the day.

Key Challenge 1 –Intermittency of Solar Power

To generate 'green' hydrogen under the aims of the project, solar generation must be balanced with the loads of the electrolysers and those auxiliary systems needed to run them. Additionally, a minimum of 35kW grid export must be left over to meet the base load aim. To achieve this, electrolyser loads must be dispatched dynamically by a master controller as the solar generation varies throughout the day and year.

While significant battery energy storage exists within the power system its use to store solar energy to be used to generate hydrogen at a different time was specifically excluded from the project scope. The aim here is to test the possibility of directly powering electrolysis from an intermittent renewable source. Similarly, the wind turbine generators in the power system were excluded as an available source for hydrogen generation.

The use of existing wind assets might be an extension to the current demonstration plant in the future.

The NEL electrolysers have the following key constraints in their operation which pose challenges to instantaneously reacting to the output of a solar farm. These being:

- A startup and shut-down sequence of around 8 and 5 minutes respectively, during which they must be continuously powered even if the solar resource falls away.
- A minimum run time of 30 minutes without being turned off after they begin generating to ensure hydrogen drying desiccant beds do not become saturated, avoiding the generation of "wet" gas into storage.
- While reasonably responsive to changes in setpoints, there are absolute limits to ramp up and ramp down rates. That is the rate of change of current across the cell stacks must be kept within safe bounds.
- The operation modes envisaged by the OEM did not include rapidly changing power input, consequently OEM control design decisions for the "off the shelf" units are based on the

need to fill a tank to a set pressure or generate hydrogen for a direct process use (on demand generation). The Denham HESS use case is the opposite of this control philosophy, based on availability of input power rather that demand for hydrogen on the output (with infinite input power).

During project development the concern was that the solar farm output would instantaneously drop below the load of the electrolyser due to cloud events in particular, and due to the constraints outlined above require the use of other available generation in the power system to make up the shortfall. This would include diesel generation depending on the operation state of the power system and instantaneous town load.

To ensure the electrolysers do not turn off during this period a short-term offset strategy is used. As the sun comes up and the solar farm begins to generate power the control system begins to record or 'bank' how much energy has been exported to the grid until it reaches the amount required to power the electrolysers through their start-up sequence and minimum run time. Once the minimum run time has elapsed, the electrolyser load follows the solar output without exceeding it.

One electrolyser is brought on at a time to ensure enough solar generation is present to run the electrolysers without absorbing power from other sources rather than the dedicated solar farm.

Also, it has been identified that cloud events may result in stops and starts during scattered cloudy days. With every start requiring approximately 38 mins of run time can lead to the use of other energy sources, as the electrolysers continue to operate at a low output while cloud cover continues.

Implemented solution

Control algorithms for the dispatch of Electrolysers have been established to meet the requirements outlined above and mitigate the volume of energy consumed from other sources.

During commissioning of the designed solution, which involves a short-time offset strategy of 'banking' energy, initial results showed that the settings were conservative. These early insights enabled adjustments of the control logic and setpoints, resulting in improvements and optimisations.

The following outlines the high-level description of the three key control strategies commissioned for dispatching the Electrolysers.

Dispatch limits

The Hydrogen Programmable Logic Controller (H2PLC) monitors the dedicated solar farm output and accounts (banking) the energy above the minimum target of 35 kW net to the grid. Once banked solar energy reaches the lower limit setpoint an automatic remote START signal from the H2PLC will trigger the first electrolyser to operate. Similarly, the higher limit setpoint enables two electrolysers to run.

Commissioning result graph showing dispatch limits in operation:

