Red Garnet Red Diesel Generator Alternative

Red Diesel Replacement Phase 2

AFC Energy

Brett
built on relationships

ENERGY SOLUTIONS

Executive Summary

The Project

AFC Energy formed a skilled well-to-work consortium highly experienced in delivering decarbonisation outcomes to provide two demonstrations focused on high and low power use cases in the quarrying sector as part of the Red Diesel Replacement (RDR) programme. Through the Department for Energy Security & Net Zero's £1 billion Net Zero Innovation Portfolio (NZIP), the RDR programme provided up to £33m in grant funding to develop and demonstrate low-carbon alternatives to diesel in the construction, mining and quarrying sectors.

AFC Energy's focus is the design, development and manufacture hydrogen fuel cell generators and systems to crack ammonia to produce hydrogen. For this RDR project AFC Energy developed their hydrogen fuel cell generators in the 30 kW air cooled and 200 kW liquid cooled power ranges to provide CO_2-free alternatives to red diesel in the quarrying sector. Energy Solutions' focus is the design, manufacturing and supply of hybrid power solutions to marine, vehicle and off grid markets. For the project they designed, developed and manufactured a 45 kVA and 145 kVA Battery Energy Storage System (BESS). Brett Aggregates is a quarry owner/operator with off-grid power requirements at several sites in southeast England, including the two demonstrator sites (Fairlop and East Hall Farm).

For the low power demonstration, AFC Energy deployed its 30 kW fuel cell generator (50 kVA equivalent) and Energy Solutions' 45 kVA BESS to East Hall Farm in June 2025; replacing an 18 kVA diesel genset to operate a weighbridge facility. For the high power demonstration, AFC Energy deployed its 200 kW fuel cell generator and Energy Solutions' 145 kVA BESS to Fairlop in March 2025; where it powered a 1 km aggregate conveyer and submersible pump, replacing a 318 kVA diesel genset.

Over the course of the project several of the risks developed into issues, the mitigation of these issues led to a reduction in overall cost of the project due to some key scope changes. The actual cost of £5,037,033.36 was over £4.6m less than the baseline original cost £9,647,456.26 which led to an actual claim of £2,518,516.68 compared to the grant awarded of £4,823,728.13.

Key Results

- Successful development and demonstration of a 30 kW fuel cell generator by AFC Energy and a 45 kVA BESS by Energy Solutions. The one-month demonstration at Brett Aggregates' site demonstrated the system prototype in a real-world quarrying sector application, powering a weighbridge. The system provided 100% uptime and 625.5 kWh, enabling 750 kg of CO_2 to be offset over the trial period.
- Successful development and demonstration of a 200 kW fuel cell generator by AFC Energy and a 145 kVA BESS by Energy Solutions. The one-month demonstration at Brett Aggregates' site demonstrated the prototype in a real-world quarrying sector application, powering a > 1 km conveyor and a submersible pump. The system provided 100% uptime and 7 MWh, offsetting 13,400 kg of CO_2 over the trial period.
- The TRL of both the H-Power S-Series 30 kW and S+Series 200 kW from TRL 5 to TRL 7, as both system prototypes were demonstrated in real-world site trials at Brett Aggregates quarry sites.
- Disseminated learnings through various forms of publication, and planned white papers with demonstration data to help customers, end users and policy teams assess the viability of these low carbon technologies.
- Accelerated the commercialisation of low-carbon red diesel alternatives, providing confidence that AFC Energy and our Joint Venture (JV) partner, Speedy Hire, will be able to provide hydrogen fuel cell systems at cost parity with diesel generators in 2026.

Key Learnings

The lower cost of the liquid cooled architecture at commercial scale compared to the air cooled architecture makes it suitable for a wide power range, from 5 kW to 500 kW. Ongoing work as part of our Joint Venture with Speedy Hire has shown that the liquid cooled architecture pricing can enable a 50 kVA diesel genset to be replaced with a fuel cell generator.

The liquid cooled technology architecture used on the project was validated at low turndown ratios. Enabling a 50 kVA diesel genset to be replaced by a 30 kW liquid cooled hydrogen fuel cell. The liquid cooled architecture suits a larger market for deployment due to the wider thermal operating range of the liquid cooled system (-20 °C to 50 °C vs -5 °C to 40 °C for air cooled).

AFC Energy are developing a Beta version of our liquid cooled 30 kW fuel cell generator directly from the RDR project learnings in the air cooled and liquid cooled developments. This is expected to have completed an initial production run in 2026. The unit also has export potential to Europe, the Middle East, the USA and Canada and will by type marked for these regions.

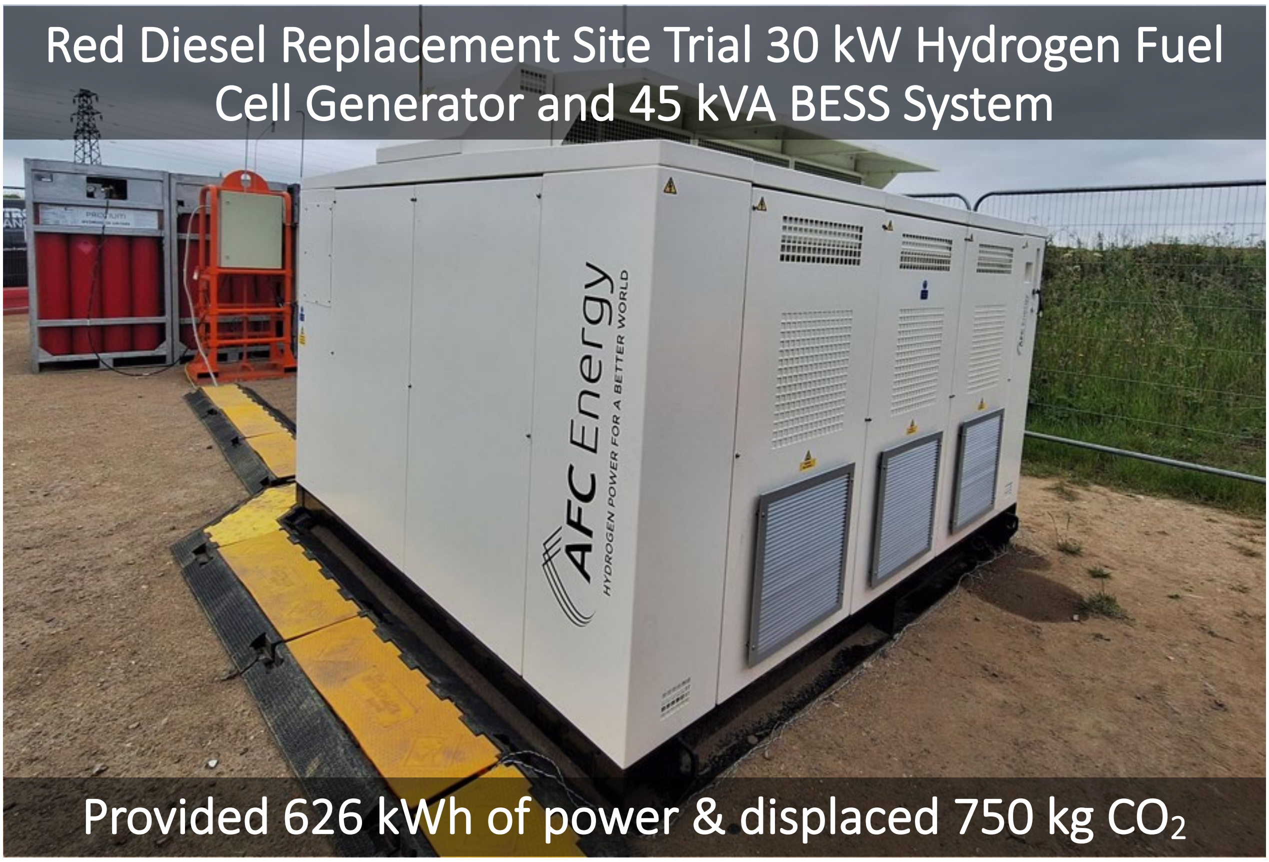
The deployment of the larger 200 kW system requires large amounts of hydrogen The sites to support quarries are remote and the access is often unmade with no hard standing for a tube trailer. The turning circles for the vehicles are large which increase the need for ground works where the vehicles are manoeuvring. This means that groundworks may be needed to use some 40 ft tube trailers. In addition, exclusion zones required can be up to 8 m for 40 ft tube trailers, not all sites would be able to accommodate this.

