Denham Hydrogen Demonstration Project

ARENA Funding Milestone 1 and 2
Lessons Learnt Report

Version No: 1.3

HORIZON POWER

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1. PROJECT DETAILS

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Reporting Period	Milestone 1 and 2 – Procurement, Design, Mobilisation and Equipment to Site (Nov 2020 – Jul 2022) Updated March 2023

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.

2. EXECUTIVE SUMMARY

The purpose of the Project is to demonstrate the technical viability of incorporating renewable hydrogen power systems into a microgrid.

The Project is integrating hydrogen with solar and diesel and to demonstrate the ability to provide firm capacity from renewable energy sources equivalent to the average load of 100 residential houses in Denham, Western Australia (nominally 526 MWh per year, with 220 MWh per year from Hydrogen) (the **Project**).

The high-level objectives of the project include:

- Improvement in technology readiness and commercial readiness of renewable hydrogen, by developing the technical ability to duplicate and decarbonise other remote micro-grids if economically appropriate, and
- Increased skills, capacity and knowledge relevant to hydrogen energy technologies.

The hydrogen plant will use electricity from a dedicated 704kWp solar farm, that will supply the town directly, and power the electrolyser to produce hydrogen using 2 x 174kW electrolysers, after which the hydrogen gas will be compressed and stored on site in a pressurised storage system.

When solar generation is not available, Horizon Power will utilise the stored hydrogen through a 100kW fuel cell to produce electricity ensuring a constant and reliable renewable power supply to supplement the diesel generation in Denham.

This lessons learnt report details key learning from the procurement and design phase of the project.

3. KEY LEARNINGS

3.1 Lesson learnt No 1 Contracting Strategy and Approach

Category: Commercial

Objective: Increased knowledge relevant to procurement complexities and access to appropriate EPC Contractors

Detail:

The procurement process for this project was initiated via an Expression of Interest (**EOI**) to the market. A foreseen key challenge for this procurement was the estimated long lead-time for the electrolyser and a fuel cell and so Horizon Power went to market for the overall requirement comprised of two separable portions of work being:

1. Part A, the supply of long-lead items required for the Plant, i.e. electrolyser and fuel cell; and
2. Part B, the engineering and construction of the Plant, and procurement (**EPC**) of all other required items

EOI Participants were invited to respond to either or both parts.

This separable portion procurement strategy was selected to allow Horizon Power to obtain an overview of the available market solutions whilst maintaining the flexibility to procure the long lead items first (if suitable) and minimise any impact that the lead times could have on the EPC part by separating the contracts.

Responses to the EOI gave us the following learnings:

- Initial budget estimate was lower than that indicated as required from the EOI response with a significant range of pricing across the responses
- Synergies of procuring the full scope through one Contractor would result in a better outcome and lower risk for Horizon Power and the Contractor. This view was primarily based on the responses that suppliers would be required to be part of the installation process, not just the equipment supply, and that the relationship between the equipment supplier and installer of the equipment was identified as key to achieving a high-quality outcome. However, this limits Contractor options due to existing commercial agreements of Hydrogen equipment manufacturers with Australian representatives.
- At the time of the EOI in early 2020, whilst there were a number of renewable hydrogen projects associated with refuelling and blending of hydrogen gas, there were no companies in Australia that Horizon Power could identify that had completed a renewable hydrogen facility, using the hydrogen directly for electricity generation in a power system via a fuel cell.

From the EOI, Horizon Power proceeded to a Restricted RFT process, and responses to the RFT gave us the following additional learnings:

- Initial expectation of equipment sizing, especially sizing of the solar farm, to meet the initial energy objective was underestimated which in turn impacted overall project budget. Compromises to system sizing and energy outcome expectations were required to more closely align with budget expectations.
- Contractor design and delivery experience is still limited, due to the development stage of the hydrogen market.
- The integration of renewable assets and hydrogen systems i.e. electrolyser and fuel cells were going to be a significant challenge for any prospective EPC contractor, due to the lack of experience in the Australian market, and there was no demonstrated experience that EPC contractors had managed the interface risks of the end-to-end hydrogen system that Horizon Power had scoped.

The outcome of the Request for Tender (RFT) process resulted in Horizon Power entering into an Early Works Agreement to order the long lead items in parallel with the process to conform contractual documentation and the Financial Investment Decision process leading to the award of the Contract.

Implications for future projects:

This project will assist with future projects in understanding and aligning expectations around the renewable plant sizing versus hydrogen output and overall energy expectations with budget expectations.