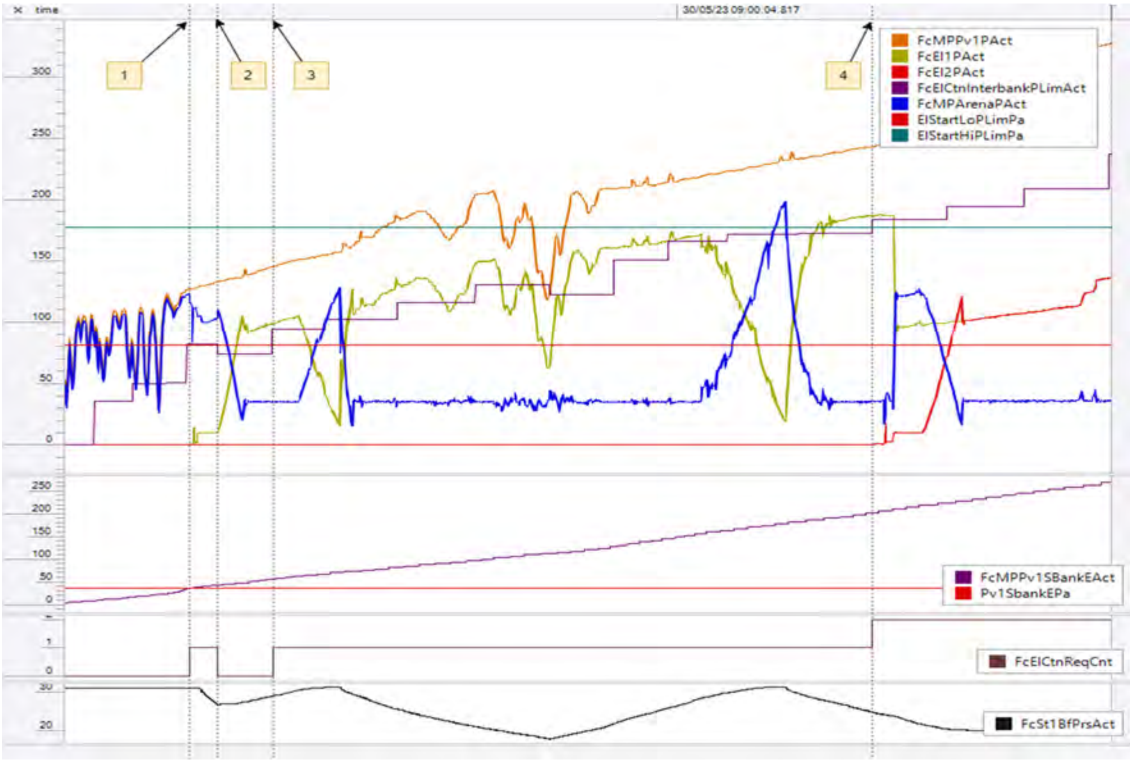


Figure – Startup period of a typical day showing dispatch limits in operation.

The signals on the plot are:

- Pv1PAct – Solar Farm Actual Power Output,
- El1Pact - Electrolyser 1 Instantaneous Power,
- El2Pact - Electrolyser 2 Instantaneous Power,
- ElInterbankPlimAct – Actual Interbanking limit, as describe in the section below ,
- MPArenaPAct – Virtual Point of Connection Power Out - If negative, then power from other sources is being consumed by the plant,
- ElstartLo/HiLimPa - Dispatch limits for starting one or two electrolysers,
- SBankEAct - Daily cumulative net of VPoC energy,
- SBankEPa - Setpoint of solar bank banking balance, see heading 2.1.5 below,
- ElReqCnt - Number of electrolysers to be dispatched,
- BfPrsAct - Buffer tank storage pressure, included to explain the dips in El power consumption as their output pressure approaches their maximum output pressure (this behaviour will be further investigated for optimisation).

Before point 1. Solar output has risen, ArenaPAct is following PvPact minus plant auxiliary loads as clouds cross the dedicated solar farm. Average of PVpact minus AreanPMin (35.5 kw) is evaluated over 5 minutes. The resulting signal InterbankPLim climbs with the Sun.

1. Interbanking PLim goes above LoPLim and ElReqCnt goes to one, a single Electrolyser is dispatched. Electrolyser starts its startup cycle and begins consuming solar farm power.

2. Interbanking PLim goes below LoPLim and ElReqCnt goes to zero, the minimum run time has not elapsed, so Electrolyser 1 does not shut down. Electrolyser 1 continues its startup sequence climbing to 70% power output before power setpoint control is handed to the H2PLC. H2PLC matches Electrolyser 1 power setpoint to instantaneous solar farm PAct minus ArenaPMin. Arena Pmin is maintained at a steady state of 35.5 kW with a short deviation before Electrolyser 1 hands over power setpoint control.
3. ElReqCnt returns to one, electrolyser 1 continues to run. Cloud events cause short term deviations to ArenaPAct as Electrolyser 1 follows power setpoint with small mismatch in ramp rate vs power setpoint.
4. ElReqCnt goes to two as the second dispatch threshold is crossed. Second electrolyser starts.