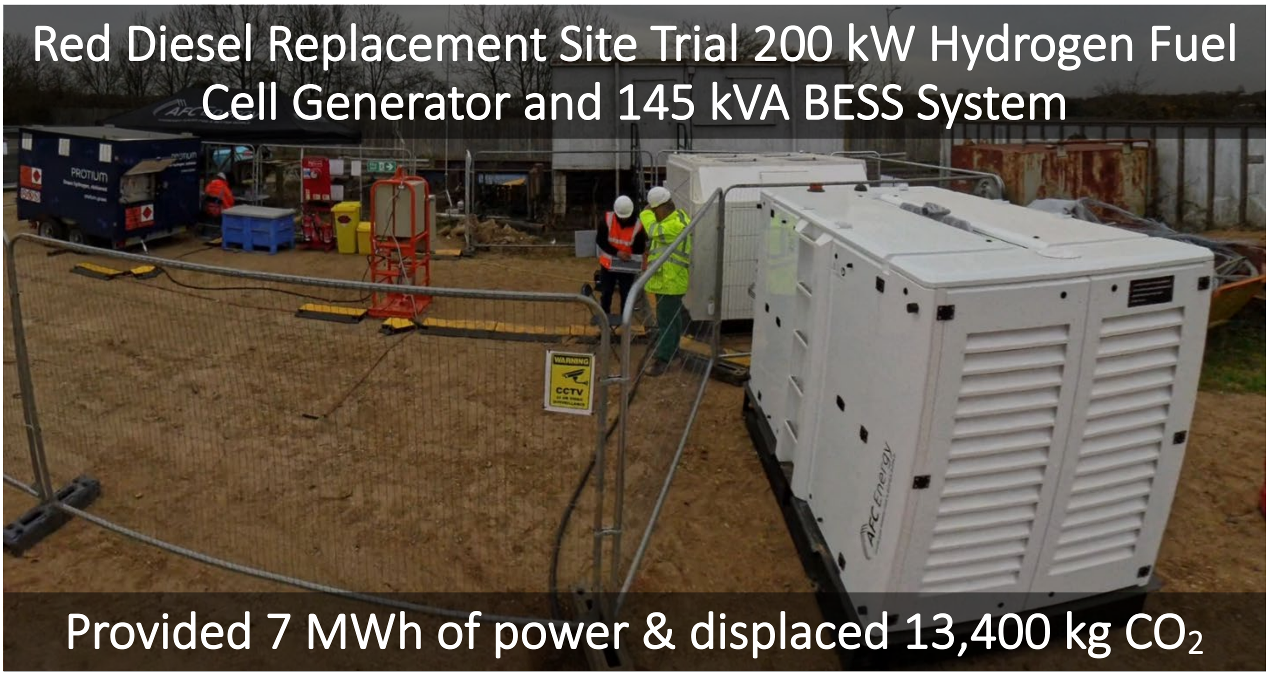
The cost of the delivery and vessel rental elements can be more than the gas itself. If there are reductions in hydrogen usage on site it will extend the rental period thus increasing the cost/kWh. As the usage on the site varies day to day, the logistics and timings of the hydrogen deliveries become more important to the overall cost efficiency of the site. This is more impactful if there is a site equipment shutdown close to a planned delivery as it means that there is gas remaining in vessel as the usage drops suddenly.

AFC Energy's launch of the HY 5 unit enabling ammonia to be cracked into hydrogen in suitable volumes to distribute to sites will allow us to reach total cost of ownership (TCO) cost parity with diesel in 2026. Hydrogen fuel cell generators reaching the point of cost parity with diesel is achievable in the near term and this is key to wider market adoption of the technology in the construction, mining and quarrying sectors.

Both AFC Energy’s hydrogen fuel cell systems and Energy Solutions’ BESS ran at 100% uptime for the demonstrations and the setup and install of the equipment on site took 1 day for the air cooled system and 3 days for the liquid cooled. The power provided from the hydrogen fuel cell generator displaced emissions from diesel gensets demonstrating that there are no fundamental barriers to the installation of hydrogen fuel cell generators on sites in the quarrying and mining sectors.

Graphical Abstract





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Glossary/Abbreviations/Acronyms

BESS	Battery Energy Storage System
BoP	Balance of Plant
CO_2	Carbon Dioxide
CRL	Commercial Readiness Level
DESNZ	Department for Energy Security and Net Zero
EMC	Electromagnetic compatibility
FCM	Fuel Cell Module
H_2	Hydrogen
HAZOP	Hazard and Operability study
HPS	H-Power S Series Air Cooled
HPS+	H-Power S+ Series Liquid Cooled
JV	Joint Venture
kg	1000's gram
km	1000's metres
kVA	1000's Volt Amps
kW	1000's Watts
kWh	1000's Watt hours
kW_{net}	1000's Watts net power output
MCP	Manifolded Cylinder Pack
NZIP	Net Zero Innovation Portfolio
OCV	Open Circuit Voltage
P&ID	Piping and Instrumentation Diagram

PEM	Proton Exchange Membrane
PPM	Parts Per Million
PRP	Prime Rated Power
RDR	Red Diesel Replacement
SIL	Safety Integrity Level
TRL	Technology Readiness Level
TCO	Total cost of Ownership
WP	Work Package

Background

Project partners

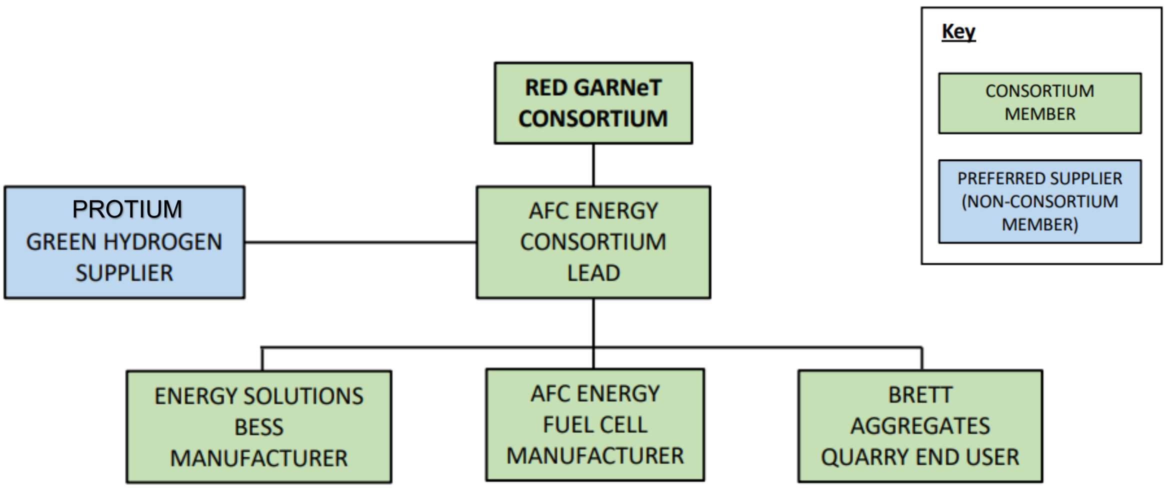
The lead partner AFC Energy is a medium size business based at Dunsfold Park in Surrey. AFC Energy is on a mission to displace diesel fuelled power generation with clean hydrogen in construction sectors. For over a decade we've been using our engineering know-how, innovative technology, and shared vision of a cleaner world to drive our development of hydrogen fuel cell technology. Our strategy is to develop great products and solutions that deliver affordable, flexible, and clean energy, and empower our customers to achieve their net zero commitments.

Energy Solutions, founded in 1996 and based in Kent comprises a committed team of over 30 engineers, production technicians, logistics, sales and service staff. Their focus is the design, manufacturing and supply of hybrid power solutions to marine, vehicle and off grid markets. Energy Solutions work with some of the biggest names in the marine industry and have established themselves as a key supplier bringing new ideas and technical updates on a continual basis.

Brett Aggregates are a leading regional independent producer of sand and gravel, with quarry, marine dredged aggregates and coated roadstone operations serving London, the East and Southeast of England. Brett's aim is to develop its core business, hand in hand with the expertise and quality of its teams, in order to create sustainable growth for the future. Brett's independent status and spirit of entrepreneurism means that they can take the long-term view on their commitment to the environment, community and to the people with whom they work.

RED GARNeT Consortium Organogram

Figure 1 - Consortium Organisation



Project Background

AFC Energy's H-Power S Series Air Cooled (HPS) and S+ Series Liquid Cooled (HPS+) generators provided CO_2-free alternatives to red diesel at two quarry sites. AFC Energy have formed a skilled well-to-work consortium highly experienced in delivering decarbonisation outcomes. Brett Aggregates is a quarry owner/operator with off-grid power requirements at several sites in southeast England, including the two demonstrator sites (Fairlop and East Hall Farm).

For the first demonstration use case AFC Energy deployed its 30kW fuel cell generator (50 kVA equivalent) and Energy Solutions' 45 kVA Battery Energy Storage System to East Hall Farm; replacing an 18 kVA diesel genset to operate a weighbridge facility. For the second demonstration use case AFC Energy deployed its 200 kW fuel cell generator and Energy Solutions' 145 kVA BESS to Fairlop where it will power a 1 km long aggregate conveyer and submersible pump, replacing a 318 kVA diesel genset.

Two fuel cell technologies are selected for this project, air cooled and liquid cooled. Air cooled technologies provide higher turn-down ratios and are typically more cost effective and higher efficiency at low power levels. Liquid cooled fuel cells have a higher power density and are more cost effective in high power levels. The overall system incorporates a fuel cell generator and a BESS to provide continuous power via the fuel cell and peak demand filling from the BESS; the two technologies allow the final system to comply and meet the ISO Prime Rated Power Requirements set out for diesel generators. The use of Manifolded Cylinder Packs (MCPs) (16.7 kg) for the lower power Easthall demonstration and the use Mini Trailers (99 kg), and 20 ft Trailers (288 kg) for the higher power Fairlop demonstration were selected as hydrogen storage vessels to minimise change overs and costs.

The project benefits include, eliminating CO_2 emissions from incumbent gensets, demonstration of a potential low-cost diesel alternative and completion of a real-world reliability/durability and total cost of ownership (TCO) assessment. The project delivers key recommendations for elimination of red diesel in quarrying with cross over into construction and mining. The consortium partners have together set out a technology approach which employs a harmonised single solution, zero-emission fuel cell generator and BESS to replace diesel gensets in quarrying which has the potential to be meet the cost and performance metrics necessary to ditch diesel within the decade.

Project Overview

Project Scope

This project designs, develops and demonstrates AFC Energy's fuel cell generators combined with Energy Solution's harmonised BESS, within a real-world quarrying operation. The AFC Energy fuel cell generators are emissions-free and provide power from 5-250 kVA encompassing much of the existing diesel generator market.