3.2 Lesson learnt No 2 Hydrogen Capability and Experience – Horizon Power

Category: Technical / Safety / Risk

Objective: Increased skills, capacity and knowledge relevant to ability to appropriately integrate the technology end to end in a remote microgrid

Detail:

The Technical Specification written for the project was a modified hybrid diesel/solar/BESS power station specification, with performance requirements for the Hydrogen Plant rather than prescriptive requirements. This was done to allow Contractors to provide their recommended solutions based on their proposed technology solutions.

However, through the design phase it become clear that Horizon Power not only lacks general hydrogen experience, but also experience in process engineering and those areas of risk management of fire and safety risks associated with the design of gas plants and hazardous areas, that go hand in hand with the introduction of Hydrogen.

It is also noted that the EPC contractors, local engineering houses, and local regulatory authorities also have little experience dealing with these technologies and the whole industry is on a substantial learning curve.

To fill this gap and provide confidence that risks were being managed, Horizon Power engaged an engineering consultant to act as Horizon Power's engineer as well as engaging a subject matter expert third party to complete ignition consequence modelling and analysis where Horizon Power felt there were gaps in what the EPC contractor had delivered.

Horizon Power's inexperience, coupled with the maturity and experience level of the Contractor (See next Lessons Learnt Item 3) has led to the learning that a more prescriptive specification around project deliverables and process would have been helpful to both set and align expectations regarding:

- What deliverable, and associated level of completion, is required at each design stage
- What is required / expected as level of detail on process instrumentation and flow diagrams
- Expectations on risk management reports / deliverables for hydrogen systems
- Specific expectations for operation, maintenance and training information

Implications for future projects:

For future projects, Horizon Power will seek specialist advice into the Technical Specification, where we have a skills gap, to ensure sufficient coverage of design and deliverables requirements prior to commencing any procurement activities in this space.

Training and upskilling should be considered as to whether this skill set is acquired in-house or whether this is outsourced as done for this project.

3.3 Lesson learnt No 3 Hydrogen Capability and Experience – Contractor

Category: Technical

Objective: Increased skills, capacity and knowledge relevant to ability to appropriately integrate the technology end to end in a remote microgrid

Detail:

Hydrogen facilities require multidiscipline engineering design including process and control system engineering. If gaps exist in both client and Contractors in terms of discipline experience and coverage - then design progression can be inefficient and unstructured.

With the current immaturity of the Hydrogen market, finding an EPC Contractor who has this experience developed already is challenging.

In this case the EPC Contractor subcontracted the hydrogen equipment supply and design to a company that held the relationships with the equipment vendors. Whilst they had experience with individual equipment packages, they had limited experience in design and integration for the suite of packages to work together. The inexperience of Horizon Power, the lead contractor and the subcontractor integrating the various equipment packages is significant. This inexperience as resulted in the design and engineering deliverables going through more iterations than expected, causing significant timing delays to the overall project.

It should be noted however that improving industry knowledge is one of the main objectives of this project.

Throughout the design phase, both the contractor and sub-contractor have expanded their resource base supporting the project; however, resources with the required competencies are not yet readily available in the market, with resources building skills sets as the project has progressed. Resourcing constraints with inability to back fill due to specialist skill sets / knowledge has also impacted with COVID related lock downs and illnesses. This has impacted agreed project timeframes.

Immaturity in the hydrogen industry has also meant that being able to establish the training, qualification and competencies requirements for the personnel who will be operating and maintaining this plant in future has been a challenge. It is expected that any major maintenance required on the plant will need to be undertaken by OEM trained personnel. Training local resources in such specialised skills is not feasible due to complexity, warranty terms and frequency required, leading to the requirement for O&M contracts with Vendors or Vendor representatives.

Implications for future projects:

Future projects should consider:

- Complexity of a multidiscipline project and associated experience the Contractor (noting that projects like this one are rapidly increasing the skills and improving local knowledge), and
- Availability of resources with the required experience and capability to efficiently deliver the design and deliverables requirements set out in the Technical Specification.
- Inclusion of Maintenance Services Contract for the more complex maintenance as part of initial contract negotiations.

3.4 Lesson learnt No 4 Location challenges for Remote Microgrids

Category: Technical

Objective: Increased knowledge relevant to ability to appropriately integrate the technology end to end in a remote microgrid

Detail:

Denham, like many of Horizon Power's coastal towns is in a cyclone prone area, with high temperatures experienced in summer.

Whilst details of location and environmental conditions were detailed in the specification, understanding what this means in regard to equipment selection can be challenging.