Interval averaging for electrolyser dispatch

The dispatch limits are evaluated against average solar power, not the instantaneous value. This is to avoid rapidly power cycling (over-cycling) the electrolysers during cloud events. During these cloud events the solar resource can rapidly fluctuate and then restabilise. The averaging function has been called ‘interval banking’ in project documentation.

The interval of averaging is set to 5 minutes. Commissioning has shown the setting gives good balance between repeating the 30-minute minimal run time (over-cycling) and following the solar resource availability as the sun rises and sets each day. The net result being that start up energy use is reduced by controlling for less start up periods in total.

The energy consumption cost of remaining online for intermittent cloud events within the 5-minute averaging window is less that the cost of adding an additional start up cycle, should the sun in fact be setting. Should the event be significant enough to reduce the average output of the solar farm within the 5-minute window, then one or two electrolysers are shut down as the average of that interval propagates though.

Referring to the figure above - Typical day showing dispatch limits in operation. *The graph shows this function in operation. As the solar resource fluctuates the average (InterbankPLim) drives the number of electrolysers required to be online (ElReqCnt). The volume of energy consumption from other sources is kept minimal, in the example given none is consumed.*

Solar banking

The final mechanism is termed Solar Banking in project documentation. The intention being that a set volume of energy from the dedicated solar farm can be banked during the morning of each day. When the balance has reached its setpoint, the electrolysers may be started, and the balance may be spent if there is insufficient solar generation during the remainder of the day. The net result is that all energy used to generate hydrogen that comes from other sources is offset by the dedicated solar farm as it uses its excess generation to supply other loads on the network.

In practice, the dedicated solar farm capacity is such that banking would not be required if a purely offsetting strategy was the goal. That is because its energy consumed by the grid exceeds the solar banking balance many times over on the average day.

However, the overarching project aim in this case is to ensure as far as practicable the use of the dedicated solar farm energy to power the electrolysers. In this regard, commissioning results of tracking solar banking strategy demonstrated that the volume of energy consumption from other sources is much lower than initially estimated in conservative modelling scenarios. This is for the following reasons:

- Instantaneous solar power is used as input to the electrolyser's dynamic power setpoint. The initial algorithm design used the interval banking limit as the P setpoint, which did consume considerably more of the solar banking balance. In the current implementation, should a cloud event occur the electrolysers instead are commanded to reduce their consumption of power rather than consume the banked balance.
- The reaction time of electrolysers to setpoints is adequately quick compared to the rate of change of the solar resource. Leading to the electrolysers following solar closely and low power deficits. For reference, control system tuning, and algorithm refinement have led to step load tests showing responses in the order of 10 seconds from minimum to full power consumption (and vice versa).

Given that, during the commissioning phase the banking balance was optimised and only the dispatch limit strategy implemented for dispatching the electrolyser, due to its simplicity and efficiency.

Resulting behaviour

Utilising the above control strategies these favourable preliminary results can be presented. Noting that numbers are not reflective of long-term performance.

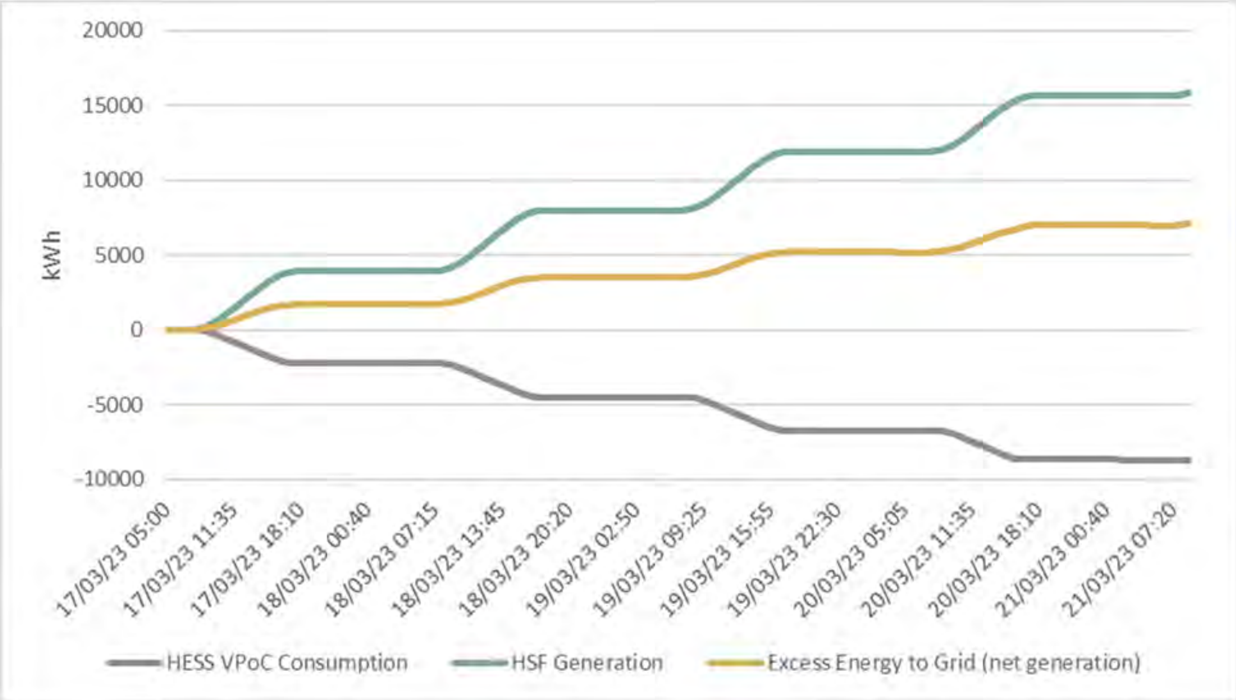
Key statistics:

