Zero Carbon Turn

Winter Operations HyGPU project

Technical Report

August 2026

Acknowledgements

The consortium of partners, collaborators and supporting organisations played a key role in the conception, design, delivery and achievements of the Project. We are grateful and acknowledge the contribution of you all.

Contents

1. The Zero Carbon Turn Project

The Zero Carbon Turn project, led by Exeter Airport in collaboration with Cranfield University, TUI, ULEMCo, Boeing and MULAG, and supported by the CAA as part of the Hydrogen Challenge Sandbox programme, brought together three different hydrogen technologies to support a live turnaround of a TUI Boeing 737 in April 2025.

Its objective was to **demonstrate, test and evaluate multiple hydrogen-powered ground support technologies in a real airport environment to build operational knowledge, safety cases and evidence to support future hydrogen use and net zero ambitions at airports.**

The trial, conducted at Exeter Airport, successfully demonstrated a hydrogen internal combustion tug, a hydrogen fuel cell baggage tractor and a dual fuel hydrogen–diesel GPU operating together airside, achieving several UK firsts in the process. Namely;

- The first concurrent use of multiple pieces of different hydrogen fuelled equipment at a UK airport.
- The first time a hydrogen fuelled GPU has been used to power a commercial aircraft in the UK.
- The first time a hydrogen fuelled aircraft tug has been used with a commercial passenger aircraft in the UK.
- The first application of a dual fuel hydrogen/diesel dual-fuel piece of equipment at an airport.
- The first application of green hydrogen (produced via electrolysis using renewable energy) at an airport in the UK.

Among the key outcomes and next steps identified in the project’s technical report, published in February 2026, was **the need to conduct additional and extended trials during ‘real-world’ operating conditions** to support decision making and help build the business case for hydrogen at airports.

Consequently, a follow-up trial was developed utilising a dual-fuel hydrogen-powered GPU (Ground Power Unit) to simulate a series of aircraft turnarounds in winter conditions and during hours of darkness.

2. Winter Operations HyGPU project

2.1 Background and rationale

The rationale for the Winter Operations HyGPU project was a recognition of the need to extend hydrogen trials and demonstration activities at airports to include more ‘real-world’ operating conditions. This is needed both to build confidence and experience of using hydrogen equipment in a demanding operational environment, and the generation of ‘real-world’ datasets to support decision making.

Specifically, it was recognised that existing hydrogen trials have taken place under tightly defined timeframes, usually over the course of a matter of hours or a few days. Equally, they have typically taken place in favourable weather conditions and during daylight hours for reasons of project delivery and safety. However, given many airports are 24/7 365 operations, there is clearly a need for equipment to be operational at all times of the day and during both ambient and inclement weather conditions.

There are important technical and safety reasons for testing the equipment in these conditions. Namely, it is not known to what extent cold ambient conditions affect hydrogen operations, where the colder conditions could potentially reduce fuelling times (with less need to pre-cool before fuelling commences) and/or reduce the performance of the equipment (taking longer for the engine to get to temperature, reduced battery performance, or even potentially causing damage to the membranes of fuel cells).

Outcomes from the current project sought to contribute towards these existing gaps in knowledge by testing a dual-fuel hydrogen powered ground power unit (GPU) in winter conditions and during hours of darkness in February 2026.

2.2 Aim and Objectives

The aim of the project was to **assess the technical and safety impacts of hydrogen GSE operations in winter conditions and during hours of darkness**. This was assessed via a limited trial of a dual-fuel hydrogen powered GPU at Exeter Airport in February 2026.

This is fulfilled via fulfilment of the following objectives.

O1. Test a dual-fuel GPU at Exeter Airport during winter conditions and night operations.

O2. Collect, analyse, and develop a dataset on technical performance under varying ambient conditions.

O3. Assess technical impacts of H2 operations in cold and inclement weather, and safe operations during hours of darkness.

O4. Generate insights to inform future hydrogen applications, regulatory development, and business case for dual fuel as a practical decarbonisation pathway.

2.3 Activities and work plan

The project consisted of three phases.

Stage 1- Planning and Safety case development (October-December 2025)

The specifics of the trial were planned, including timeline and logistics. The safety case was developed and a CAP791 application made to the CAA at the end of the planning phase in late November.

Stage 2- Demonstration and data collection phase (January – February 2026)

The trial was scheduled for February 2026, with selective use of the HyGPU scheduled to mimic its use with different aircraft turnarounds. Data was collected on the operation of the HyGPU and analysis conducted on how performance varied during different operating conditions.

Selected ground crew at Exeter operated the HyGPU during hours of darkness. Qualitative data was collected during the trial in the form of a user log and afterwards via a semi-structured interview.

Stage 3- Analysis and dissemination (March 2026) -The outcomes of the trial were analysed and documented in this written technical summary report.

2.4 Consortium

The ZCT consortium was convened to represent the key stakeholders required to support a live demonstration of an aircraft turnaround. A summary of the consortium and a summary of their key roles is provided below.