Aims

- Design and development of the fuel cell modules and the generator systems. Advancement of the TRL of AFC Energy's next generation fuel cell systems from TRL 5-7.
- The generator systems will demonstrate the technology and supply chain across two power ratings which represent most diesel generators on the market: 30–50 kVA and >200 kVA Prime Rated Power (PRP).
- Evaluate a scaled TCO for deployments.
- Demonstrate a cessation of CO_2 emissions for the applicable site activities when compared to the existing diesel gensets.
- Demonstration 1: AFC Energy's air cooled S Series 30 kW fuel cell generator will displace diesel at Brett's Essex quarry site, which uses an 18 kVA diesel generator to power weighbridge facilities. The demonstration will cover one month of typical site operations.
- Demonstration 2: AFC Energy's liquid cooled S+ Series 200 kW fuel cell generator will displace diesel at Brett's Fairlop site, which uses a 318 kVA diesel generator powering conveyors and pump equipment at the site. The demonstration will cover one month of typical site operations.

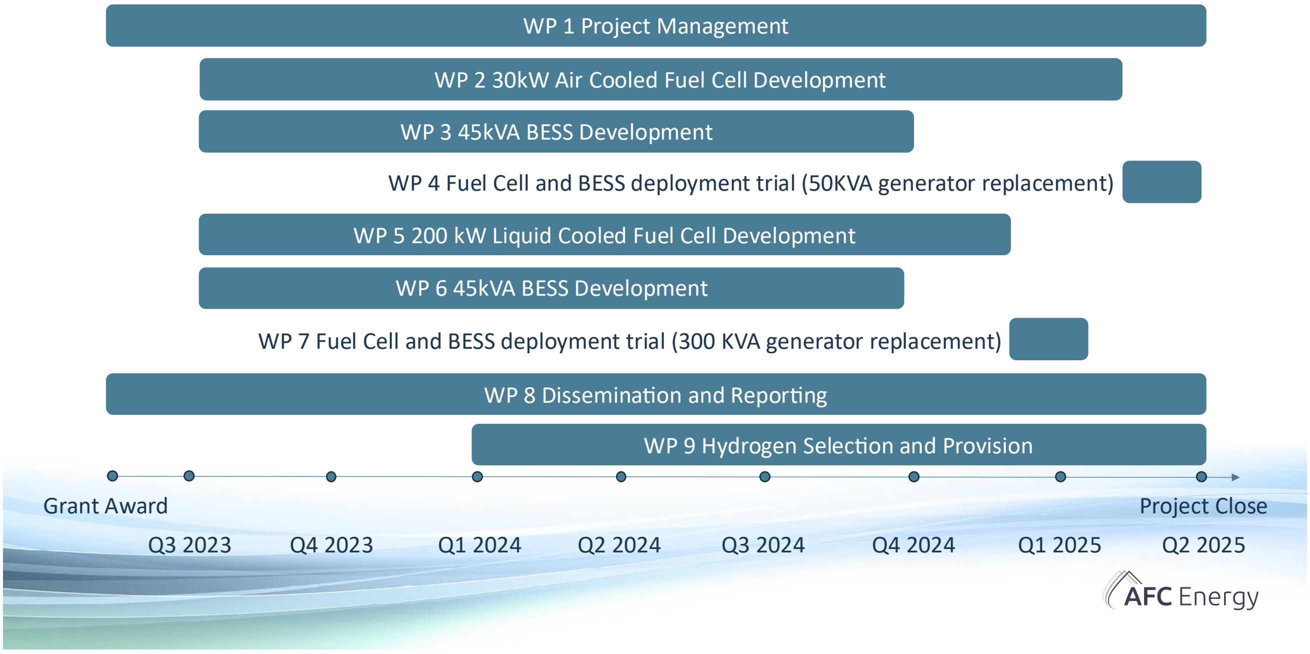
Objectives

- Development of a 30 kW and a 200 kW fuel cell generator by AFC Energy, and a 45 kVA and 145 kVA BESS by Energy Solutions.
- Demonstration of AFC Energy's and Energy Solutions' systems in two one-month demonstrations at Brett Aggregates' sites to validate each generator system against typical duty cycles and operational uptime/availability requirements in the quarrying, mining and construction sector.

- Disseminating learnings from the demonstrations through white papers, and various forms of publication; further, data from the demonstrations will be provided to help policy teams assess the viability and disseminate awareness of low carbon alternatives.
- Deliver match funding from industry.
- Accelerate the commercialisation of low-carbon red diesel alternatives.

Work Packages and Schedule

Figure 2 – Work Packages and Schedule



- WP1 Project Management - AFC Energy

Project initiation, consortium governance plan and project management including resource plan and Gannt, risk log, PM reporting, KPIs & benefits, accruals & invoicing.

- WP2 H-Power S Series Genset (30 kW) - AFC Energy

Development, procurement, manufacturing, internal verification of H-Power S Series Genset (air cooled) and integration with Energy Solutions BESS

- WP3 BESS (45 kVA useable capacity) - Energy Solutions

Development, procurement, manufacturing and internal validation of 45 kVA BESS.

- WP4 Trial in quarry site 1 (H-Power S Series Genset + BESS) - AFC Energy

Site survey, preparation of safety documentation, transportation and installation of the system, trial operation and data collection (1 month) and decommissioning and restoration of space used.

- WP5 H-Power S+ Series Genset (200 kW) - AFC Energy

Development, procurement, manufacturing, internal verification of H-Power S+ Series Genset (liquid cooled) and Integration with Energy Solutions 145 kVA BESS.

- WP 6 BESS (145 kVA useable capacity) - Energy Solutions

Development, procurement, manufacturing, internal validation.

- WP7 Trial in quarry site 2 (H-Power S+ Series Genset + BESS) - AFC Energy

Site survey, preparation of safety documentation, transportation and installation of the system, trial operation and data collection (1 month) and decommissioning and restoration of space used.

- WP 8 Compilation of information / Dissemination - AFC Energy

Compilation of learnings from demonstrations (eg. TCO analysis), preparation of information for dissemination, and proposals for next iteration.

- WP 9 Hydrogen supply - AFC Energy

Hydrogen supply solution to support the demonstrations in the field

Financial Information

Table 1 - Finance Information for the Project

	Baseline Original Cost (£)	Grant Awarded (£)	Actual Cost (£)	Actual Claim (£)
Total	9,647,456.26	4,823,728.13	5,037,033.36	2,518,516.68

Over the course of the project several of the risks developed into issues, the mitigation of these issues led to a reduction in overall cost of the project due to some key scope changes. The actual cost of £5,037,033.36 was over £4.6M less than the baseline original cost £9,647,456.26 which led to an actual claim of £2,518,516.68 compared to the grant awarded of £4,823,728.13.

A full replan of the project was needed due to the impact of overrunning projects and skill shortages impacting the replacement of staff leaving the business. This meant that the durability testing was reduced in length and the costs of testing and hydrogen related to that were removed from the project.

Lead time issues affected the timings of the delivery of key parts for the air cooled system. In order to deliver the air cooled units within the project timelines it was decided to only build and purchase one liquid cooled unit this also reduced the cost of the project due to only building one liquid cooled system and a reduction in the gas that would have been consumed in testing.

In addition, several work packages came in under cost due to savings on component parts versus the initial estimates for the project.

Design Considerations, Technical Development and Challenges

H-Power Generator - S series 30 kW_{net} Air Cooled Fuel Cell Generator

FEED/System Design

The front-end engineering design of the S Series 30 fuel cell generator centred around delivering a self-contained, modular and self-starting system for integration into both temporary and permanent applications. The system incorporates six fuel cell modules (FCM), each comprising a single 7 kW air cooled fuel cell stack. The prior configuration of twelve 2.5 kW net units was consolidated into six 5 kW net systems, reducing component count, wiring complexity, and system integration overhead while maintaining performance. Each fuel cell module operates independently within the integrated generator chassis, which houses all reactant, thermal, electrical, and safety systems required for operation. The single package minimises external interfaces, simplifies deployment, and reduces external installation requirements.

Requirements were gathered from external stakeholders and customers as well as internal requirements, and safety requirements taken from BS EN IEC 62282-3-100:2020. System design was split into the following areas.

Systems Engineering

Led the definition of system-level requirements, interfaces, and performance targets. Responsible for process engineering, including hydrogen flow architecture, purging strategy, pressure control, reactant air supply system and thermal management logic. Oversaw process safety analysis (e.g., P&ID development, HAZOP coordination), and selected balance of plant (BoP) components based on system compatibility, reliability, and cost-performance trade-offs.

The work packages involved:

- Top-level requirements gathering/understanding
- Piping & Instrumentation Diagram
- Heat & Mass balance
- Component selection

Heat & Mass Balance

The heat and mass balance developed for this platform started at the fuel cell system level by calculating the required number of cells to deliver 5kW net output at end of life, giving roughly 135 cells. The stack size determines the flow rates of reactants required to produce this power and also enables calculation of the heat production throughout the lifetime of the stack.

A thorough understanding of the stack reactant requirements and heat production is required to select balance of plant components such as blowers, pumps, cooling fans, valves, and sensors. Models of varying complexity are integrated into AFC Energy's heat and mass balance calculators, which allows the generation of parametric data sets exploring the performance of the systems at various power levels, environmental conditions, altitude, and run hours.

Control Engineering

Developed the system control logic and software architecture, including start-up/shutdown sequences, fault detection and response, load-following strategies, and communications with external systems such as BESS and external telemetry. Implemented safety interlocks and operational limits derived from risk assessments and system constraints.

This team was split into two control areas: the fuel cell system control and the overall generator control. The former focused on maintaining the safety, performance, and durability of an individual stack, whereas the latter provided the framework within which multiple fuel cell systems deliver power to the customer via the BESS.

Electrical Engineering

Designed the high and low voltage electrical architectures, DC distribution, protection schemes (fuses, contactors, isolation), and EMC mitigation strategies. Responsible for grounding, enclosure wiring, power connectors, and ensuring compliance with HVDC output and BESS compatibility.