Fraction of non-hydrogen solar farm energy used during electrolyser startups (inclusive of min run time) compared to total electrolyser consumption while in automatic control.

- Representative cloudy day 0.16% .
- Representative sunny day 0.00% .
- Entire test period 0.02% .

While external factors, such as seasonal variations, could potentially alter these results, commissioning outcomes demonstrate that the implemented control strategy ensures the dedicated solar farm output consistently exceeds hydrogen production consumption during each daily period.

A graph of four days of operational data is presented below showing the total cumulative energy generation of the dedicated solar farm vs the cumulative consumption of the HESS including auxiliary loads during automatic operation. The sum of these two traces is shown to be positive, or net generation to the grid, and significantly greater than zero.



Key Challenge 2 –Fuel Cell, Inverter and DC-DC converter Integration

The plant's primary power generation system comprises the following equipment:

- 100kW Fuel Cell that generates electricity by converting stored hydrogen and oxygen from the air into water using Proton Exchange Membrane (PEM) technology.
- 100kW four quadrant inverter-rectifier that connects the system to the grid, serving as both a rectifier to provide the necessary DC voltage for fuel cell startup and an inverter to convert the voltage output of the DC/DC converter and fuel cell for grid integration.
- DC/DC Converter, responsible for maintaining the required DC voltage and current ranges for the inverter and fuel cell.

Control of the fuel cell and inverter dispatch is overseen by the H2PLC using a Proportional Integral Derivative (PID) loop controller, accounting for various inputs, including the dedicated solar farm output, auxiliary loads, and fuel cell output, ensuring a minimum 35 kW baseload supply to the grid.

It's worth noting that there's no prior record of these equipment being integrated to operate together.

The PS100 fuel cell requires two voltage DC sources. One is to primarily power its auxiliary loads, and the other is to allow energy to flow to supply the load. The manufacturer recommends coupling both connections to a single DC/DC converter.

The Fuel Cell, as designed, is primarily intended for traction use, for example as the power source for a bus electric drive train, and as such, downstream of the DC/DC converter, an electric vehicle's DC motor and battery are anticipated. In the case of a grid-coupled fuel cell, a grid-connecting inverter is required. In this design, the inverter is only one connection between the fuel cell and the grid.

This inverter must supply an uncontrolled load from the grid during fuel cell startup, seamlessly transitioning to controlling a generator to export power as the fuel cell output exceeds its own consumption. The control architecture required to perform this action was novel and not trivial, especially the control algorithms dictating the startup sequencing and the expected behaviour of the fuel cell and its control over the interconnected DC-DC converter.

Initially, the proposed design drew from the expertise in battery energy storage systems (BESS) and aimed to operate the inverter in virtual generator mode (VGM). In VGM mode, a set of grid management functions (GMF) are provided alongside a virtual governor, synthetic inertia, and others, making it commonly used in hybrid power stations with BESS for grid stabilisation. However, VGM mode proved unsuccessful due to unsatisfactory inverter behavioural characteristics specific to this application.

Addressing this challenge required substantial efforts and time, including exploring various alternative solutions, conducting multiple tests, collecting data, and engaging with manufacturers.