Organisation	Summary/ Project Role
ExeterAirport Part of Regional & City Airports	Exeter Airport is a regional airport located in Devon in the South- West of the UK. The airport serves predominantly domestic UK and Chanel Islands Routes, as well as selected European leisure destinations. Exeter Airport have a proven track record of engagement with innovation and decarbonisation projects. The airport provided the location for the trial, led the risk assessment and CAP791 approvals process, helped arrange and undertook the logistics of equipment for the demonstrations, design and delivered familiarisation training.
Cranfield University	Cranfield University is a leading UK University specialising in aviation and aerospace teaching and research. The University has also played an active role in pioneering H2 demonstrations, including Project ACORN (the first hydrogen refuelling trial of GSE at Bristol Airport), HIMATT (the first airside pushback of an aircraft using a hydrogen powered vehicle at an airport in the UK, held at Cranfield, and the Zero Carbon Turn Project.
ULEMCo ULTRA LOW EMISSION	ULEMCo are a UK firm renowned for pioneering technology that supports the conversion of traditional liquid fuel vehicles to run on hydrogen. ULEMCo provided technical oversight of the project, including the calibration, preparation and data collection from the GPU. ULEMCo will be responsible for supplying gaseous hydrogen to fuel the GPU, and will provide on-site technical support during the trial phase.
CATAPULT Connected Places	Connected Places Catapult is the UK's innovation accelerator for transport, the built environment, and local growth. In this project, the organisation provided funding, technical and commercial oversight, as well as dissemination and project outreach. It has led and supported Innovate UK and Department for Transport funded research and demonstration initiatives focused on zero-emission infrastructure and operations, driving innovation across the UK aviation and transport sectors while acting as a convener between industry, academia, and government.
UK Civil Aviation Authority	The Sandbox forms a key component of the CAA Hydrogen Challenge, which was launched in 2023 and supported by the UK Department for Transport. Members of the CAA Hydrogen Challenge team were embedded in the project and provided key oversight in the safety case development and approvals process.

3. Planning and Safety Case Development

3.1 Technology and equipment

3.1.1 Hydrogen dual fuel GPU (HyGPU) and Loadbank Tester

The trial utilised the same converted Houchin 690 L393 ground power unit (GPU) as was used in the Zero Carbon Turn project in April 2025. The unit is owned and operated by Exeter Airport, with the conversion to run on hydrogen conducted by ULEMCo (see Figure 1).

The dual fuel system allows Hydrogen to replace a share of the diesel fuel in a diesel engine. The engine always starts and warms up on 100% diesel fuel, before the diesel is used to ignite the Hydrogen to power the unit. The quantity of Hydrogen used is automatically controlled by an Electronic Control Unit (ECU), with the quantity of hydrogen used dependent on requested engine torque output and engine speed. If the Hydrogen supply is interrupted the engine reverts to 100% diesel operation with no tangible difference to the operation or performance of the GPU.

The GPU used in the trial was mechanically controlled, meaning no ECU was available for ULEMCo to monitor the engine parameters. This meant that during the calibration process a conservative approach had to be taken, resulting in a lower overall displacement and hydrogen usage. Installing the same dual fuel system on an electronically controlled engine would allow ULEMCo to make significant calibration adjustments, increasing hydrogen usage and therefore further reducing the emissions.

Figure 1 The HyGPU

Unlike the Zero Carbon Turn trial, where the GPU was utilized to power a TUI 737-800 aircraft during a live turnaround, here a loadbank tester was used to mimic the operation of an aircraft (see Figure 2). Loadbank testers are widely used pieces of electrical test equipment used to simulate, prove and verify the operational performance of power sources by applying a precise, controllable load without using actual site load. The tester converts electrical energy into heat (using resistors) to test system capacity and to prevent potential issues like 'wet stacking' occurring- a condition in diesel engines where unburned fuel and soot form a dark, oily mixture when operating under light loads.

Aside from reduced complexity, utilising the loadbank tester for the purpose of this trial provided considerable flexibility and advantages to data collection. Namely, it allowed for repeated and selective use of the HyGPU to reflect more specific durations of use or timings of operation. For example, it was possible to target the use of the unit at times of the day when temperatures were expected to be colder and allowed for the unit to be used for as long as desired rather than being constrained to the operational requirement of a turnaround.

For the trial, the loadbank tester was set to mimic a small narrow body jet (737 or A320 family) at 400hz, representing one of the most common commercial aircraft types and the largest aircraft routinely handled at Exeter Airport.

Figure 2 Loadbank Tester

3.1.2 Manifolded Cylinder Pallets (MCPs)

During the Zero Carbon Turn trial, the hydrogen supply for the HyGPU was provided via a small external 'Portabull' unit (see Figure 3). This contained a maximum of 10kg of Hydrogen storage at 350bar, which ensured portability but at the expense of extended run times.