Component Selection

The component selection process was carried out based on a combination of system-level performance requirements, safety standards, supplier availability, and integration with AFC Energy's control architecture. Components were evaluated according to their compatibility with hydrogen fuel cell operation, mechanical and electrical interface requirements, and their ability to meet both steady-state and transient system conditions.

Key considerations included:

- Thermal and mass balance calculations to ensure proper sizing and performance under expected operating conditions.
- Hydrogen system pressure and flow requirements, considering stack inlet pressure regulation, safety, and efficiency.
- Electrical compatibility with the system's power electronics, control logic, and auxiliary subsystems.
- Environmental durability, including resistance to temperature, humidity, and potential exposure to hydrogen.
- Compliance with relevant safety and functional standards for fuel cell systems.

Safety Strategy

The safety system is built around safety integrity level (SIL) rated hardware safety relay. All of the safety critical signals required for safe operation of the generator are wired through this safety relay, such that if any one of the signals is interrupted the entire chain breaks, preventing startup (if in idle) or causing immediate emergency shutdown if in operation.

If the safety chain is broken, it cannot be automatically reset. It requires manual intervention to ensure that the cause of the break understood and resolved prior to restart. This function is provided by a manual reset switch.

The primary safety critical systems which comprise the safety chain are:

- Generator E-Stop contact (Red mushroom button)
- External E-Stop contact (wired from connected equipment or remote e-stop, optional)
- Heat alarm relay, which opens during unsafe thermal conditions
- Hydrogen sensor

When the safety relay opens, critical components are reverted to their safe state.

Mechanical Engineering

A new chassis was designed for this project and the intention was to use this single platform for both the liquid cooled and air cooled generators. The chassis design went through a few iterations but component delays during the detail design stage pushed back the chassis design timescales significantly. As a risk mitigation, the chassis used for the previous revision of the air cooled generator was modified to fit each of the two platforms.

An example of the new chassis design is shown below. The decision to pivot to the previous generator chassis was made before significant effort was expended fine-tuning the design for efficient manufacture.

Figure 3 - New chassis design

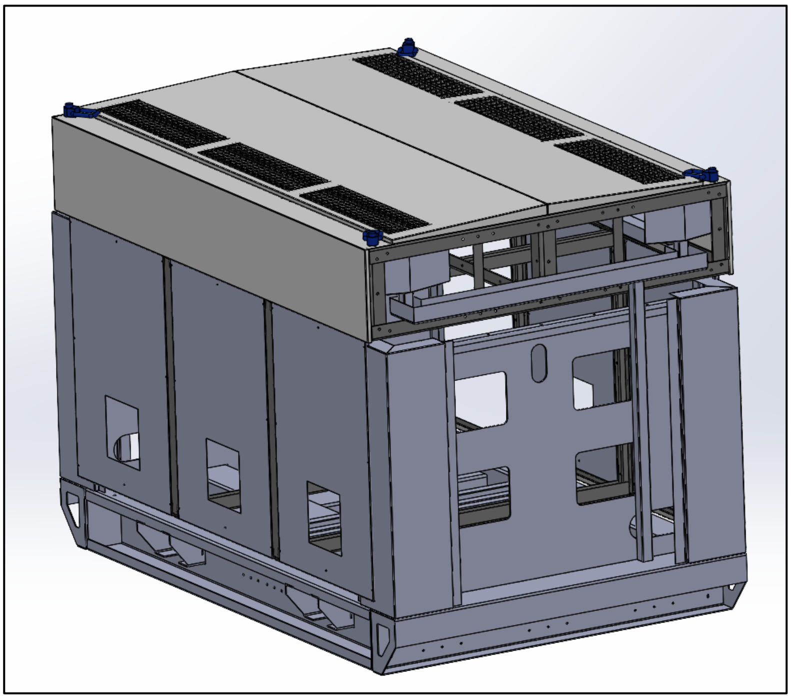
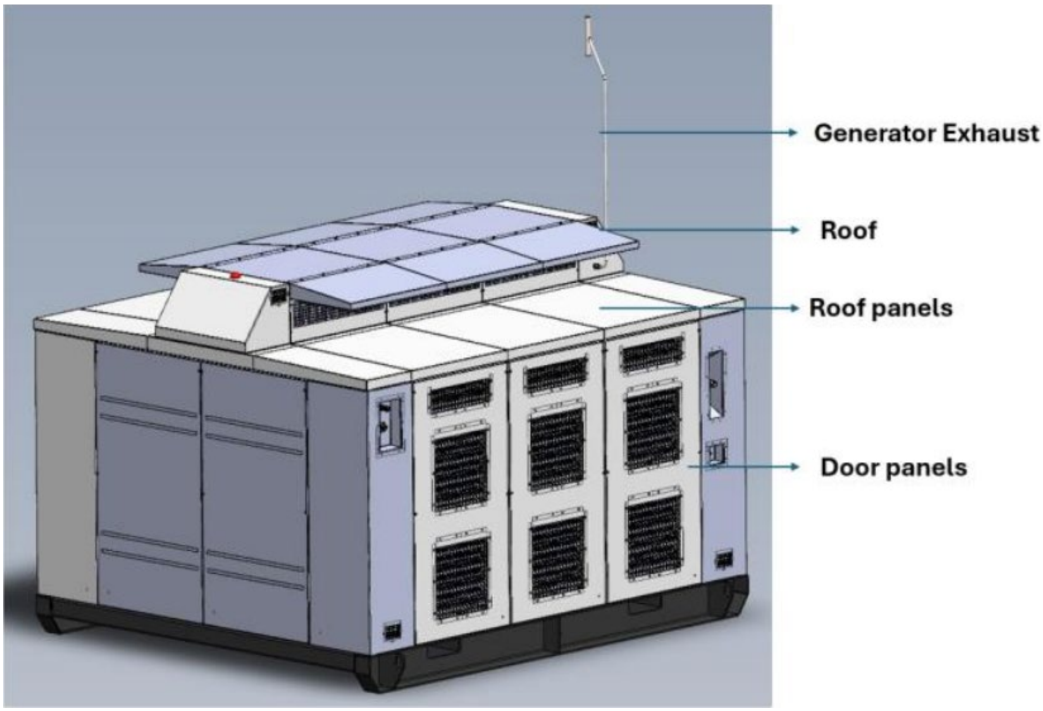


Figure 4 - Old generator chassis and panel design overview that was modified for use in the project



The system is built around the cooling air supply duct, which collects ambient air from outside the generator at low level, passes it up through the horizontally orientated fuel cell stack, and exhausts by draught cooling fans out the top. This duct provides useful mounting locations for the balance of plant subsystems, including fuel and air supply handling and electrical components. Where possible various subsystems are built as sub-assemblies and mounted complete. Completely new air inlet ducts were designed for the stack cooling and electrical panel cooling. Additional exhaust ducts were designed to direct the air out from the generator.

Testing

Prior to demonstration, the generator was tested for safety and operation/performance. Throughout the testing, any issues identified were reported and rectified. The following key safety features were checked and confirmed operational -

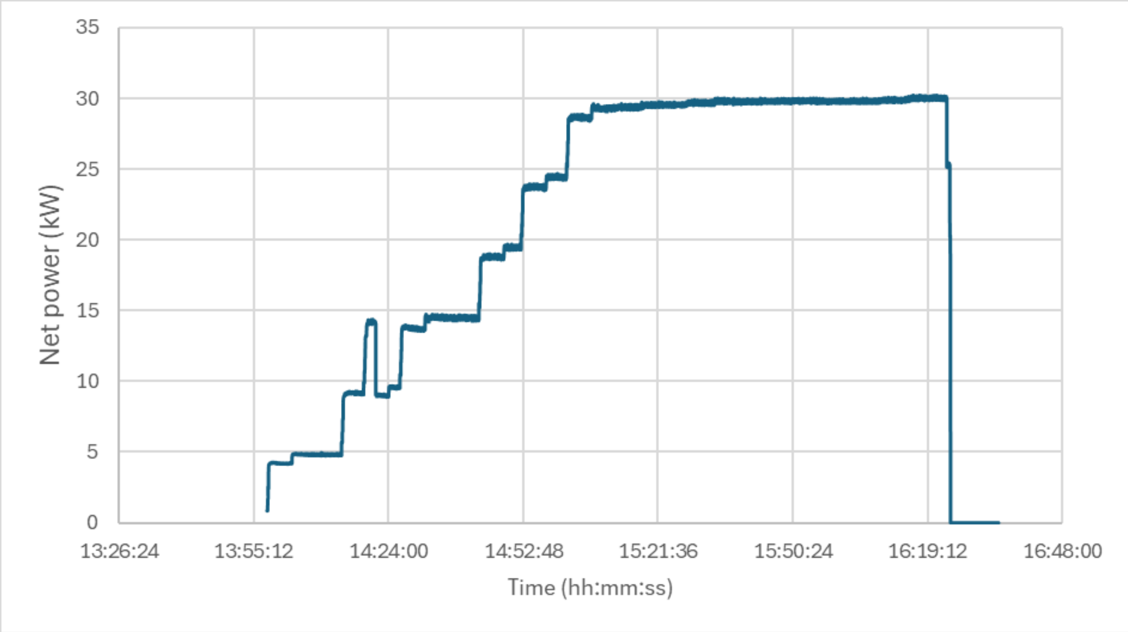
- Emergency stop on BESS
- Emergency stop on Generator
- Hydrogen sensors (x2)
- Isolation resistance monitoring of the high voltage line

The Generator was run in the following modes to ensure correct operation and smooth transition of each fuel cell modules.

Figure 5 shows output power from the Generator was increased over time, reaching its nameplate rating of 30 kW. The Generator was run at 30 kW for >1 hour.