Specific location environmental conditions that have impacted this project are identified below:

- Requirement for "off-the-shelf" products to be modified to be appropriately cyclone rated
- The initial design did not adequately allow for the cooling and operation of the electrolyser and fuel cell containers, and this resulted in the need for a larger evaporative cooling tower system.
- The requirement for a water tower cooling system not being understood at an earlier stage led to an initial:
  - Underestimation of potable water required to effectively run the hydrogen plant, noting that water is a precious resource in Denham which has two reticulated water supplies in the town: being drinking quality and saline.

  - Underestimation of wastewater from the system, including cooling system, leading to a requirement of a leach drain system (including environment approvals) due to the power station site not having a sewerage connection.

- The requirement for a water cooling tower system has also introduced a new process for Horizon Power generation operations group who have not had experience with this process at any of Horizon Power other power station sites.

Implications for future projects:

Whilst environmental conditions are stated in the technical specification, ensuring that the contractor understands implications to the equipment selection and design is important.

Lessons learnt from this project in relation to heat load of hydrogen equipment, auxiliary loads and water requirements should be used to inform the planning and Technical Specification for future systems making consideration to budget, land availability for solar PV sizing, potable water availability, sewage, approvals.

3.5 Lesson learnt No 5 System Complexity and Power System Integration

Category: Technical

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

Detail:

Whilst the individual hydrogen equipment packages have been utilised previously, the systems have never been integrated together using solar to produce electricity that can be used as base load power. 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,

As a result of the HAZOP workshop and design review, several challenges were identified in relation to the integration between the hydrogen plant equipment due to incompatible operational requirements that required a mechanical solution. For example, to overcome technical challenges to integrate the compressor's constant flow operation with the electrolyser's inconstant hydrogen production and large operating range, the original 50L buffer tank between the electrolyser and compressor was increased to 630 L and procured at a later stage.

It should also be noted that the current system with fuel cell (with inverter) and solar PV is not believed to be able to be the only energy sources of the power system as neither can act as the voltage reference (isochronous source), being able to load follow a typical load profile like a generator or a BESS. Response of the fuel cell is yet to be seen as part of testing and commissioning.

In addition, integration of the plant with the microgrid power system and using solar as the energy source has required complex programming and control system development. Two key challenges are detailed below.

Key Challenge 1 –Intermittency of direct power from PV:

To produce renewable hydrogen, the electrolyser load will be set by the hydrogen plant control system, which will monitor the solar farm power output and use it as an input to send commands to the electrolyser setting its load.

As per the manufacturer instructions, the electrolyser requires a minimum 30 min run time after 8min start-up (at 70-100% load) has occurred to cycle the dryers and be "Ready to Start". Turning off the electrolyser during the start-up sequence can result in out of specification gas due to water vapor being present. This gas would be unsuitable for storage and then later consumption by the fuel cell.

The concern is the solar farm output could drop below the load of the electrolyser due to cloud events, so powering the electrolyser from the solar farm "instantaneous" output may not be able to supply the minimum of 30 minutes of continuous operation that is required. Also, it has been identified that cloud events may result in stops and starts during scattered cloudy days. Which with every start requiring a 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.

Options considered

The following options were considered as possible solutions:

1. Diesel or other forms of generation pick up the difference between solar farm output and electrolyser load for this period, rather than waiting for the solar farm to meet the 70% of the electrolysers load. This would allow the electrolysers to turn on earlier in the day and generate more hydrogen. This was deemed as being not in line with the project objectives of green hydrogen.
2. Operating the Fuel Cell at maximum output (≈ 70kW after parasitic loads) during the 38-minute start-up and minimum run sequence in addition to the instantaneous PV output to provide a buffer for possible cloud events. This was not considered ideal for several reasons including: there are scenarios where this would still result in the Electrolyser shutting down / re-starting, could not be used when there was no stored hydrogen, and it compromised the overall performance of the hydrogen plant as it was seen as an inefficient use of hydrogen energy.
3. Apply a short-time offset strategy of "banking" energy, e.g. the electrolyser only starts when sufficient renewable energy has been produced to ensure completion of its start-up. This solution was selected with the key considerations impacting its selection and more detailed description of the solution provided below.

Note that the addition of a BESS, or use of the power station BESS was not considered as an option to mitigate this concern due to the following reasons:

1. The Hydrogen contract was awarded on the understanding that a BESS would not be required and so exploration of other options was preferred. Horizon Power would like to understand whether a BESS is physically required or whether a different solution can be found.
2. Use of a BESS may cover up some of the nuances of how a fuel cell/inverter system operates. Exploring other solutions may provide us with additional learnings related to fuel cell operation.