Figure 3 HyGPU with Portabull (circled) configuration during Zero Carbon Turn trial, April 2025

Here, the priority for the trial was maximising extended run time without the need for portability, given the HyGPU would remain in the same location throughout the trial. Subsequently, larger volume MCPs were utilised with a maximum of 16.5kg of green hydrogen, which were connected directly to the HyGPU (see Figure 4). As before, the MCPs were supplied by Protium from their facility in South Wales.

Figure 4 HyGPU connected directly to MCPs for Winter Ops HyGPU project

A summary of the overall equipment set up is show below (Figure 5).

Landside		Airside		
Production	**Distribution**	**Storage**	**Refuelling**	**End-Use**
External Supplier of Green Hydrogen	Manifold Cylinder Pallets (MCP) delivered on a certified truck.	MCPs stored airside at the airport.	Direct connection	HyGPU (dual fuel) connected to loadbank tester

3.2 Operational Plan

3.2.1 Planned trial activities

The following activities were planned for the trial.

- Simulated operation of a dual-fuel hydrogen/diesel ground power unit (HyGPU).
- GPU operation designed to cover a range of ambient conditions, times of the day (light and dark), and types of aircraft turnaround operation.
- Data collected and analysed concerning the operation of the HyGPU.

In turn, these supported the following;

Comprehensive Risk and Safety Assessment

Systematically identify and evaluate potential hazards associated with hydrogen operations during winter and night-time conditions. Analyse operational risks, validate mitigation measures, and document findings to strengthen safety protocols and inform future regulatory guidance.

Develop a Comprehensive Performance Dataset

Collect and analyse quantitative data on technical performance across varying ambient conditions, complemented by qualitative feedback from ground handling crews.

Evaluate Technical Performance in Adverse Conditions

Assess the operational impacts of hydrogen-powered systems during cold, inclement weather and ensure safe functionality during hours of darkness.

Generate Insights for Future Applications

Use findings to inform regulatory development, future hydrogen integration strategies, and business cases for use of dual fuel as a viable decarbonisation pathway.

3.2.2. Site location

A suitable airside location adjacent to the Motor Transport Compound (Figure 6) to the north of the airfield was selected as the location for conducting the trial. This site was selected due to its airside location with easy dedicated road access (via a control post to the north of the airfield), and remote from regular operations including aircraft and other GSE. The location also provided some practical benefits, namely, an undercover location to place the load bank tester to protect it from the rain. The HyGPU, MCPs and connection hoses/pipework always remained outside and in the open air.

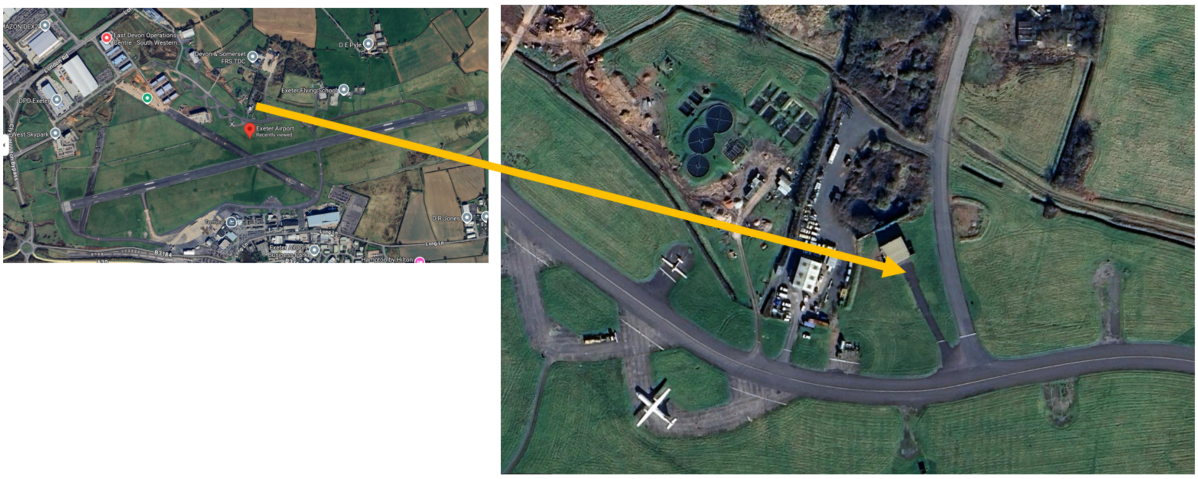

Figure 5 Site location of trial

3.2.3 Trial schedule

The trial took place between the 16th February and 6th March 2026. As the GPU was also required for normal day-to-day operations at the airport in 'diesel mode' during this time, the number of days in which the HyGPU could be used for the purpose of the trial in 'hydrogen mode' was limited to activity across 8 days (see Figure 6). A schedule was formulated ahead of each trial mimicking a realistic 'busy day' at the airport, with the timing and duration of operation the HyGPU set to simulate a realistic intensity of use of the unit (see Table 1). This was shared with the ground crew operating the HyGPU ahead of each trial day. The schedule required that the HyGPU was coupled and then decoupled from the Hydrogen supply during the trial period by trained ground crew at the airport.