- Pre-Open Circuit Voltage (OCV)
- OCV
- Ramp-up (3 stages)
- Warm-up
- Nominal operation
- Shutdown (2 stages)

Figure 5 - Operation of S AR3 Generator, showing peak power output at 30 kW



Lessons Learnt

- Design for costs targets needs to consider market volumes earlier in the concept development to avoid issues with future commercialisation.
- The air cooled systems have a -5 °C to 40 °C operating range which could impact the total market for this product.
- Delays to key components impacted the project timescales even though they were identified as risks early in the planning stage. The mitigations to these risks weren't effective and there were issues with delays of key components that had a knock-on impact to project timelines.

H-Power Generator - S+ Series 200 kW_{net} Liquid Cooled Fuel Cell Generator

FEED/System Design

The front-end engineering design of the S+ series 200 kW_{net} fuel cell generator centred around delivering a self-contained, modular and self-starting system for integration into both temporary and permanent applications. The system incorporates 2 liquid cooled fuel cell modules, each comprising a single 140 kW stack. Each fuel cell module operates independently within the integrated enclosure, which houses all reactant, thermal, electrical, and safety systems required for operation, simplifying deployment and reducing external installation requirements.

Requirements were gathered from external stakeholders and customers as well as internal requirements, and safety requirements taken from BS EN IEC 62282-3-100:2020. System design was split into the following areas.

Systems Engineering

System engineering led the definition of system-level requirements, interfaces, and performance targets. The team were responsible for process engineering, including hydrogen flow architecture, purging strategy, pressure control, reactant air supply system and thermal management logic. Oversaw process safety analysis (e.g., P&ID development, HAZOP coordination), and selected balance of plant (BoP) components based on system compatibility, reliability, and cost-performance trade-offs.

The work packages involved:

- Top-level requirements gathering/understanding
- Piping & Instrumentation Diagram
- Heat & Mass balance
- Component selection

Heat & Mass Balance

The heat and mass balance developed for this platform started at the fuel cell system level by calculating the required number of cells to deliver 200 kW_{net}. This was determined to be roughly 500 cells (split across 2 stacks), which was used to calculate the necessary flows required to produce this power. AFC heat and Mass balance calculations gave us the necessary specifications to use when selecting components (i.e. BoP coolant pump, BoP & Stack radiator, hosing, valves, mass flow meters, pressure & temperature sensors and deionizer).

Control Engineering

Developed the system control logic and software architecture, including start-up/shutdown sequences, fault detection and response, load-following strategies, and communications with external systems such as BESS. Implemented safety interlocks and operational limits derived from risk assessments and system constraints.

This team was split into two control areas: the fuel cell system control and the overall generator control, which oversees the fuel cell systems and interfaces with externals.

Electrical Engineering

Designed the high and low voltage electrical architectures, DC distribution, protection schemes (fuses, contactors, isolation), and EMC mitigation strategies. Responsible for grounding, enclosure wiring, power connectors, and ensuring compliance with HVDC output and BESS compatibility.

Component Selection

The component selection process was carried out based on a combination of system-level performance requirements, safety standards, supplier availability, and integration with AFC Energy's control architecture. Components were evaluated according to their compatibility with hydrogen fuel cell operation, mechanical and electrical interface requirements, and their ability to meet both steady-state and transient system conditions.

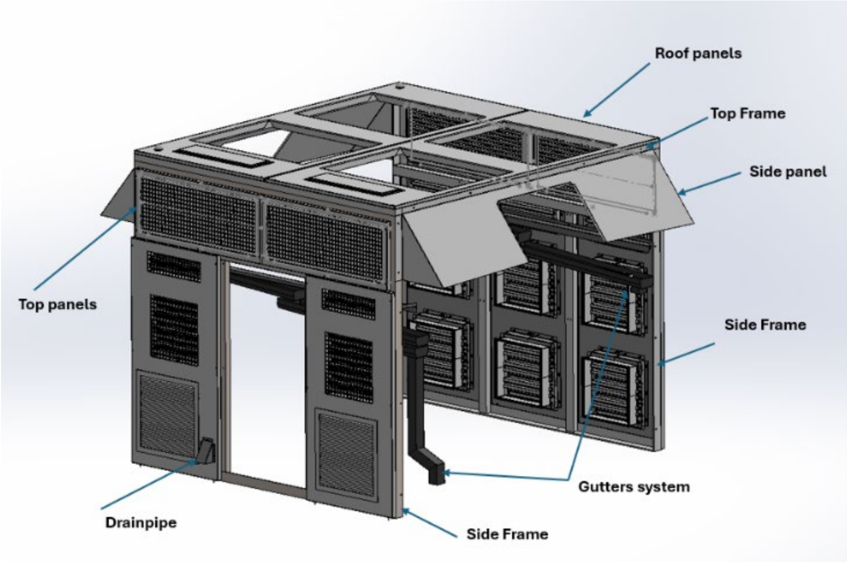
Key considerations included:

- Thermal and mass balance calculations to ensure proper sizing and performance under expected operating conditions.
- Hydrogen system pressure and flow requirements, considering stack inlet pressure regulation, safety, and efficiency.
- Electrical compatibility with the system's power electronics, control logic, and auxiliary subsystems.
- Environmental durability, including resistance to temperature, humidity, and potential exposure to hydrogen.
- Compliance with relevant safety and functional standards for fuel cell systems.

Mechanical Design

The initial design was based on a housing originally developed for an air-cooled system. Since the current system is liquid-cooled, appropriate modifications were required to adapt the enclosure. The working section of the LC system contained only two blades, which were shorter than the original blades used in this housing. To avoid major changes to the original design and to reuse as many existing components as possible (such as blade doors and mounting holes), a frame was designed to replace the space originally occupied by three blades. The frame consisted of two identical vertical side sections, mounted in the existing blade mounting holes, and a top section that held the roof panel.

Figure 6 - Enclosures and outer frame design



The side frame was extended by adding two sealed panels above the existing blade doors. Since one of the main priorities of this stage was to ensure maximum sealing, additional side covers, and a gutter system were installed between the side frames and the LC blade structures. After the roof panels were installed, the joints were sealed with silicone to prevent any leakage. The blade doors were mounted on the side frames using new mounting holes drilled with the same spacing as those on the original doors. Due to necessary system modifications, grille covers were added to all blade doors, and extraction pipes were installed on one side only.

Figure 7 – Outer frame in the production fabrication stage

Testing

Prior to demonstration, the Generator was tested for safety and operation/performance. Throughout the testing, any issues identified were reported and rectified. The following key safety features were checked and confirmed operational -

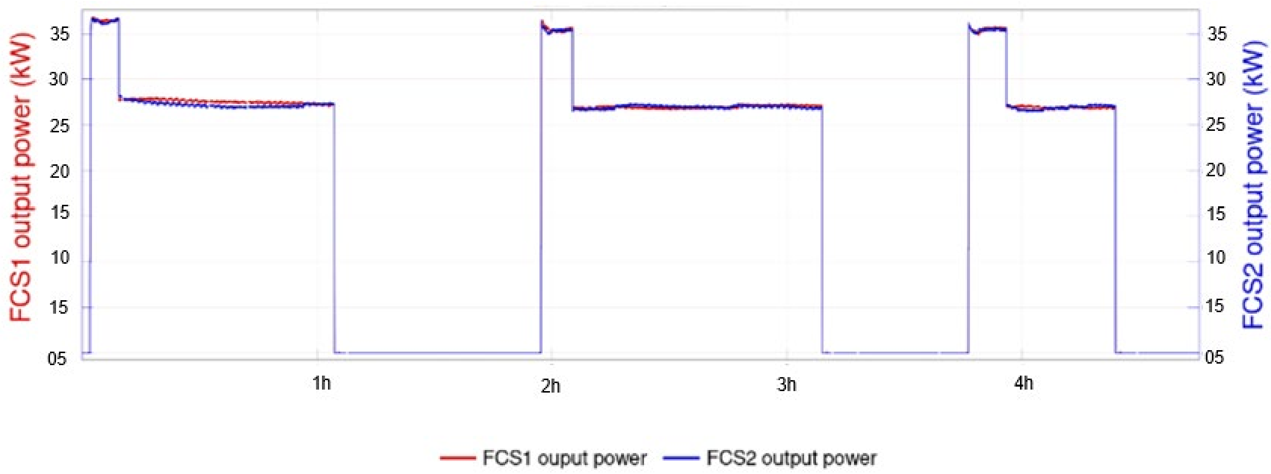
- Emergency stop on BESS
- Emergency stop on Generator
- Hydrogen sensors (x2)
- Isolation resistance monitoring of the high voltage line

The Generator was run in the following modes to ensure correct operation and smooth transition from one mode to the next -

- Start-up
- Mode 1 – run Fuel Cell System (FCS) 1 only
- Mode 2 – run FCS 2 only
- Mode 3 – run both FCS 1 & 2
- Shutdown

The Generator was run for a total of 2.85 hours outputting between 54-72 kW in total (both FCS 1 & 2). This was achieved in 3 sessions, as shown in **Error! Reference source not found.**. Each session began with total power output to BESS of 72 kW for approx. 10 mins, with each FCS outputting 36 kW each. Total power demand was then reduced to 54 kW and each FCS responded by reducing power output to approx. 27 kW each. This was successfully repeated 3 times over the course of the day.

Figure 8 - Operation of S+ Generator. Power output from FCS 1 is shown on the left axis (red) and power output from FCS 2 is shown on the right axis (blue).



