Zero Carbon Turn

The UK's first airside trial of multiple hydrogen powered Ground Support Equipment (GSE)

Technical Report

February 2026

Acknowledgements

The consortium of partner organisations and collaborators played a pivotal role in the conception, design, delivery and achievements of the Zero Carbon Turn Project. This required unwavering dedication, ingenuity, tenacity and resilience over many months. In turn, the partner organisations were variously supported by organisations and generous individuals who volunteered their time and expertise to the project to ensure it fulfilled its aims. We are grateful and acknowledge the contribution of you all.

Dedication

In memory of Andy Barton, a much loved, respected and missed member of the team.

Contents

1. Executive Summary

Hydrogen represents an important opportunity for air transport to decarbonise and contribute towards achieving and sustaining net zero operations by 2050 and beyond. While the first regular commercial operations of hydrogen aircraft may still be some years away, there is a need to lay the groundwork in terms of developing the regulatory framework and industry know-how to support hydrogen aircraft once they enter service.

At the same time, there is an opportunity for airports to adopt hydrogen technologies to support decarbonisation initiatives in the very short-term. Unlike hydrogen aircraft, much of the hydrogen technology needed to support decarbonisation of airport operations is already relatively well established and mature by comparison, albeit rarely tested in an airport setting. Indeed, there is a growing realisation that hydrogen can play an important role in supporting, or even superseding, other technologies like battery electric vehicles and e-GSE, which can require extensive electrical grid connections and long periods of downtime for equipment while on charge.

These prevailing gaps in knowledge were driving factors for developing 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.

The project commenced in September 2022 with a desk-based study calculating existing ground-based emissions at Exeter Airport, including the relative specific emissions contributions of GSE and types of flight operations. This in turn led directly to the trial phase of the project, which commenced in September 2023. This culminated in the testing of three pieces of hydrogen fuelled GSE at Exeter Airport as part of scheduled TUI operations in April 2025. The three pieces of equipment were selected and developed to represent three potential pathways and configurations for introducing hydrogen for ground operations at airports; hydrogen internal combustion, hydrogen fuel cell configuration, and a dual-fuel hydrogen-diesel hybrid configuration.

This report covers the various stages of the project, including the development of the safety case and acquiring the necessary approvals, as well as technical information regarding the equipment used in trial.

Aside from contributing to the regulatory framework to support regular hydrogen operations at airports, the project has sought to build confidence and awareness in the value and viability of hydrogen as a fuel for aviation for industry, government and the wider travelling public. While this phase of the project has concluded, it is hoped that the work represents an important stepping stone towards the delivery of similar trials at other airports and advances the adoption of hydrogen as a fuel for aviation more generally in the future.

2. Hydrogen and aviation decarbonisation

The need for air transport to decarbonise is well known, and the industry has made ambitious commitments to achieve net zero carbon dioxide (CO_2) emissions by 2050. However, there remain considerable questions about how these ambitions will be realised, and the required timeframes associated with the transformation. The scale of the challenge cannot be understated. With currently no viable alternatives to fossil-based fuels and advances in aircraft technology taking many years or even decades to be realised and filter down into the market, air transport has the unenviable position as one of *the* hardest sectors to decarbonise. However, inaction or failure to decarbonise is not an option. Doing so poses the clear risk that as other sectors progressively decarbonise aviation falls behind, with emissions from the sector rising proportionally and in overall terms. Such a scenario would likely mean a very different air transport industry to the one we are used to today, come 2050.

Perhaps the greatest, yet most complex, step towards decarbonisation will be the replacement of conventional fossil-based jet fuel with zero emissions alternatives. These zero emissions fuels are distinct from more Sustainable Aviation Fuel (SAF) in that the CO_2 'savings' from SAF are derived by absorption of CO_2 by the feedstock used to create it; at the point of consumption, aircraft burning SAF emit very similar levels of CO_2 to aircraft burning conventional fuel. By comparison, a zero emissions fuel is one where zero or only negligible levels of emissions are generated at the point of consumption. Of the very few energy sources with comparable energy properties compared with conventional fuels, hydrogen is seen as the most viable alternative. Hydrogen can be used in either its gaseous or liquid (cryogenic) form and applied in either a fuel cell configuration or burnt directly (referred to as direct combustion) in an internal combustion engine in an aircraft. It is widely considered that developing knowledge and experience of using gaseous hydrogen (GH_2) for selected airport applications and small regional aircraft in the short to medium term is a necessary step to facilitate the introduction of LH_2 for larger aircraft in the longer term.

2.1 The role for hydrogen and airport ground operations

While it would be easy to assume that this is a problem solely for aircraft manufacturers to address, this overlooks the vital role airports play in this process, both in terms of the need for airports to cut their own emissions and support wider efforts towards decarbonisation.