Date	Day	Phase/Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
09/02/2026	Monday	On-site calibration and pre-testing			Hydrogen MCP delivered to EXT								Couple						
10/02/2026	Tuesday				Calibration and testing of HyGPU- ULEMCo						Familiarisation/training of ground crew								
11/02/2026	Wednesday				Pre-testing									Decouple					
12/02/2026	Thursday																		
13/02/2026	Friday																		
14/02/2026	Saturday																		
15/02/2026	Sunday																		
16/02/2026	Monday	Trial Day 1											Couple	H2 trial					
17/02/2026	Tuesday	Trial Day 2	H2 trial																
18/02/2026	Wednesday	Trial Day 3	H2 trial																
19/02/2026	Thursday	Trial Day 4	H2 trial			Decouple													
20/02/2026	Friday	Trial Day 5																	
21/02/2026	Saturday	Trial Day 6																	
22/02/2026	Sunday	Trial Day 7																	
23/02/2026	Monday	Trial Day 8											Couple	H2 trial					
24/02/2026	Tuesday	Trial Day 9	H2 trial																
25/02/2026	Wednesday	Trial Day 10	H2 trial																
26/02/2026	Thursday	Trial Day 11	H2 trial			Decouple													
27/02/2026	Friday	Trial Day 12			Hydrogen MCP collected from EXT														

Figure 6 Trial schedule plan

Table 1 Extract of detailed operational schedule for trial.

Monday 16th February	Aircraft (indicative)	Aircraft type	Time	Target Duration (mins)
	737-800	Narrow-body	16:30	25
	E145	Regional jet/turboprop	17:00	30
	737-800	Narrow-body	18:30	60
	737-800	Narrow-body	20:00	45
Tuesday 17th February	737-800	Narrow-body	07:30	25
	ATR72	Regional jet/turboprop	08:15	30
	E145	Regional jet/turboprop	09:00	45
	737-800	Narrow-body	10:30	60
....				

3.3 Safety Case and CAP791 application

A key milestone for gaining approval for conducting the trial related to obtaining CAP791 approvals from the CAA, which concerns procedures for changes to aerodrome infrastructure in the UK.

The certification of an aerodrome is governed by Commission Regulation (EU) No 139/2014 (Aerodromes) 'the Aerodrome Regulation', assimilated into UK legislation. When an aerodrome receives its certificate, it is granted on the basis that it meets aerodrome certification criteria including the establishment of a Certification Basis (CB) and a management system.

The aerodrome regulation requires that all changes to aerodrome facilities and those procedures and policies that have the potential to affect the aerodromes continuing basis for certification need to be notified to the CAA.

However, the regulation requires that some changes require prior approval by the CAA, which was deemed the case for this project. For EASA aerodromes, such as Exeter Airport, changes that require approval from the CAA need to be submitted using 'SRG2011: Application of Changes to a UK Certified Aerodrome'. The process for this is shown in Figure 7.