The most suitable alternative was found in the direct conversion mode with bi-directional supply. This allowed power draw for fuel cell auxiliary loads during startup and shutdown, simplifying the control architecture and reducing the plant's response time.

Rigorous testing confirmed the effectiveness of this revised operation, ensuring alignment with the project's requirements.

Implications for future projects:

While direct conversion mode maintains all grid-level protections, higher-level grid management functions are not available. Although not a concern for this application because the size of the inverter, adherence to codes for future larger grid-connected installations will be required. Specifically for this installation, the grid-tie inverter was unable to successfully grid form. While not an aim of the project, it was hoped this installation could prove the capability for future projects.

Potential alternatives not explored in this project but worth considering for future designs include using a battery energy storage device to supply the energy deficit between the DCDC converter and the grid-tied inverter (DC coupled) or employing a dedicated DC or AC supply for fuel cell auxiliaries that bypasses the inverter.

As the market develops for grid connected fuel cells it can be expected that product offerings from major manufacturers will be tailored to the application. The result is expected to be separate supplies for auxiliary loads and generator terminals. In this way more options will be available to system integrators for simple grid-interfaces.

Further research and development by manufacturers into control algorithms managing all equipment for hydrogen-based power generators should be considered to ensure fully integrated, comprehensive solutions that meet the technical requirements of novel applications. A manufacturer's packaged solution, featuring a fuel cell and inverter with a specifically developed and extensively tested control system, might be a viable alternative to bespoke, project-specific solutions.

11.3 Lesson learnt No 3 Power System Response

Category: Technical

Objective: Increased skills, capacity, and knowledge relevant to the ability to appropriately integrate the technology for power supply remote microgrid

The hydrogen power plant in Denham employs polymer electrolyte membrane (PEM) technology in both its electrolysers and fuel cell. This technology is recognised for its fast response times and flexibility in production, making it well-suited for hydrogen generation from renewable sources. The PEM electrolysis method is particularly promising for high-purity hydrogen production, a critical requirement for fuel-cell electricity generation applications.

The fuel cell demands high-purity hydrogen gas as fuel and is renowned for its efficiency in power generation from hydrogen. With no moving parts, fuel cells are expected to operate smoothly and reliably.

Details: During the commissioning phase, exhaustive tests were undertaken to evaluate the hydrogen power plant's capability to supply baseload electricity through the conversion of green hydrogen. The study aimed to comprehend the fuel cell ramp rate, Electrolyser ramp rate, responses to fluctuations in solar generation, and the ability to provide voltage and frequency support typically offered by spinning generators or BESS in small power systems.

Electrolyser Ramp Rates:

The project successfully achieved rapid controlled response in electrolyser ramp rates, demonstrating step responses from 35% (132 kW total) to 100% (378 kW total) loads and vice versa within 10 seconds, aligning closely with the rate of change of the dedicated solar farm during cloud events.

Performance verification tests with both electrolysers in service showed a total ramp-up rate of 24.7 kW/s and a total ramp-down rate of 30.9 kW/s. This favourable outcome minimised energy usage from other sources during cloud events, exceeding initial expectations. The electrolysers exhibited potential as controlled loads for grid management, although such functionality was not a project requirement.

Purity tests confirmed hydrogen gas concentration above 99.86%, meeting fuel cell requirements.

Fuel Cell Ramp Rates:

In the design phase, concerns were raised regarding the fuel cell's ability to promptly respond to load requests. Anticipated challenges arose from the intricate requirements of system components, compounded by grid power quality demands encompassing mechanical, chemical, and electrical aspects. Application of lessons learned during commissioning facilitated improvements, particularly in overcoming initial concerns about meeting load demands. Control system enhancements, including the addition of a new PID control level, were instrumental in reducing lags between DC/DC, Inverter, and the fuel cell.

This resulted in stable and accurate HESS output, providing steady baseload power with minimal deviation from setpoints. The improved control allowed reduction of the initial conservative 5 kW buffer to 0.5 kW.

Fuel cell performance verification tests demonstrated a total ramp-up rate of 7.0 kW/s and a total ramp-down rate of 4.6 kW/s, affirming its ability to supply baseload power and respond to load demand oscillations. The fuel cell's average startup time of approximately 60 seconds aligned with acceptable tolerances for power generation units in small power systems.