Key Considerations:

The following were key considerations in coming to a solution:

- The system always needs to be generating a minimum 35kW output (in aggregate from the Hydrogen point of connection and the Hydrogen Solar Farm (HSF) point of connection.)
- The available solar resource varies throughout the day and has seasonal patterns. As such there is a need to run either one or two electrolysers to efficiently utilise the available resource while minimising the reliance on imported energy from other sources.
- The efficiency of the electrolyser shows that optimum range to run the system is between 50% to 100% Remote Current Control (current [**I**] **C**o**M**an**D –** hereafter referred to as **ICMD**). The possible operating range is 35% to 100% ICMD therefore they cannot be driven down to zero consumption during cloud events, the only option to limit consumption further is to power down.
- Once powered down, on each restart the electrolyser OEM recommends a 30 min run time after start-up has occurred, to cycle the product gas desiccant bed dryers, maintaining product purity.
- The start-up sequence can last for up to 8 mins during which time the electrolyser must be provided with at least 70% of its full load. After this start-up sequence has elapsed, the electrolyser can be controlled between 35-100% of its output.

Solution – Electrolyser Dispatch Strategy

Control algorithms for the dispatch of Electrolysers have been established to balance the competing outcomes of the constraints outlined above. The key processes can be summaries as:

a. Solar Banking balance used for offsetting non-solar load use,
b. Electrolyser load setpoint based on instantaneous solar energy output,
c. Electrolyser duty based on average solar energy output (referred to as Interval Banking).

The solution chosen was to apply a short-time offset strategy of “banking” energy, e.g. the electrolyser only starts when sufficient renewable energy has been produced to ensure completion of its start-up.

The following outlines the high-level description of how the Electrolysers will be controlled including the solar and interval banking concepts.

High level description of Electrolyser control

The Electrolyser is equipped with Remote Current Control, referred to as ICMD, which is controlled directly by the Hydrogen Programmable Logic Controller (H2PLC) via Modbus. The current command can be used to set the input current to the cell stacks which is directly related to the hydrogen production rate and power consumption of the C Series generator.

When adequate solar energy is banked, an automatic remote START signal from the H2PLC and a pressure sensor in each electrolyser will trigger the electrolyser(s) to operate. In this project the electrolyser will always be run following the output of the Hydrogen Solar Farm (HSF).

Once commanded to start, the electrolyser will enter “generate to vent”, from cold start a full start up procedure takes 5 to 8 minutes normally, depending on ambient temperature. Once warmed up, the electrolyser moves into a “generating” state.

The OEM recommends minimum of 30 minutes run time after start-up to ensure the dryer is cycling and to avoid overloading a single desiccant bed of dryer. This will still occur when the production is zero (for example in load following at no output)

The two electrolysers will run concurrently (parallel operation). The H2PLC will control ON/OFF operation and required load factor via issuing ICMD. The H2PLC will automatically start and stop the electrolysers based on renewable production.

With “banked energy” implemented, there still may be occasions when the electrolyser will need to be started using network power.

Modelling simulations indicate that main network power may be required up to 1% of the time, on a cloudy event day. Or alternatively the system could be designed with BESS for storage of renewable power and managing start load of the electrolyser. System commissioning and performance testing is required to validate this simulated result.

Figure 1 and Table 1 below illustrates at a high level how the plant transitions with respect to the solar banking strategy. It does not represent how the plant acts in real time. For example, depending on the HSF output at the time, there may be a brief period at the end of the day where both the electrolyser and fuel cell are off with the solar farm maintaining 35kW at the point of connection. Eventually the HSF output will be low enough to allow the fuel cell to transition to its ON state.