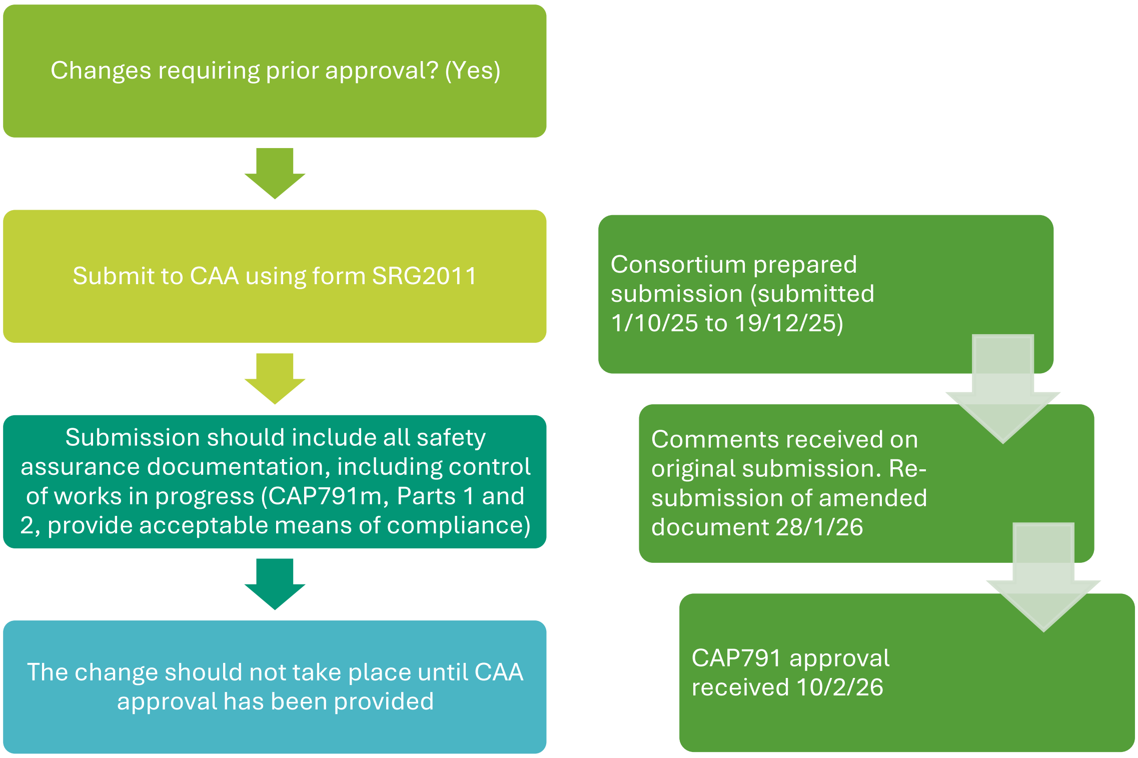

Figure 7 CAP791 application process

The application for this trial subsequently consisted of an Airfield Maintenance Safety Plan (AMSP), including a detailed Risk Assessment, training plan and fire safety briefing, and an SRG 2011 form. The submission was made on Friday 19th December 2025, and approval confirmation was provided on Tuesday 10th February 2026.

3.4. Data collection and metrics

The following metrics were collected for the purpose of data collection and analysis to address the various research objectives. The metrics relating to the operation of the HyGPU were collected using a specialist data logger that was fitted for the purpose of the trial. Meteorological data was extracted using existing high fidelity meteorological and atmospheric data provided to the airport as part of their regular operations. Table 2 below details the various data collected, the rationale for its inclusion and primary application for practitioners.

Table 2 Data metrics collected during the trial

Data collected	Rationale	Primary application
Hydrogen consumption of GPU while in operation (g/min)	At a basic level it is necessary to determine the rate and overall consumption of hydrogen during the operation of the GPU. This will allow for more accurate forecasting (per aircraft turn, per hour, day, or week of operation) of hydrogen requirements to support HyGPU operations if deployed at scale.	Airport planning and decision making. Building the business case. Education and awareness.
Diesel consumption of HyGPU (kg)	A key benefit of using the dual fuel configuration is to reduce the quantity of diesel consumed (and hence, CO2 and emissions this produce). To determine the extent of the 'saving', it will be necessary to monitor the level of diesel consumption for the HyGPU in its dual fuel set up, compared with its operation as a standard (non-hydrogen unit). See linked point below.	Building the business case. Airport planning and decision making.
Diesel consumption of GPU while in standard diesel-powered configuration (kg)	Diesel consumption data will be collected and analysed for the same unit in its 'standard' non-hydrogen configuration. This will aid assessment of the diesel and CO2 savings of the dual fuel system.	Building the business case.
Ambient temperature (degrees Celsius)	It is anticipated that ambient temperature will impact the operation of the equipment. Namely, the colder the conditions and the state of the engine when starting up, the longer it will take for the engine to reach the required temperature for the dual-fuel operation to 'kick in'. In the coldest conditions and/or where the GPU has not been in use for several hours, this situation could be exacerbated.	Technical understanding. Building the business case.
Mass of hydrogen in MCPs (kg)	This is collected primarily for safety purposes (e.g. to identify leaks or faults in the lines). Here it will be used and cross checked with the consumption data of the HyGPU to verify the HyGPU consumption data is accurate and quantify the extent of any leakage/wastage.	Safety / regulatory development
Time to first H2 injection	This represents the point at which the engine reaches the required temperature to start injecting hydrogen and running in dual fuel mode rather than purely on diesel	Technical understanding.
Time to peak injection	The time taken from the point of start up to reach peak hydrogen injection flow rate.	Technical understanding.

4. Findings

4.1 Total operations

Across the 8 operational days of the trial, 15 separate tests of the HyGPU were conducted. In some cases, the data logger also recorded data for only a short period of time (typically a few seconds or up to a few minutes). On subsequent inspection, it was found that these occurred where the ignition of the GPU had been turned on but the engine had not been fully started (identified by the fact that the RPM of the engine in the short occurrences showed a value of zero throughout). These shorter occurrences were filtered out and not analysed further, given that the HyGPU was non-operational in these cases.

Once the data had been cleaned and usable occurrences extracted, 15 separate operations were taken forward for final analysis. A summary of these is provided below in Table 3. The 15 tests amounted to 5 hours 53 minutes of total operating time, with the tests ranging from 06min 34sec in duration to 29min 59sec. Six (6) tests took place around sunrise and in the early morning, with the earliest taking place at 07:07 (Test 2). A further nine (9) tests were conducted during normal daylight hours, with the latest conducted at 14:20. No tests were conducted in the late afternoon, evening or overnight due to the unavailability of suitably trained ground crew to operate the HyGPU at these times.