Lessons Learnt

- Working with our partners to design a bespoke fuel cell system to integrate into the generator, derisked the project.
- Initially the fuel cell was not able to achieve warm-up state because the signals from the cathode mass flow meter were interrupted. This lack of feedback from an external sensor caused the FC to throttle significantly during warmup - never allowing continuous / effective energy production and therefore the stack was not able to heat up. The signal issue was caused by bent pins on a connector. When this was resolved, the error was removed. These lessons learnt relate to ensuring that connectors used are designed to ensure incorrect installation is not possible.
- Airflow pathways as thus noise related to the fuel cell fan could be improved by modifying the ducting in future iterations. These improvements would enable the genset to be quieter than a diesel genset on site.

Demonstration Study

Overview of Demonstration Plan at Project Outset

Demonstration 1 Easthall Farm 18 kVA diesel generator replacement

The H-Power S Series 30 kW fuel cell generator provided power to a weighbridge at Brett Aggregates Easthall farm site based on an equivalent ISO Prime Rated Power (PRP) 18 kVA diesel generator. The PRP rating sets out that the unit must provide 70% of the PRP rating over a 24-hour period with 1 hour in 12 allowed to draw up to 110% of the PRP rated power.

A site survey was undertaken early in the project to establish a suitable site layout and to collect accurate generator power data to calculate the optimal hydrogen storage vessels for the site based on hydrogen usage requirements.

Once the fuel cell generator and the BESS build and test phases were completed all the equipment was delivered to the customer site, installed, and integrated with the customer load. This was followed by the first hydrogen delivery. The system displaced diesel on site for a one-month trial.

Figure 9 - Easthall Site 18 kVA Diesel Generator and Weighbridge

Demonstration 2 Fairlop 318 kVA diesel generator replacement

The H-Power S+ Series 200 kW fuel cell generator provided power based on an equivalent PRP 318 kVA rated diesel generator. The PRP rating sets out that the unit must provide 70% of the PRP rating over a 24-hour period with 1 hour in 12 allowed to draw up to 110% of the PRP rated power. The output of the unit was via the BESS unit AC output. The AC output was tied into Brett Aggregate's local electricity circuit to power a 1 km conveyor, and a submersible pump.

A site survey was undertaken early in the project to establish a suitable site layout and to collect accurate generator power data to calculate the optimal hydrogen storage vessels for the site based on hydrogen usage requirements.

Once the fuel cell generator and the BESS build and test phases were complete all the equipment was delivered to the customer site, installed, and integrated with the customer load. This was followed by the first hydrogen delivery. The system displaced diesel on site for a one-month trial.

Figure 10 - Fairlop Site Diesel Generator and Conveyor Overview

Results and Benefits of Demonstration 1

Delivery and installation took place on 26th/27th May 2025. The field trial ran between 28th May 2025 & 27th June 2025, a one-month period with 20 working days on the site.

The fuel cell generator was supplied with hydrogen from MCPs and the power produced was used to charge the accompanying 45 kVA BESS. The BESS was connected directly to the customer load and used to run the site weighbridge. The site loads are normally powered by an 18 kVA diesel generator.

Figure 11 - AFC Energy's 30 kW fuel cell generator, let-down station, and Energy Solutions' BESS being readied for transit from AFC Energy to Brett Aggregates site (left to right in image).

Figure 12 – Protium MCPs, AFC Energy’s 30 kW let-down station and fuel cell generator, and Energy Solutions’ BESS on Brett Aggregates site (left to right in images).

- Up time: 100%
- Total power delivered: 625.5 kWh
- Efficiency: Measured at 0.056 kg/kWh in line with target of <0.07 kg/kWh
- Hydrogen consumed: 35 kg
- CO_2 equivalent abated: 750 kg
- Diesel Cost/l: £1.24 [5]
- Diesel Cost/kWh: £0.54 /kWh
- Trial hydrogen Cost/kWh: £5.99 /kWh
- Future hydrogen cost/KWh: <£0.54 /kWh using low carbon hydrogen derived from ammonia cracking.

Results and Benefits of Demonstration 2

Delivery and installation took place on 6th/7th March 2025. The demonstration ran between 10th March 2025 & 4th April 2025, a one month period with 20 working days on the site.

The 200 kW fuel cell generator comprises 2 identical 100 kW fuel cell systems, configured in modular 'blades'. The generator was supplied with fuel from a hydrogen trailer and the power produced was used to charge the accompanying 145 kVA battery energy storage system. The BESS was connected directly to the customer and used to run the existing site loads, including the on-site conveyor belt (50 kW) and a submersible pump. The site loads are normally powered by a 318 kVA diesel generator.

Figure 13 – AFC Energy's 200 kW fuel cell generator and Energy Solutions' BESS installed on site with let-down station and 20 ft Tube trailer

- Up time: 100%
- Total power delivered: 6937.6 kWh
- Efficiency: Measured at 0.064 kg/kWh in line with target of <0.07 kg/kWh
- Hydrogen consumed: 444 kg
- CO_2 equivalent abated: 13,400 kg
- Diesel Cost/l: £1.24 [5]
- Diesel Cost/kWh: £0.893 /kWh
- Trial hydrogen Cost/kWh: £4.223 /kWh
- Future hydrogen cost/kWh: £0.640 /kWh using low carbon hydrogen derived from ammonia cracking.

Challenges and Lessons learned from the demonstration (technical and operational)

Throughout the demonstrations a range of different technical and operational challenges were encountered and lessons learnt. The following section provides detail on findings around electrical interfaces, parasitic energy demand and most significantly, logistics and costs for hydrogen supply to site.

The demonstrations in this project were established sites with a diesel generator supply. On a site where there is an existing electrical interface from the genset to the load, the integration requirements into electrical interfaces need to be audited in the site visit and electrical works planned with qualified contractors that can sign off the works for the site. This requires planning and costs for installation is this particular use case. While the costs are not significant, the planning of the interface configuration needs to be accounted for in demonstration timings.

Reduction of the balance of plant overhead for the generator has a significant positive effect on the fuel economy of the fuel cell system. The recorded fuel economy on the air cooled system of 0.056 kg/kWh is significantly below accepted industry targets of 0.07 kg/kWh.

The demonstrations monthly hydrogen usage rates on the air cooled system trial were 35 kg for 625.5 kWh and 444 kg for 6938 kWh for the liquid cooled trial. These consumption rates show that for higher usage 20 ft or 40 ft Trailers of hydrogen are required and that for lower usages mini trailers and MCPs offer the correct solutions.

A 20 ft trailer **Error! Reference source not found.**14, contains 288 kg hydrogen @300bar and lasted 2 weeks on site for the liquid cooled trial use case. The main issues with 40 ft containers are the requirements for hard standings and exclusion zones which can make the deployment of these vessels on construction sites impractical.

For lower usages, MCPs (Figure 15) are readily available, however deployment on construction sites may require a HiAb for unloading and can increase costs. Mini trailers **Error! Reference source not found.**16, are a novel customer focused option for lower usage, containing up to 99 kg, they can be towed by an ADR compliant pickup truck or vehicle capable of towing 3500 kg making them easy to deploy on construction sites even in heavy-duty off-road conditions. An MCP of hydrogen will last up to 2 weeks on site for the air cooled trial use case.

Figure 14 – 20ft Trailer containing 288 kg of hydrogen

Figure 15 – Protium MCP containing 16.7 kg hydrogen

Figure 16 – Protium mini trailer containing up to 99 kg hydrogen

Hydrogen supply vessels on the market are yet to be fully standardised, connections and pressures can vary by supplier or vessel type and some have requirements that mean they cannot be fully emptied so it is key that the specifications of the storage vessel and any HSE requirements are shared in the quote phase so that compatibility with the connected technology can be assessed by competent professionals.

The usage rate of hydrogen over the average week is key to determining when a new hydrogen delivery needs to come to site. If a delivery is early, then hydrogen usage will be lower and an amount will be left in the vessel, which depending on the contract may or may not be charged for. If the deliveries are late the BESS has a limited capacity to continue powering the site. If there are interruptions to the load such as unplanned maintenance then the expected usage on site will fall and the rental period for an asset may need to be extended, which would incur additional costs.

Rental of the storage vessels, delivery and surcharges can contribute up to 50% of the total cost of hydrogen. This can rise to >80% of the costs if a wrong size vessel is used, or a site issue causes the rental period to be extended. It is critically important for the TCO of fuel cell generators that the correct size of hydrogen vessel is used and the full costs per kg of hydrogen are understood including delivery, rental and surcharges.

In future to achieve cost parity with diesel it is important that customers can lease or own hydrogen storage assets at a lower cost than is currently available in the marketplace, that the cost of green hydrogen continues to fall to <£10.00 kg all in (including hydrogen, gas vessel rental, delivery and all other costs), and that the delivery costs and logistics issues with the use of HGVs and unloading vessels on site are also reduced by new customer focused hydrogen vessels such as Protium’s mini trailers.

Project Metrics

The project is focussed on the advancement of the TRL from 5 (technology validated in relevant environment) to 7 (system prototype demonstration in operational environment) and is based on the existing technology foundation within AFC Energy. Over the project both the H-Power S-Series 30 kW and S+Series 200 kW were validated in a real-world site trial at Brett Aggregates Quarry sites. Within 3 years of the project end we expect the H-Power Generator products to be TRL 9 (actual system proven in operational environment) by leveraging our existing JV, Speedy Hydrogen Solutions in the UK hire market with new units supplied for deployments in 2026.

The commercial readiness level of the H-Power fuel cell generator development is 3c (prepare route to market & supply chain) at the end of the project. 3 years after the completion of the project we expect the CRL to be 4b (proven) with potential for 4c (growth) if market uptake is high. This has been established in parallel by AFC Energy's commercial team and the Speedy Hydrogen Solutions JV.