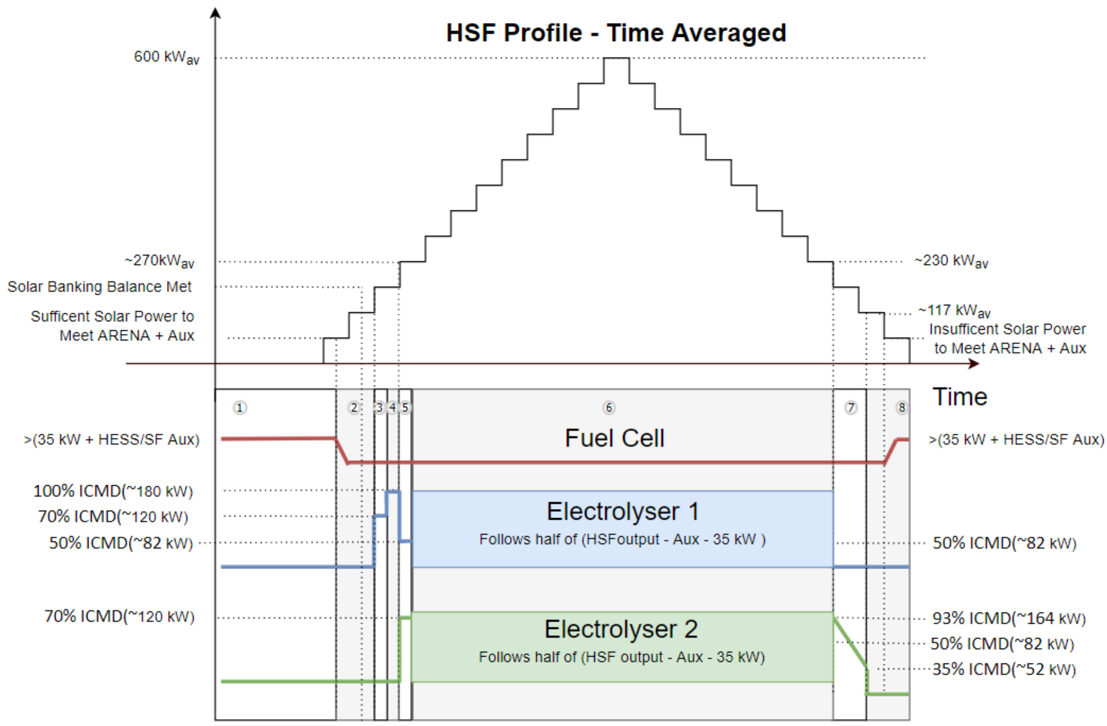

Figure 1 Hydrogen System Control Strategy (HSF control only)

Table 1: Equipment states with respect to interval banking

Step	H2 Solar Farm	Fuel Cell	Electrolyser 1	Electrolyser 2
1	Night – output zero	Maintains minimum ARENA commitment by outputting >35kw + metered auxiliary loads.	Off state	
2	Sun has risen, output is increasing. Solar Banking balance is increasing.	Rising solar output satisfies minimum ARENA commitment plus a small buffer. Fuel cell ramps output to zero and goes into OFF state.	Solar banking balance has been met, however there is still insufficient power in the sun to start the first electrolyser of the day.	
3	Solar farm has sufficient energy to provide start-up of first electrolyser at 70% + Aux for 8 mins + 35% + Aux for 30mins.	Fuel Cell transitions remains in OFF state. If solar Interval Banking Limit drops due to cloud cover the FC will restart.	Electrolyser 1 starts its start-up sequence, ramps to 70% for 8 mins and vents any produced H2.	Remains in standby mode, 0kW.
4	Monitor Solar farm output for second electrolyser start up	No change	Output is limited by ICMD between 35% and 100%, hydrogen is produced and stored	Remains in standby mode, 0kW.
5	HSF average power is greater than 50% EL1 and 70% of EL2 + Aux + 35kW	No change	Ramps to 50%. Hydrogen is produced and stored	Electrolyser 2 starts its start-up sequence and runs at 70% for 8mins. Hydrogen produced is vented.
6	Monitor Solar farm output and calculate interval banking limit	No change	Electrolyser 1 follows half of (HSF – AUX – 35kW)	Electrolyser 2 follows half of (HSF – AUX – 35kW)
7	Monitor Solar Farm output, when average power is less than 1st Electrolyser OFF (2 x 50% + AUX + 35kW)	No change	Electrolyser 1 ramps to zero and transitions to standby mode	Electrolyser 2 ramps to follow HSF – AUX – 35kW. Hydrogen is produced and stored.
8	Monitor solar farm output, when average power is less than last electrolyser OFF (35% ICMD + AUX + 35kW) and transition plant to standby mode until 35kW + buffer is reached.	Fuel cell starts-up and transitions to Run State on once HSF output < 35kW + Buffer. Outputs >= 35kW at HESS POC including HSF/HESS AUX.	No change	Electrolyser 2 ramps to 0 and transitions to standby mode.

Modelled Output

Until the system is in operation, a chart of the time series data showing the relative contributions of the energy sources (PV and diesel) to powering the electrolyser during a typical full day, including a start-up period is not yet available.

A simulator was developed to test and debug the site master controller under AUTO mode; to observe correct behaviour with respect to discrete state transitions, dispatch rules for electrolysers, fuel cell and compressor; and to observe correct operation of process valves and dispatch of cooling system.

A subset of simulation outputs has been extracted to illustrate the Solar Banking, Interval Banking, Dispatch and State Transition algorithms.