Table 3 HyGPU operational data

ID	Time of day	Time (24hr)	Test duration (hh/mm/ss))	H2 consumption (kg)	Diesel saving (ltr)	Time to first H2 injection (sec)	Time to peak (1.4kg/hr) injection (sec)	Temp ºC
1	Am	08:23	00:29:58	0.64	2.10	150	293	6
2	Sunrise	07:07	00:29:58	0.64	2.10	9.5	115	4
3	Sunrise	07:58	00:29:59	0.68	2.22	18	150	4
4	AM	08:51	00:29:59	0.66	2.18	16.5	107	5
5	AM	09:50	00:06:34	0.11	0.35	37	85	12
6	PM	12:24	00:29:59	0.69	2.18	39	144	12
7	PM	13:18	00:29:59	0.69	2.27	14	107	11
8	PM	13:48	00:05:54	0.12	0.39	0.5	0.5	11
9	PM	14:20	00:15:57	0.33	1.09	10	98.5	12
10	Sunrise	07:14	00:29:59	0.41	1.36	728.5	868	12
11	Sunrise	07:44	00:17:31	0.39	1.29	0.5	0.5	10
12	AM	08:40	00:29:07	0.61	2.02	17	113.5	11
13	PM	13:41	00:29:59	0.70	2.28	8	106.5	14
14	Sunrise	07:48	00:29:59	0.57	1.86	323	464	11
15	Sunrise	07:18	00:08:08	0.17	0.54	0.5	0.5	11
	Totals		05:53:01	7.41	24.23	-	-	
	Avg			0.49	1.62	91.47	177	

4.2 Hydrogen consumption/diesel savings

Overall, 7.41kg of hydrogen was consumed during the 15 test operations, at an average of 0.49kg per test. This equates to a total of a saving of 24.23 litres of diesel fuel had the GPU been used purely in traditional 'diesel mode', or 1.62 litres per test. In terms of CO_2 savings, this relates to savings of 63.9kg of CO_2 across the 15 tests or 4.3kg per operation on average (assuming a standard conversion of 1litre of diesel produced 2.68kg of CO_2).

One of the key benefits of conducting trials of this nature is to help support decision making using 'real-world' operational data. For the 10 tests that lasted 29-30 minutes in duration, average hydrogen consumption was 0.63kg, ranging from 0.41kg in Test 10 (1.36 litres of diesel saved) to 0.70kg in Test 13 (2.28 litres of diesel saved). Taking the average consumption of 0.63kg and a 30-minute test period, this equates to 0.021kg (21g) of hydrogen consumed per minute.

In terms of potential diesel and CO_2 savings, the average diesel saved for 30 minutes of operation was 2.06 litres (or 0.06 litres per minute), and 5.52kg of CO_2 (or 0.184kg per minute)

To consider the potential implications of this at an airport level, data was used from the desk-based study of GSE operations conducted for Exeter Airport in the first phase of the Zero Carbon Turn project. Using data collected for September 2022 to August 2023, it was calculated that the 7 GPUs at Exeter were collectively operational for a total of 189,254 minutes (3,154 hours), consumed 30,681 litres of diesel and produced 76,055kg of CO_2e. If we were to assume that all these units were converted to the dual fuel set up used in this trial, we could estimate potential savings of 11,355 litres of diesel per year (189,254 x 0.06 litres) and 34,823kg of CO_2e (just over 34 tonnes). Using the same approach, we could estimate that 12 months of operation of this dual fuel GPU fleet would consume just under 4,000kg (4 tonnes) of hydrogen, equivalent to around 75kg per week.

While it is problematic to try and compare like-for-like costs of diesel versus hydrogen, given the former is clearly a more established technology, it is still worth considering the potential financial savings of reducing diesel use. In 2023 the average cost of diesel in the UK was £1.68 according to the Office for National Statistics. Using the calculations above, a dual fuel GPU fleet would have saved the airport £19,076.40 in purchasing diesel.

While on a like-for-like basis green hydrogen remains more costly to produce (estimated to be around 4 to 5 £/kg[1]) and purchase (up to around 20 £/kg[2]) than the equivalent quantity of diesel, it is plausible to consider a future where diesel is considerably more expensive than it is today, either due to dwindling or unreliable supply, or potential future environmental taxes imposed on more polluting vehicles. With growing economies of scale, falling renewable electricity costs, greater demand, and targeted support and incentives, it is possible (even probable) that costs of green

[1] De Castro, G., Culhane, C., Piracha, H., Seaton, J., and Bagnato (2025). Power to Hydrogen: a geospatial and economic analysis of green hydrogen for Uk high-heat industry, Fuel Processing Technology, 273.
[2] 'Hydrogen Gas Supply in the Uk: Supply, Quantities and Costs. www.haush.co.uk

hydrogen will fall, with some studies suggesting that production costs of 2-3 £/kg by 2030 are possible.[3]

It is worth also considering the potential unit cost savings and operational flexibility offered by prolonging the life of existing diesel-powered GSE by converting them to run on hydrogen. As an illustration, a new eGPU can typically cost two to two and half times more than a comparable diesel-powered unit (approximately £40,000-100,000)[4]. While the market for conversion of diesel engines to run on dual fuel hydrogen-diesel is currently very small, is estimated that conversion costs are considerably lower than acquiring new equipment and will fall further as this market develops[5]. Conversion of existing equipment may also help reduce the immediate cost burden of providing new charging infrastructure, given eGSE will also require suitable accompanying charging facilities and increased power demand. In this case, conversion could be used as a less costly and practical solution to support a phased transition to electric GSE. A more detailed analysis of the relative costs of conversion of GSE fleets to a dual fuel set up represents an interesting area for further study.