Implications for Future Projects:

1. **Electrolysers as Controlled Load:** PEM electrolysers can be considered as controlled loads within their inherent ramp rate limitations. However, future projects should consider developing and testing novel dispatch and power control algorithms for this purpose, as well as integrating a BESS for operating reserve to address grid stability concerns during rapid cloud cover changes. Results of this project indicate that a low energy high power type BESS of modest size would be sufficient for this purpose due to the relatively low power and energy delta between solar output and controlled electrolyser consumption seen in the worst case.

2. **Fuel Cell Dispatchability:** The Project confirmed its ability to supply baseload power, and with the addition of energy storage for the purpose of virtual inertia, fuel cells are proven to be readily dispatchable, by the learnings of this project. However, future projects should explore further its dispatchable capability with dynamic output setpoints, ideally using a control system developed by adhering to industry-standard software development practices.

3. **Consideration of BESS:** As fuel cells have inherent limits to the rate at which they can ramp up and down power generation future projects should contemplate integrating a BESS to provide short time voltage and frequency support, and operating reserve for grid stability.

These insights provide valuable lessons for future projects, emphasising the importance of robust control systems, testing, and considerations for renewable energy integration in microgrid setups.

11.4 Lesson learnt No 4 Concise Control Philosophy

Category: Technical

Objective: Increased skills, capacity, and knowledge relevant to the reliability of the hydrogen technology as a power source for remote microgrid

Detail: The development of a clear and concise Control Philosophy emerged as a critical aspect of the project, proving instrumental in guiding the development and commissioning of a control system capable of orchestrating the seamless operation of diverse systems and equipment to function cohesively within the microgrid.

This philosophy facilitated effective collaboration among multiple parties and teams, mitigating divergent works and integration issues during commissioning.

Developing a clear and concise Control Philosophy at early stage of the project provided significant guiding direction, allowed effective collaboration between multiple parties to a common goal and can avoiding divergent works and integration issues at the time of commissioning.

Implications for future projects:

The Denham project underscores the importance of formulating a clear and concise control system philosophy early in the project lifecycle. Future projects can leverage this lesson to streamline development, enhance collaboration, and navigate the intricacies associated with integrating diverse technologies, especially within a small power system.

The potential benefit for future projects includes:

- providing clarity on operational requirements,
- facilitating efficient collaboration between teams,
- minimising integration issues during commissioning,
- identifies and mitigates potential risks early in the project,
- minimising risks of costly delays and revisions,
- facilitates knowledge transfer among project teams,
- optimising system performance for increased efficiency and reliability, and
- facilitating development of O&M documentation and training programs,

11.5 Lesson learnt No 5 Equipment Reliability

Category: Technical

Objective: Increased skills, capacity, and knowledge relevant to the reliability of the hydrogen technology as a power source for remote microgrid

Detail: Despite utilising equipment manufactured by market-leading companies such as Nel, PowerCell and Veolia, the project had equipment failures prior to operational handover, which have resulted in project delays and the replacement of malfunctioning equipment. These events demonstrate the importance of understanding the reliability of specific hydrogen equipment technologies.

Electrolysers and fuel cells were deemed proven technology and in use for years by other industries, however, reliability data remains unconfirmed, contingent on the accrual of sufficient statistical data through large-scale deployments to inform reliability assessment studies.

The durability of the selected equipment appears to be low, and further work should be undertaken to determine if design, manufacturing, transport, or installation activities are the main cause of equipment failures.

During the final commissioning stage, the following technical issues occurred:

1. **Electrolyser power supply modules failure**: In March 2023, coolant leak of a packaged C30 electrolyser liquid cooled rectifying power supply module damaged power supply modules in Electrolyser 2. The power supplies are manufactured by a third-party supplier.
   One of twelve modules leaked causing a cascading failure of that unit and those arranged underneath it. The leak was undetectable until the managing device reported loss of communications warnings to those units.

The EPC Contractor in conjunction with the electrolyser manufacturer, Nel, promptly investigated the failure with the equipment and arranged replacement of the power supplies with no cost to Horizon Power.

The electrolyser remained in operation powered by the five power supplies not damaged by the leakage. This allowed the EPC contractor to proceed with the commissioning activities.

The replacement of the modules and re-test of the electrolyser took approximately 2 months due to the stock being overseas and shortage of equipment and parts. This caused further delays postponing the operational handover of the plant.

Nel reported that this was a batch issue with low incidence and have been addressed with a more robust test and part screening as part of vendor's manufacturing process, and a high stress test process that is performed on 100% of the power supplies prior to shipment.