The solar data used for the simulation is from a site in the central Midwest from May this year, scaled to the size of hydrogen plant solar farm. It has been chosen for intermittent solar, giving periods of sun and cloud. It is chosen to give a representative sample of the best and worst solar resource available in the data set gathered.

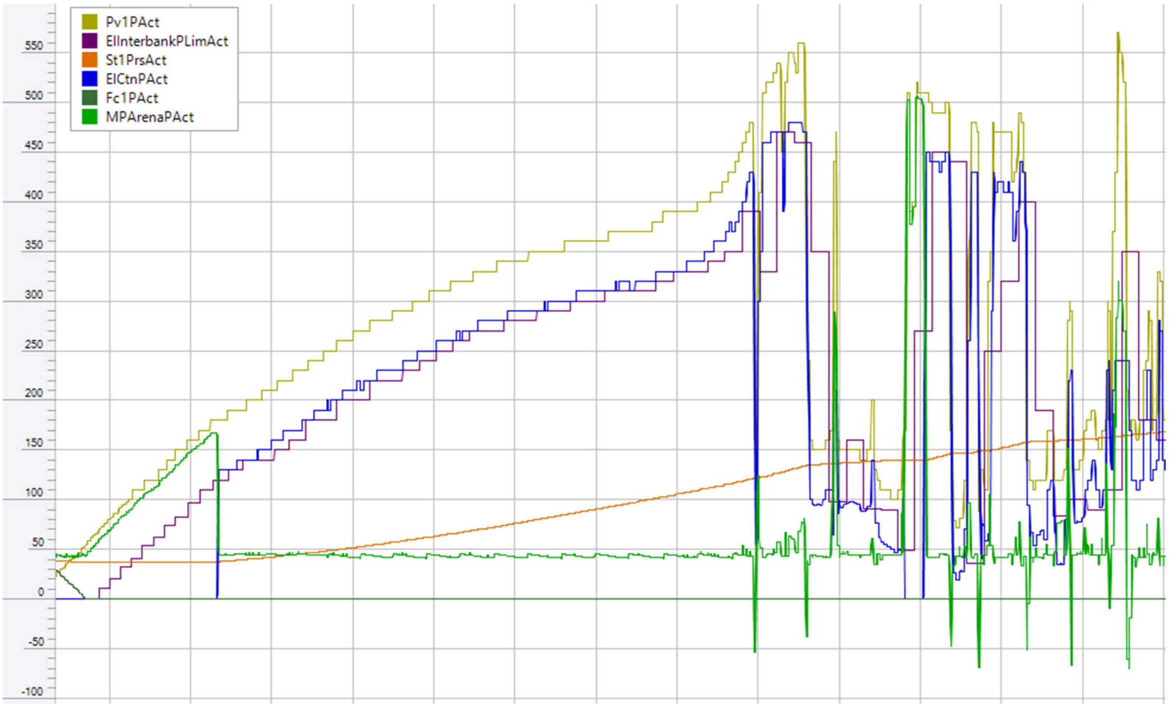

Figure 2 Simulation of Operation with Solar / Interval banking

The signals on the plot are:

- Pv1PAct – Solar Farm Actual Power Output
- ElInterbankPlimAct – Actual Interbanking limit
- StPrsAct – Main storage pressure
- ElCntPAct – Electrolyser container P Actual. Sum of electrolyser 1 and 2 consumption
- FcPAct – Fuel Cell Actual Generation
- MPArenaPAct – Virtual Point of Connection Power Out

Other notes regarding the simulation are:

- Simulation speed is 10 times real time. For example, 5 seconds in csv time stamp is 50 seconds IRL.
- Electrolyser P ramp rate has been set to 1pu/min in simulation - note the actual response time by the electrolyser is a key project learning to be finalised during commissioning
- H2 generation rate of electrolyser and H2 consumption rate of the Fuel Cell have been exaggerated for the purposes of simulation to increase the rate of state transitions. Actual performance is not reflected.
- Commissioning has not yet occurred, therefore there may be updates to behaviour during commissioning period, including planned parameter optimisations.

This solution will:

- avoid damages to the equipment.
- avoid stops and starts during scattered cloudy days.
- enable the control system to run the electrolyser at its optimum performance range, better kg H2/kWh ratio.
- Increase the electrolyser life cycle.
- reduce maintenance frequency and costs.
- deliver a stable operation for the hydrogen plant and power station, but still following the solar farm output.

Key Challenge 2: Load of Electrolyser compared to Town Load

In Denham, the maximum load for the town is around 1,650kW, but is often much less.