4.3 Time to first H2 injection

The time taken from the point of first start-up of the HyGPU to the first injection of hydrogen was also recorded. This represents the point at which the engine reaches the required temperature to start injecting hydrogen and running in dual fuel mode rather than purely on diesel. It would be expected that a colder starting temperature and/or colder ambient conditions would delay the amount of time this process took.

This process varies considerably across the 15 trials, ranging from almost instantaneous injection (0.5 seconds in tests 8, 11, and 15) to more than 5 minutes (test 14), with the longest being 12 minutes (test 10). In both cases, the tests represented the first time the GPU had been used that day, where the engine would be coldest and take longer to warm up. This is evident from the other tests that took place at sunrise, where the 6 tests averaged a time of 180 seconds to first injection.

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[3] 'Splitting the difference- reducing the cost of green hydrogen to accelerate deployment' (2025) - RenewableUK
[4] 'Powering Modern Airports; Airside International, June 2026
[5] Hydrogen Dual-Fuel Technology, www.ulemco.com/solution s/h2iced/

By comparison, the 9 tests that took place during the day (after which the HyGPU had already been operated at least once) averaged a time of 32 seconds.

4.4. Time to peak H_2 injection

The time taken from the point of start up to reach peak injection of hydrogen was also recorded. Again, this would be expected to take longer from 'cold starts' and in colder conditions. For each test, the peak injection flow rate was observed as 1.4kg/h, considered as the point at which the flow remained steady and did not drop back below the peak flow rate.

These figures also varied, ranging again from almost instantaneous attainment of peak flow (0.5 seconds in tests 8, 11, and 15), to much longer durations (nearly 8 minutes in test 14, and just over 14 minutes in test 10). Again, the tests conducted at sunrise on average took longer to reach peak flow rates than those conducted at other times.

4.5 The impact of ambient temperature

Across the trial period ambient temperatures were slightly above average for the location and time of year (daytime averages of 9°C / 3°C High/Low in February). Temperatures recorded for the various tests ranged from 4°C (tests 2 and 3 conducted at Sunrise) to a maximum of 14 °C. While there was no direct discernible impact of lower temperatures on the technical operation or performance of the HyGPU at the test level, it is worth highlighting that the two occurrences where the HyGPU took longer to reach operating temperature and peak flow were earlier in the morning when the unit would have remained cool overnight. It seems likely that the impact of non-operation (i.e. sitting dormant) has a much greater impact on performance than ambient temperature alone, but that these impacts can be amplified in colder ambient conditions and if left dormant for longe periods. However, this would need to be assessed over a longer test period with a much larger number of data points before a conclusive judgement on this can be made.

4.6 Qualitative insights

In addition to the operational data collected from the GPU, qualitative insights were gathered from ground handlers who operated the equipment both during and after the conclusion of the trial. This took the form of a daily log and a semi-structured interview conducted after the trial had been completed.

For the log, the ground handler who operated the equipment on each day of the trial was asked to complete a short entry before finishing their shift, indicating the number of tests conducted, the time the equipment was turned on/off for each test, and any notes, general comments or observations. The idea here was that if any problems or issues arose during the trial, these could be quickly identified and rectified. Equally, if trends or issues were identified from the analysis of the quantitative data after the trial had been completed, these could be cross checked with the log to confirm whether this had affected the use of the GPU in any way. As it happened, the comments in the log for each day simply noted that the trial was proceeding normally and as expected. For future trials it may be useful to include more detailed observations about different phases of operation of the equipment on each day, although we were aware of not overly increasing the time burden of conducting the trial for those operating the equipment.

Once the trial was complete, a short semi-structured interview was conducted with a member of the senior airport services team who oversaw the operation of the trial. Questions were designed to elicit information about the organisation and implementation of the trial, as well as specific observations/experiences of using the HyGPU and how this compared with operating the equipment in its normal diesel configuration.

<u>Organisation and implementation of the trial:</u>

Overall, responses indicated that previous experience gathered from the planning and execution of the previous hydrogen trials at the airport (the Zero Carbon Turn Project, conducted in April 2025) had been key to the success of the project. As noted,

> *"We knew a little more about what to expect this time, so we felt more prepared for the planning and delivery of the trial. Obviously, Hydrogen is still pretty new* [for use in aviation], *but it helped that it was the same group of people we had worked with before, so it felt more like a continuation of that work (Zero Carbon Turn) more than having to start from scratch."*

In terms of other factors that benefitted the successful planning and delivery of the trial, the nature of the airport's operation, facilities and site access was also considered to be important.