2. **Fuel Cell failure:** After overcoming a few challenges with the fuel cell hydrogen firmware and sensors that caused multiple nuisance trips, in July 2023, technical issues with the PS100 fuel cell prevented the equipment from operating and required replacement of the unit. This caused further delays and postponement of the operational handover of the plant.

   The EPC Contractor in conjunction with the fuel cell manufacturer, PowerCell, promptly arranged replacement of the fuel cell with no cost to Horizon Power. PowerCell's analysis of the faulty unit identified the presence of salt on the cell stack which indicated that the likely root cause of failure was the ambient air salt concentration. Analysis of salt concentration both within the controlled environment of the container and outside in unfiltered air did not support the theory of elevated salt levels causing the failure.

   Before placing the new fuel cell unit in service, the EPC contractor performed air quality analysis of the air both inside and outside of the fuel cell container and submitted the results to PowerCell. Air quality results were confirmed to be within the fuel cell specification for salt concentration. Despite this, the EPC Contractor upgraded the air intake filtration of the fuel cell container to avoid future potential issues.

3. **Reverse osmosis faults**: The CENTRA™ R120 unit, that utilises reverse osmosis and deionisation processes to purify water for electrolysis, presented multiple intermittent alarms and faults, as well as multiple part failures which resulted in further postponements of the plant's operational handover.

   After multiple attempts to investigate and resolve these problems, the EPC Contractor replaced the faulty unit in its entirety and with remote support from the vendor, Veolia, commissioned the new unit which is currently being tested to prove that it is clear of intermittent faults prior to proceeding with operational handover.

Possibly, the reasons behind theses issue are that early-stage technology has had limited industrial deployment and therefore prone to failure, and COVID supply chain issues such as equipment and labour shortage may have compromised quality and reliability of the units supplied to the project.

Implications for future projects:

Future project should consider the following:

- Request equipment manufacturer's quality assurance and quality control process details, and equipment reliability data for assessment and evaluation to inform the selection and acceptance of the proposed equipment.
- Undertake HAZOP with the equipment manufacturer regarding the project's application.
- Extended warranty to protect the project against uncertainties associated with new technology.
- Specification containing the quality requirement of all equipment to ensure that different equipment packages are compatible.
- Reliability of the hydrogen equipment might be a challenge, as well as parts and services available in Australia.
- The choice of equipment suitably robust for a remote industrial installation.
- The use of local manufacturers for those auxiliary systems that are available in the Australian market. Such as water treatment systems. Potential advantages are ready access to expert support and spares, reduced outage timeframes and adherence to design for Australian climatic conditions.

11.6 Lesson learnt No 6 Regulatory Approval Process

Category: Regulatory

Objective: Increased skill, capacity, and knowledge relevant to regulatory compliance

Detail: Hydrogen technology in the electricity industry is a new technology. Current regulations are regularly changing and aiming to kept pace with the rate of development and as such, regulatory frameworks and training are being developed but still lack definition. DMIRS is the applicable Regulator for the appliances used on this Project.

It is important that the regulatory framework is updated regularly to reflect the acceptable limits in design, construction and safe use and handling in the manufacture and storage of hydrogen. These updates carry significant implications for future projects.

An early and collaborative approach with DMIRS both, Building & Energy and Dangerous Goods branches proved to be beneficial for both parties. The project consulted and maintained open communication with DMIRS throughout all stages. The Regulator conducted thorough documentation assessments and site inspections and provided constructive feedback to the project. This process informed Horizon Power in how to upskill its workforce appropriately and helped the project to identify and mitigate potential risks, enhancing the plant's safety performance.

Implications for future projects:

Future projects to consider the valuable lessons gained from the regulatory approval process, including:

- early consultation with the Regulators,
- engaging SME consultants to facilitate approvals,
- open communication with the Regulators, and
- scheduling site inspections with the Regulators.

12. DATA SPECIFICATION – PUBLIC UNRESTRICTED DATA

Data provided at Milestone 3 is actuals and forecast based on commissioning results, design, warranted rates or consistent with relevant supply agreements or the financial model.