The electrolyser load is 360kW, which is proportionally high for the power system.

Using large renewables systems to supply the electrolyser requires high operating reserve to avoid instabilities and outages in the town. Spinning reserve requirements may also increase on the diesel/gas generators to mitigate risks of outages if the electrolyser trips.

The Electrolysers will be ramped up in stages and the point of connection energy requirements will be explored further as part of testing and commissioning

Having a high-power energy storage system as part of the solution for providing renewable smoothing and operating reserve may be beneficial in ensuring the objective of replacing thermal generation is achieved.

Implications for future projects:

A Battery Energy Storage System (BESS) was not included as part of this project on the understanding it would not be required.

After design development, it appears that any future Hydrogen System (relying heavily on intermittent renewables) may need to consider the provision of a BESS, with sufficient capacity to power the electrolyser for a few start-up cycles and provide smoothing and operational reserve functions for the solar and/or wind power generation systems.

Testing and commissioning will provide further learnings regarding the behaviour of the system at the point of connection.

Further investigation of the Fuel Cell ramp rate and Electrolyser ramp rate during commissioning is required to draw a conclusion on the operation of the system. However, the response time of the fuel cell is currently not expected to be able to supply rapid fluctuations in load due to mechanical limitations of the fuel cell, so it is expected that a fuel cell can provide a base load supply but has limitations in performing voltage and frequency support. In the case of Denham the diesel generators or the BESS will perform this function to maintain the system strength. Horizon Power will investigate these limitations of the fuel cell in the next stage. This is irrespective of "banked energy".

3.6 Lesson learnt No 6 Regulatory Frameworks

Category: Regulatory

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

Detail:

As hydrogen technology is new technology, current regulations have not kept pace and as such, regulations and training are being developed but not yet defined.

The Department of Mining, Industry Regulation and Safety (DMIRS) is the applicable Regulator for the appliances used on this Project, with the Building and Energy Division 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 gasfitting 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 pertinent to the plant are the requirements for approval of the hydrogen fuel cell as a Type B appliance under section 13D of the Act, and for appropriate competency and authorisation of gasfitting work under section 13A; and under the Gas Standards (Gasfitting 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).

Certification and Approval of Hydrogen Type B Appliances

Consultation with DMIRS has highlighted that hydrogen fuel cells are still new to WA, and If it is not a "Consumer" installation under the *Gas Standards Act 1972*, there is currently no framework for certification and approval of hydrogen fuel cell Type B appliances. DMIRS Building and Energy has advised that a formal approval process is not currently required, noting that once a formal approval process is established, the fuel cell will need to be assessed and certified if any modifications are made.

The documentation and design of the fuel cell was initially expected to comply with the relevant ISO standards as they were in the process of being adopted by Standards Australia, including:

- IEC 62282.3.100 Fuel cell technologies Part 3.100: Stationary fuel cell power systems – Safety; and
- IEC 62282-3-300 Fuel cell technologies Part 3-300 Stationary fuel cell power systems – Installation.

Australian Standards for the Fuel Cell have now been gazetted and are now 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)

Published guidance document on 'Regulatory requirements of hydrogen fuel cell in WA' is also to be taken into account: https://www.commerce.wa.gov.au/announcements/hydrogen-fuel-cell-safety-regulations-wa and Adoption of hydrogen appliance standards | Department of Mines, Industry Regulation and Safety (commerce.wa.gov.au).

In the absence of hydrogen specific regulations, DMIRS have 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.).

Horizon Power has documented the Due Diligence followed in the development of this project to ensure this process is captured.

Particular to this project, the Fuel Cell utilised in the system was designed and manufactured for mobile application, therefore DMIRS required that the system supplier/designer must undertake a gap analysis of the equipment against the Standards for stationary fuel cell power systems, then demonstrate safety for each identified gap via a risk assessment process. The Regulator expects this to be completed before fuel cell commissioning starts

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' is not consistent with instances where a person supplies gas for their own use.

Advice from DMIRS is that it appears that installations consistent within this supply arrangement do not presently need to have their Type B appliances approved for the purpose of section 13D of the Gas Standards Act 1972 (GSA). This is subject to change in the future.

Dangerous Goods

The Dangerous Goods Licensing Branch is 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 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 will therefore not trigger the requirements for Major Hazard Facility legislation.

The existing Denham power station holds a Dangerous Goods Site Licence under the Dangerous Goods Safety Act 2004 for storage of up to 140 kL of diesel for current operations.