"I think our operation and being a regional airport probably means we are perhaps more able to support these types of trials [compared with larger, busier airports]. We also knew that we had a suitable location and easy site access in a relatively remote location on the airfield where we could safely position the equipment without it interfering with any of the other day-to-day operations. It also makes sense that we [a regional airport] are among the first to be conducting trials like this, as hydrogen aircraft are most likely to come to these sorts of airport first."

However, it was also noted that planning and delivery of trials can also be time and resource intensive, which smaller airports may find challenging to accommodate.

"Although we had the experience from the previous trial, it still takes time to plan everything, prepare and submit the safety cases, risk assessments, operational plans and everything else that's required. We don't have a massive team and limitless resource, so this is something we need to consider as well."

<u>Specific observations/experiences of using the HyGPU</u>

Overall, responses indicated that there was little, if any, difference when operating the HyGPU with hydrogen compared with traditional operations.

"*Obviously it looked a bit different as it was connected to the hydrogen and we'd usually connect it to an aircraft, but apart from that there was very little difference. Aside from the visual differences, it operated exactly the same as any normal GPU."*

This similarity was found to be the case in all operating conditions. When asked if any differences or considerations were observed operating the HyGPU during hours of darkness;

"…none at all, it was exactly the same as a normal GPU. The only thing different this time was that we needed to disconnect and then reconnect the GPU ourselves during the trial. Once we had been shown how to do it, it was very straightforward."

While a more detailed qualitative assessment of end user experiences and perceptions of hydrogen GSE operations might be beneficial, allowing for broader insights to be derived from a much wider sample of personnel and airport types, for the purposes of this trial, it is clear that little (if any) adaptations had to be made by the team at Exeter or any differences to ‘normal’ operations observed.

5 Key learnings, achievements and next steps

5.1 Key learnings

The project sought to assess the technical impacts of H_2 operations in cold and inclement weather, and safe operations during hours of darkness. While the data cannot conclusively show a direct link between ambient temperature and performance, the findings suggest that the impact of periods of inactivity on performance (for example, when sitting overnight) can be amplified in cooler ambient temperatures. While it would be necessary to conduct an extended test over a longer period of time to determine the full potential implications of this, it could suggest that dual fuel powered equipment is less suited to operating from cold starts or after a period of inactivity, at least with the set up used here.

Equally, it is worth highlighting that the dual fuel nature of the equipment used in this trial means that there is always a delay before the hydrogen is utilized, even if this is only for a few seconds. While GPUs are often used for extended periods of time at airports, other GSE may be used for much shorter cycles with longer periods of inactivity between uses. In such cases, a dual fuel set up may be less suited than a fully zero emissions alternative. This is a similar philosophy to hybrid road vehicles, where the benefits of the technology are felt most readily over longer journeys rather than short trips, where a batter electric alternative would be more suited.

The HyGPU was operated both during the day and during hours of darkness and partial darkness with no discernible changes to its operation and without any safety incidents. The trial suggest that there is little, if any, difference in operating hydrogen GSE compared with traditional GSE, as supported by the qualitative insights provided during the project.

While still a modest dataset, the trial represents one of the only examples of the operation of a dual fuel hydrogen dual fuel GSE operating in real world conditions. The data generated allows for estimations to be made about the potential implications for operating dual fuel hydrogen GSE in this way. Here, it was estimated that potential savings of over 11,000 litres of diesel and nearly 35000kg of CO_2e (35 tonnes) could be accrued at Exeter by converting the existing GPU fleet to hydrogen dual fuel. These findings are an important step in building the business case to support strategic decision making about the adoption of hydrogen at airports.

5.2 Next steps

The project has provided valuable insights into the operation of the dual-fuel HyGPU in a real world environment. To build on this work there is a need to focus research activities in the following areas.

- Longer duration trials and demonstration of equipment as part of ‘business as usual operations.’ This will allow for significantly expanded data collection and analysis, demonstrating the ability to ramp up hydrogen adoption at airports from limited trials and proof of concepts to full-scale regular operations.
- Bulk storage and semi-permanent refuelling facilities- to support longer term use of hydrogen at airports there is a need to develop and test higher volumes of hydrogen storage and more permanent refuelling capabilities. This is also recognised as a key building block and enabler of hydrogen aircraft operations.
- On-site fuel purity testing – for longer duration trials it will be necessary to devise and demonstrate approaches for scalable on-site testing and validation of hydrogen fuel purity. This is a key and unresolved enabler of hydrogen aircraft operations, where it will be necessary for fuel purity to be tested and validated on-site and in a short period of time.

Fundamentally, it remains paramount that a coordinated programme of trial activities continues. By utilising hydrogen at airports in operational conditions, over time the evolution of trials to full scale operational implementation will gradually help build the awareness, experience, knowledge and skills needed to support decision making around hydrogen adoption. In turn, these are critical components of developing the necessary regulatory and safety frameworks for hydrogen aviation, and the continued productive close collaboration between industry stakeholders, regulators, and the academic and research community remains more important now than ever.