Timing of reporting – Milestone 3				
Project Data	**Units**	**Definitions**	**Forecast**	**Comment**
Solar Energy to Grid	MWh p.a.	Amount of estimated direct renewable energy imports to the grid not used for Electrolysis.	503.5	Average energy imports to the grid during the first 10 years of the project subject to network constraints
Solar Energy to H2 Plant	MWh p.a.	Amount of renewable energy used as feedstock to produce Hydrogen including all Balance of Plant and auxiliary power.	872.3	Average Electrolyser energy input during the first 10 years of the project at ~67.46 kWh/H2 kg, based on commissioning results
Hydrogen Delivered	t H_2 p.a.	Calculated as the annual tonnes of hydrogen delivered in normal operations over a 12-month period based on the designed average system efficiency guaranteed by the equipment supplier, and the electricity capacity factor (the extent to which the electrolyser is used) as assumed in the financial model and / or relevant commercial agreements	12.9	Average hydrogen output during the first 10 years of the project subject to further testing at 5.4 H2 kg per hour at ~27.9% electrolyser efficiency. The electrolyser performance ratio is ~69.64 kWh/H2 kg based on commissioning results

Electrolyser Data	Units	Definitions	Actual	Comment
Equipment supplier		The chosen or preferred supplier of the electrolyser equipment	NEL	PEM Electrolysers
Electrolyser Capacity	MW	Electrolyser Capacity is the electrolyser stack capacity warranted by the equipment provider at the Commissioning Date	0.348	
Capacity factor	%	The extent to which the electrolyser is used	27.9%	H2 production (kg) per year compared to maximum production in a year.
Efficiency (at design capacity factor)	MWh/t_H_2	This is calculated as MWh per tonne of hydrogen delivered	67.46	Based on commissioning results
Asset life	Years	The expected term before electrolyser replacement capital is required	28	Estimated 80,000 max run hours at 2,880 average run hours per annum
Warranty period	Years	The warranty period of the electrolyser equipment as warranted by the equipment supplier	1	The warranty period provided by the EPC Contractor The warranty period offered by NEL is typically one year from Shipment (Equipment) and 90 days from Shipment (parts)

Stack replacement interval	Hours	The scheduled lifetime of the electrolyser equipment before significant replacement of electrolyser stacks are required	80000	The lesser of 80,000 hours or 10 years
Hydrogen purity	%	The purity of the final hydrogen product as a percentage on a (per molecule basis)	99.86%	Laboratory test results od=f samples taken at the fuel cell H2 inlet.
Capital expenditure	**Units**	**Definitions**	**Actual**	**Comment**
Total project cost	$m	The total capital expenditure to deliver the Project including all contingency. This should be able to be supported by relevant supplier contracts and be consistent with the financial model	10.02	As per the baseline project budget submitted to ARENA including cost of in-kind funding
Hydrogen equipment capital cost	$m	The total combined cost of electrolyser, fuel cell, compression and storage equipment associated with the project, not including O&M costs.	4.41	Equipment supply cost only. The figure does not include equipment the installation costs
Balance of plant capital cost	$m	The cost of all other equipment required to produce hydrogen at the required offtake pressure not including the electrolyser or compressors and Renewable energy generation capital cost	0.29	Equipment supply cost only. The figure does not include equipment the installation costs
Renewable energy generation capital cost	$m	The cost of all renewable energy generation equipment (if relevant)	1.50	Solar Farm l cost, including solar arrays, inverters, switchboard and network connection.

Environmental	Units	Definitions	Forecast	Comment
Water source		Note water source	Water Corporation - Denham	Potable water supplied from the town's system.
Volume of water consumed annually	ML p.a.	This should include all water input to the electrolysis process, including desalination and demineralisation for example, it should not include any water required for other processing activities	0.38	Average water consumption per annum over the first 10 years of the project including electrolyser water consumption and cooling water
Water intensity of production	$L\_H_2O/kg\ H_2$	This is the total volume of water used as an input (L_H_2O), divided by the total amount of hydrogen produced in the electrolysis process (kg_H_2)	29.9	Includes electrolyser water consumption only. (no cooling water is included)
Estimated Greenhouse emissions abatement	t_CO2 p.a.	This is the total carbon tons abated per annum by the Hydrogen Plant (including solar). t	470	based on diesel offset from the plant's total output (at 2.7 ton of CO2/kl of diesel)
Resourcing	**Units**	**Definitions**	**Forecast**	**Comment**
FTEs required during construction period	FTE	Full time equivalent employees (including those working on the project under contract or other employment arrangements).	52	
FTEs required during operations period	FTE	As above	0.5	FT operator = 38hr/week Estimate at this stage

The Horizon Power's Denham solar and wind farms situated alongside the Little Lagoon, with the Francois Peron National Park at the horizon.

HORIZON POWER