CO_2 equivalent emissions comparison

Liquid cooled trial at Brett Aggregates Fairlop site

For the liquid cooled trial at Brett Aggregates Fairlop site, if a 50 kW diesel generator was utilised to run the conveyor belt on this site, typical CO_2 emissions would be 1.27 kg/kWh. By using AFC hydrogen fuel cell technology, a total of 8811 kg of CO_2 would be offset by this trial.

The diesel generator used by Brett Aggregates on the Fairlop site is an SDMO V350C21 rated at 350 kVA ESP / 318 kVA PRP. This genset is significantly oversized for the load powered; based on PRP ratings, the generator is operating at roughly 17% of its nameplate capacity. This severely affects its fuel economy, as typical diesel generator sets of the non-inverter type, like this one, run at idle up to 25% load or even higher. Running a diesel generator at low load for long periods will also shorten the maintenance intervals as the engine suffers from wet-stacking and soot buildup.

Published fuel consumption data for this genset is provided in Table 2. No data is published at the loads used at the Fairlop site, but typical idle consumption of generators in this range are not generally lower than 25 l/h, which is taken as a conservative estimate for the next calculations.

Table 2 - Published fuel consumption data for SDMO V350C2

Consumption with cooling system	
Fuel consumption @ ESP Max Power (l/h)	70,3
Fuel consumption @ PRP Max Power (l/h)	63,5
Fuel consumption @ 75% of PRP Power (l/h)	48,1
Fuel consumption @ 50% of PRP Power (l/h)	33,4

An accepted conversion factor for CO_2 emissions factor for diesel: 2.68 kg CO_2 / L.

The diesel generator is therefore calculated to emit 25*2.68 = 67 kg CO_2 per hour of operation. Over the duration of the trial, the generator uptime is 20 days @ 10 hours/day, or 200 hours of power generation time. The total amount of CO_2 not emitted by the diesel generator during this period as a result of this trial is therefore 13,400 kg.

Air cooled trail at Eash Hall Farm

A common estimate of typical CO_2 emissions from a diesel generator is 1.27 kg/kWh. By using AFC Energy hydrogen fuel cell technology, approximately 750 kg of CO_2 was offset by this trial.

The diesel generator used by Brett Aggregates on the Easthall site is a Stephill SSDK20M2 rated at 17.8 kVA ESP / 16.3 kVA PRP. This genset is significantly oversized for the load powered; based on PRP ratings, the generator is operating at roughly 10-20% of its nameplate capacity. This severely affects its fuel economy, as typical diesel generator sets of the non-inverter type, like this one, run at idle up to 25% load or even higher. Running a diesel generator at low load for long periods will also shorten the maintenance intervals as the engine suffers from wet-stacking and soot buildup.

Published fuel consumption data for this genset is provided below.

Table 3 - Published fuel consumption data for Stephill SSDK20M

Fuel tank capacity	120 Litres	
Autonomy 100% load	21 Hours	5.6 L/h
Autonomy 75% load	26 Hours	4.6 L/h
Autonomy 50% load	43 Hours	2.8 L/h
Autonomy 25% load	86 Hours	1.4 L/h

An accepted conversion factor for CO_2 emissions factor for diesel: 2.68 kg CO_2 / L.

The diesel generator is therefore calculated to emit 1.4*2.68 = 3.75 kg CO_2 per hour of operation. Over the duration of the trial, the generator uptime is 20 days @ 10 hours/day, or 200 hours of power generation time. The total amount of CO_2 not emitted by the diesel generator during this period as a result of this trial is therefore 750 kg.

Table 4 - CO_2 Equivalent Emissions Comparison for the one- month trial period

CO_2 equivalent emissions	30 kW S Series Fuel cell generator system	18 kVA Diesel generator	200 kW S+Series Fuel cell generator system	318 kVA Diesel generator
Emissions (kg)	0	750	0	13,400

Costs of the solution

The demonstrations compared the existing onsite diesel generators, both of which were running at low efficiency loads of (72 kWh/day and 349 kWh/day), with a fuel cell generator based solution. The low loading of diesel gensets is common, especially where the use of the site and the equipment powered changes over the life of the generator. This can lead to diesel generators being run at very inefficient loads which occurs in these use cases.

Based on results of the demonstration use cases the current cost of green hydrogen at the time of the trials was 5 to 11 times higher than diesel. Until there is cost parity with diesel there is a barrier to wider market adoption beyond innovators and early adopters. AFC Energy estimates that this hydrogen diesel parity price currently stands at £10.00 /kg "all in" (including hydrogen, gas vessel rental, delivery and all other costs). To address this, AFC Energy have a route to providing hydrogen derived from ammonia at less than £10 /kg without government subsidies to achieve cost parity with diesel in 2026. With this strategy on hydrogen, which is the largest cost element of the TCO calculation; hydrogen fuel cells produced at commercial scale can reach cost parity with diesel.

The capital costs of diesel gensets are significantly lower than fuel cells, this is not unexpected given global production volumes of the incumbent diesel technology are far higher than those of the fuel cell technology. The service costs of fuel cells maintenance are lower than that of diesel genset servicing costs by approximately 65%.

The values have been established by using the trial data from the two deployment use cases and through our work with Speedy Hire, who provided the data for the diesel generators, they are compared in table 6.

Table 5 - Demonstration scale cost breakdown and Total Cost of Ownership for Prototype Fuel cells and Commercial Volumes of Diesel Generators.

Demonstration Scale costs	30 kW S Series Fuel cell generator system	18 kVA Diesel generator	200 kW S+Series Fuel cell generator system	318 kVA Diesel generator
kWh Delivered / Month	625.5	625.5	6937.6	6937.6
Total 10 year life Costs including Generator, Fuel and Maintenance (£)	616,397 [1]	92,401	3,890,949 [1]	921,693
Cost per kWh (£/kWh/yr)	8.21	1.23	4.67	1.11

[1] – Prototype costs only

Table 6 - Commercial scale cost breakdown and total cost of ownership

Commercial Scale costs	30 kW S+ Fuel cell generator system (100's)	18 kVA Diesel generator	200 kW S+Series Fuel cell generator system (10's)	318 kVA Diesel generator
Capital Costs (£)	80,000	14,000	215,716	35,245
10 year Operating costs Maintenance (£)	15,775	37,869	43,875	143,016
10 year Operating costs Fuel (£)[2]	125,209 [3]	170,614 [3]	418,130 [4]	515,840 [4]
Total 10 year life Costs (£)	220,984	222,483	684,721	699,101
Cost per kWh (£/kWh)	1.20	1.21	0.94	0.96

[2] Based on diesel £1.24/l and Hydrogen derived from ammonia at £10/kg

[3] at 72 kWh/day

[4] at 349 kWh/day

Other Factors

As well as the emissions and costs comparison between fuel cell and diesel generators it is important to highlight other key differences.

- Safety, risk assessments and method statements that are needed for deployments are different to those for diesel, mainly as industry standard practices, equipment and interfaces have not been established as yet. This will require training of customer staff and hire staff in the use of new systems. AFC Energy are already offering training to customers for the deployments of our H-Power generators onto their sites as part of our ongoing commitment to customer engagement and safety.
- Practically the total layout size needed is larger mainly due to the spacing requirements and the size of hydrogen storage vessels compared to diesel.
- Effluent tests for the fuel cell generators are needed where the purge is discharged on site to confirm compliance with the site's environmental requirements. The H-Power fuel cell generators are compliant with these requirements, and the grant has supported this testing work.
- During the site demonstrations it was difficult to get reliable noise measurement due to ambient noise from road traffic. AFC Energy are targeting noise levels of <70dBA which is less than the 77dBA rating for diesel generators.
- Site visits are critical for effective deployments, they must define areas of responsibility between the stakeholders, set the site-system interfacing requirements, and provide hydrogen usage requirements to enable the selection of the correct hydrogen solution for customers.
- For reduced hydrogen costs, ammonia as a fuel and hydrogen carrier is a desirable alternative to shipping large volumes of hydrogen over long distances. Production of hydrogen from ammonia locally also enables lower hydrogen costs than current production methods.

Secondary Project Benefits

Dissemination activities undertaken including media coverage and dissemination events

Dissemination included an initial phase of social media posts to align with the generator trials. The posts were focused on the fuel cell generator and BESS unit on demonstration, the fuel cell and the gas supply options, and the site visits themselves. This initial phase will be followed up by joint white papers with AFC Energy and Energy Solutions on the applications for fuel cell generator systems in construction, and AFC Energy and Brett Aggregates on applications in quarrying.

Number of jobs created and activities improving skills/experience in the sector

A total of 48 engineers worked on the project covering the phases from concept and detailed design through to build, test, and real-world demonstration verification. During the project a new deployments team was introduced with recruitment of 2 engineers. Training opportunities for the team included HV training, and gas safety training was also provided to those in the team handling gases.

New partnerships & Supply chain development

The Red Diesel Replacement project has significantly strengthened AFC's supply chain. New partnerships were formed and existing relationships developed further.

Throughout the system design process, we required rapid, cost-effective sheet metal and CNC solutions to support evolving mechanical requirements. This urgency prompted us to expand our supplier base, leading to a successful partnership with a new machine shop that offers improved lead times while remaining cost competitive.

Additionally, the development of the systems within limited space led us to trial a staggered delivery model with one of our largest electrical component suppliers. While previously reserved for manufacturing, this call-off approach proved highly effective during development, helping us manage internal space more efficiently. Based on its success in the RDR project, we are now implementing this model across all internal development initiatives at AFC.

The project has enabled a better overview of the suppliers in the market and the costs associated with production of green hydrogen, delivery and rental of storage vessels and how this impacts overall hydrogen price. It also highlights the different hydrogen storage vessel options and the development that is going on to create innovative vessels optimised for construction environments and usage which are key to making hydrogen solutions a commercial reality.