A revised Dangerous Goods Site Licence application under the Dangerous Goods Safety Act 2004 has been submitted for the Denham power station due to the additional storage of hydrogen on site (13.3 kL of Hydrogen). We are working with DMIRS who are applying significant rigour on the assessment which is attributed to it being one of the first applications of this nature.

Implications for future projects:

Work on hydrogen standards and regulations are progressing. Each project will need to maintain an understanding of current standards published and regulations prior to the commencement, and throughout the development of projects, to understand the impact this may have on any project.

3.7 Lesson learnt No 7 Operational Impact

Category: Technical / Commercial / Risk

Objective: Increased skills, capacity and knowledge relevant to operations and maintenance

Detail:

As mentioned in a few other Lesson Learnt sections, Horizon Power has had limited or no experience with the following new processes being introduced that will require upskilling and training to ensure operators and maintainers have the competencies required to undertake required activities:

- Hydrogen equipment (Electrolyser; Compressor, Gas Storage, Fuel Cell etc) – requiring mix of upskilling and O&M contracts with OEM trained maintainers
- Hazardous Areas
- Water tower cooling system – water treatment processes

Implications for future projects:

Change management with regional operational and maintenance teams need to be considered both specifically per project and holistically if this will become a future implemented technology across the region as it brings considerable change to the current hybrid regional power stations that consist of thermal generating sets, solar and BESS.

Training and upskilling are required for operations and maintenance staff around Hazardous Areas and other gas management practices.

4. CURRENT PROJECT STATUS

As of March 2023, the Project has achieved the following:

- Design process, including safety in design
- Operational handover of the solar farm
- 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 (ie disconnected from power system) to produce hydrogen and power
- The hydrogen plant was officially opened by the Minister for Hydrogen Industry Alannah MacTiernan and Energy Minister Bill Johnston on 11 November 2022, celebrating the first major milestone of hydrogen production.
- Commenced the final stage of commissioning, which will integrate and test the hydrogen plant with the solar farm and the power station.

Overall, like the design phase, the commissioning process has taken longer than originally anticipated, however this is not unusual in a new technology project. Delays occurred due to general complexities with equipment package integration and the overarching control system, but in particular challenges with the fuel cell and inverter integration to ensure power quality met the utility standards. In addition, the Project encountered issues with the pressure safety valve system that required resolution and modifications. This held up the progression of the final stage of commissioning as it needed to be rectified prior to commissioning of the hydrogen plant connected to the power system.

5. DATA SPECIFICATION – PUBLIC UNRESTRICTED DATA

Data provided at Milestone 1 and 2 is a forecast based on design, warranted rates or consistent with relevant supply agreements or the financial model.

Timing of reporting – Milestone 1 and 2				
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.	435.4	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.	915.0	Average Electrolyser energy input during the first 10 years of the project at ~64.5 kWh/ H2 kg, subject to further testing The balance of plant energy consumption is

				estimated to be ~7.03 khW/H2 kg.
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	14.2	Average hydrogen output during the first 10 years of the project subject to further testing at 5.4 H2 kg per hour at ~30.6% electrolyser efficiency. The electrolyser performance ratio is expected to be ~64.5 kWh/H2 kg
Electrolyser Data	**Units**	**Definitions**	**Forecast**	**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	2 x 0.174 = 0.348	
Capacity factor	%	The extent to which the electrolyser is used	30.6%	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	64.5	As per the equipment specification provided by the equipment manufacturer at 5.8 kWh/Nm3
Asset life	Years	The expected term before electrolyser replacement capital is required	80,000 run hours	As estimated by the equipment supplier
Warranty period	Years	The warranty period of the electrolyser equipment as warranted by the equipment supplier	1	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	10 years	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)	99.9998	BOL. Information provided by the equipment manufacturer
Capital expenditure	**Units**	**Definitions**	**Forecast**	**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	9.26	As per the baseline project budget submitted to ARENA, including 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)	0.52	Solar PV panel cost only. The figure does not include site works or solar farm integration costs to the hydrogen facility
Integration, Network connection and	$m	Including all integration costs to the power station and all electricity infrastructure required for the project (if relevant)	N/A	

transmission capital cost				
Environmental	**Units**	**Definitions**	**Forecast**	**Comment**
Water source		Note water source	Water Corporation - Denham	Potable water from the town water supply
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	1.7015	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 inputs (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 carbon abated by Hydrogen Plant	t_CO2 p.a.	This is the total carbon tons abated per annum by the Hydrogen Plant (including solar). t	N/A	
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).	51	
FTEs required during operations period	FTE	As above	0.2	FT operator = 38hr/week Estimate at this stage