Project Management

The project was broken down into 8 milestones and 9 work packages with multiple deliverables. The milestones aligned with the quarters of the projects and deliverables were broken down by workstream and owner as per Table 7 below.

Table 7 - Work packages, main responsible party and workstream

Work Package	Responsible	Workstream
WP 1 Project Management	AFC Energy	Project Management
WP 2 30 kW Air Cooled Fuel Cell Development	AFC Energy	S Series 30 kW generator
WP 3 45 kVA BESS Development	Energy Solutions	S Series 30 kW generator
WP 4 Fuel Cell and BESS demonstration trial (50 kVA generator replacement)	AFC Energy	S Series 30 kW generator
WP 5 200 kW Liquid Cooled Fuel Cell Development	AFC Energy	S+ Series 200 kW generator
WP 6 145 kVA BESS Development	Energy Solutions	S+ Series 200 kW generator
WP 7 Fuel Cell and BESS demonstration trial (318 kVA generator replacement)	AFC Energy	S+ Series 200 kW generator
WP 8 Dissemination and Reporting	AFC Energy	Project Management
WP 9 Hydrogen Selection and Provision	AFC Energy	Hydrogen Supply

Over the course of the project several of the risks developed into issues. Risk 18 and 1 were the first risks to become issues this required a full replan of the project due to the impact of overrunning projects and skill shortages.

Risk 19 became an issue even though the lead times and risks were identified on key components for the air cooled generator development. These delays caused a slip of 4 months to the air cooled schedule. The chassis design delays were mitigated by using modifications to an older variant to prevent further delays on the project.

Risk 10 became an issue at the end of the project when it was clear that the target product cost on the air cooled unit could only be met at high volumes with further investment required in design and manufacturing. For future commercialisation liquid cooled generators at lower power levels achieve AFCs target costs at volumes that are better aligned with the market uptake and customer adoption.

Project management lessons learned include not splitting related work packages into separate deliverables. The purchasing work packages were split into too many deliverables and as a result any changes to the schedule of parts caused by delays on the project then created additional work due to the level of changes needed to the project cost schedule. In the original plan there were 5 deliverables related to this task. In hindsight 2 would have been more effective.

Commercialisation Plans

AFC Energy's route to market for lower power units <50 kVA hydrogen fuel cell generators is more developed than that of the 200 kW fuel cell generator. AFC Energy has invested in a JV with Speedy Hire to provide the UK hire market with hydrogen fuel cells systems to replace diesel generators. Speedy Hire has relationships with leading construction firms whom AFC Energy are currently engaged with. Speedy's customers and AFC Energy's end users also cross into related markets such as mining & quarrying sectors as well as back-up power solutions. AFC Energy are also working with customers in Europe and the Middle East.

The lower cost of the liquid cooled architecture when compared to that of the air cooled at commercial scale makes it suitable for a wide power range, from 5 kW to 500 kW. Ongoing work as part of our joint venture with Speedy Hire has shown that the liquid cooled architecture can achieve commercial cost targets at volumes that match the market demand. This enables a 50 kVA diesel genset to be replaced with a 30 kWh fuel cell generator in the construction sector. The liquid cooled architecture also suits a wider market for deployment due to the wider thermal operating range of the liquid cooled system (-20 °C to 50 °C vs -5 °C to 40 °C for air cooled).

AFC Energy are developing a Beta version of our 30 kW fuel cell generator directly from the learnings in the air cooled and liquid cooled developments funded by the RDR grant. The project is expected to have completed an initial production run of 30kW liquid cooled fuel cell generators in 2026. The unit also has export potential to Europe, the Middle East, the USA and Cannada and will by type marked for these regions.

Based on results of these trials the current cost of green hydrogen at the time of the trials was 5 to 11 times higher than diesel. Until there is cost parity with diesel there is a barrier to wider market adoption beyond innovators and early adopters. AFC Energy estimates that this hydrogen-diesel parity price currently stands at £10.00 /kg all in (including hydrogen, gas vessel rental, delivery and all other costs). To address this AFC Energy have a route to providing hydrogen derived from ammonia at less than £10 /kg without government subsidies to achieve cost parity with diesel in 2026. With this strategy on hydrogen, which is the largest cost element of the TCO calculation; hydrogen fuel cells produced at commercial scale can reach cost parity with Diesel in 2026.

The liquid cooled 200 kW Generator has a commercial scale generator cost per kWh that can achieve parity with Diesel but a smaller initial target market. AFC are actively exploring customer interest in higher power generators at construction and hydrogen trade shows with our JV partner Speedy Hydrogen Solutions and with customers in markets outside of the UK.

Conclusions and Next Steps

Objectives and Key successes

- Successful development and demonstration of a 30 kW fuel cell generator by AFC Energy and a 45 kVA BESS by Energy Solutions. The one-month demonstration at Brett Aggregates' site demonstrated the system prototype in a real-world quarrying sector application powering a weight bridge. The system provided 100% uptime and 625.5 kWh enabling 750 kg CO_2 to be offset over the trial period.
- Successful development and demonstration of a 200 kW fuel cell generator by AFC Energy and a 145 kVA BESS by Energy Solutions. The one-month demonstration at Brett Aggregates' site demonstrated the system prototype in a real-world quarrying sector application powering a conveyor more than 1 km in length and a submersible pump. The system provided 100 % uptime and 6938 kWh enabling 13,400 kg CO_2 to be offset over the trial period.
- Over the project we were successful in increasing the TRL of both the H-Power S-Series 30 kW and S+Series 200 kW from TRL 5 to TRL 7 as both system prototypes were demonstrated in real-world site trials at Brett Aggregates Quarry sites.
- Disseminated learnings from the demonstrations through various forms of publication; further white papers with data from the demonstrations will be provided to help customers, end users and policy teams assess the viability of low carbon alternatives.
- Accelerated the commercialisation of low-carbon red diesel alternatives enabling AFC Energy and our JV partner Speedy Hire to provide hydrogen fuel cell systems at cost parity with diesel generators in 2026.

Key Lessons Learned

Hydrogen - Storage vessel selection, logistics and cost

- The deployment of the larger 200 kW system requires large amounts of hydrogen. The sites to support quarries are remote and the access is often unmade with no hard standing for a tube trailer. The turning circles for the vehicles are large which increase the need for ground works where the vehicles are manoeuvring. This means that groundworks may be needed to use some 40ft tube trailers.
- In addition exclusion zones required can be up to 8 m for 40 ft tube trailers, not all sites would be able to accommodate this.
- As the usage on the site varies day to day. The logistics and timings of the hydrogen deliveries become more important to the overall efficiency of the site. This is more impactful if there is a site equipment shutdown close to a planned delivery as it means that there is gas remaining in vessel as the usage drops suddenly.
- The cost of the delivery and vessel rental elements is often more than the gas itself. If there are reductions in hydrogen usage on site it will extend the rental period thus increasing the cost/kwh.

Air cooled vs liquid cooled technology, commercialisation, and market Demand

- The air cooled module developed in the RDR project is suitable for up to 5 kW and AFC Energy are exploring this as a product.
- The lower cost of the liquid cooled architecture when compared to that of the air cooled at commercial scale makes it suitable for a wide power range, from 5 kW to 500 kW. Ongoing work as part of our joint venture with Speedy Hydrogen Solutions has shown that the liquid cooled architecture can achieve commercial cost targets at volumes that match the market demand.
- The liquid cooled technology architecture was validated at low turndown ratios. This enables a 50 kVA diesel genset to be replaced by a 30 kW liquid cooled hydrogen fuel cell. The liquid cooled architecture suits a wider market for deployment due to the wider thermal operating range of the liquid cooled system (-20 °C to 50 °C vs -5 °C to 40 °C for air cooled)
- AFC Energy are developing a beta version of our 30 kW fuel cell generator directly from the learnings in the air cooled and liquid cooled developments funded by the RDR grant. The project is expected to have completed an initial production run in 2026. The generator also has export potential to Europe, the Middle East, the USA and Canada and will by type marked for these regions.

- The Liquid cooled 200 kW Generator has a smaller initial market with a comparative commercial scale cost per kWh vs Diesel. AFC are actively exploring customer interest in higher power generators at construction and hydrogen trade shows with our JV partner Speedy Hydrogen Solutions and with customers in markets outside of the UK.

Next Phases For AFC Energy

Air cooled power unit feasibility study

The air cooled module developed in the RDR project is suitable for up to 5 kW and AFC Energy are exploring this as a product.

Liquid cooled technology architecture validated across the full power range

The lower cost of the liquid cooled architecture at commercial scale makes it suitable for a wide power range, from 5 kW to 500 kW. Ongoing work as part of our joint venture with Speedy Hire has shown that the liquid cooled architecture can achieve commercial cost targets at volumes that match the market demand.

The liquid cooled technology architecture used on the project was validated at low turndown ratios. The liquid cooled architecture also suits a wider market for deployment due to the wider thermal operating range of the liquid cooled system (-20 °C to 50 °C vs -5 °C to 40 °C for air cooled)

AFC Energy are developing a beta version of our 30 kW fuel cell generator directly from the learnings in the air cooled and liquid cooled developments funded by the RDR grant. The project is expected to have completed an initial production run in 2026. The unit also has export potential to Europe, USA and Canada and will by type marked for these regions.

AFC are actively exploring customer interest in higher power generators at construction and hydrogen trade shows with our JV partner Speedy Hydrogen Solutions and with customers in markets outside of the UK.

Tackling the cost of hydrogen without subsidies

AFC Energy's launch of the HY 5 unit enabling ammonia to be cracked into hydrogen will allow us to reach TCO cost parity with diesel in 2026. Hydrogen fuel cell generators reaching the point of cost parity with diesel is achievable in the near term and this is key to wider market adoption of the technology in the construction, mining and quarrying sectors.

End Matter

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