This is especially the case with regards to decarbonising Scope 3 emissions; those that fall outside of an airports direct control. Challengingly, Scope 3 emissions typically represent the highest overall share of emissions at an airport, often >90% and in some cases as a high as 98-99%. While aircraft operations during landing and take-off (LTO) and emissions from passenger and surface access travel typically represent the highest share of Scope 3 emissions, these are also categories over which an airport typically has the least direct control. By comparison, airport ground operations are an area that can have a notable emissions profile (albeit smaller than aircraft and surface access), *and* where an airport may be able to wield a greater level of influence and decision-making power. This may be especially the case where an airport conducts its ground operations ‘in-house’, rather than outsourcing to specialist third party providers.

Ground operations (also referred to as ground handling) commonly refer to activities concerning the airside servicing of aircraft and passenger operations while the aircraft is on the apron/ramp. These activities include baggage handling and sorting, loading and unloading of aircraft, aircraft cabin servicing (including cleaning, lavatory and catering services), refuelling, de-icing, as well as transporting passengers to and from remote stands. These activities will be conducted using a specialist and extensive fleet of Ground Support equipment (GSE). At some airports these GSE fleets can extend to tens or even hundreds of pieces of both powered and unpowered vehicles and equipment. Powered vehicles will either be powered with diesel (i.e. fossil) fuel or battery electric vehicles (commonly referred to as e-GSE).

While e-GSE have been increasingly adopted at airports worldwide, there are important considerations that can limit their usability. For example, e-GSE will require sufficient connections to a reliable electrical grid infrastructure that can support charging. GSE on charge will also mean a period of downtime for the vehicle when it cannot be used, even where more rapid or only partial charging is employed. Charging can also be negatively affected by weather and climatic conditions, which can pose operational challenges in airports in very cold climates. For GSE operating at remote aircraft stands, there may be limited access to the electrical grid for charging. This could necessitate the need to return to another part of the airport some distance away, driving operational inefficiencies on the airfield.

Equally, GSE are designed to have a long life-cycle (>20 years in some cases), with fleet renewal typically being a costly undertaking. Consequently, the GSE fleets at many airports remain largely (or even exclusively) formed of traditional diesel-powered vehicles, with little prospect of a transition to e-GSE in the near-future. In such cases, converting traditional GSE to run on hydrogen offers an opportunity for some airports; help decarbonise operations in the short-term and keeping older vehicles in use for longer, and in doing so, help support the long-term transition to using hydrogen aircraft in the future.

2.2 The use case for Hydrogen at regional airports

Regional airports play a crucial role in connecting geographically diverse communities, connecting people and fostering economic growth and social cohesion. This is especially important for island communities and regions underserved by major hubs, where regional airports provide access to essential services, stimulate tourism, and help support local businesses.

While regional aviation represents a relatively small contribution in terms of overall emissions from air transport, regional airports will play a vital role in supporting the transition to zero emissions flight. This is principally because the first hydrogen and zero emissions fuelled aircraft to enter the market will be smaller turboprop aircraft, with a maximum range of up to 300-400km and up to 19 seats. Existing aircraft of this type currently serve island and shorter-range domestic routes (for example, Highlands and Islands routes in Northern Scotland or the Channel Islands). It makes sense that the first hydrogen aircraft to enter the market will service similar routes and schedules from regional airports. In other words, the first commercial hydrogen aircraft will most likely serve smaller regional airports, so it is these airports that need to prepare for handling hydrogen before other airport types.

At the same time, the specifics of ground operations at many regional airports also lends itself to the use of hydrogen. Namely, that regional airports often rely on predominantly diesel powered GSE fleets, rather than more modern e-GSE or fixed electrical ground power infrastructure found at larger airports. The capacity of connections to the electrical grid are also generally less developed at regional airports, which may also present an opportunity and use case for hydrogen over the use of e-GSE.

3. The Zero Carbon Turn Project

3.1 Overview

The Zero Carbon Turn (ZCT) Project is a collaborative research project led by Exeter Airport, part of the Regional and City Airports Group, with support from Cranfield University, TUI, ULEMCo, Boeing and other leading partners. The project focusses on decarbonising ground-based emissions at an airport using hydrogen, as well as more sustainable fuels.

The ZCT project was split into two main phases; a desk-based study (see Section 3.4) and a demonstration trial phase (see Section 3.5).

3.2 Aim and objectives

Overall, the aim of the project is to:

- Develop awareness and capability around handling hydrogen airside at an airport to support planning and decision making via an airside demonstration of hydrogen powered GSE.

This was supported via fulfilment of the following objectives.

- collect operational data of the use of hydrogen airside to support planning and decision making.
- contribute to the furthering of regulations, standards and procedures for the safe handling of hydrogen at an airport.
- demonstrate the opportunity for hydrogen to support decarbonisation of ground operations via an airside demonstration.

3.3 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
Regional & City Airports	RCA are a leading regional airport operator in the UK, including Norwich, Bournemouth, and Exeter. RCA provided strategic direction for the project, chaired the ZCT Project Steering Committee, and aided with project communication and public relations.
Exeter Airport (Part of Regional & City Airports)	Exeter Airport are 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. In 2024 the airport handled 340,000 passengers. 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, hosted the 'Live demo day'.
TUI	TUI Airways are a major UK leisure airline (4th largest in the UK in terms of passengers carried), operating scheduled and charter flights to Europe, North America, Africa, Asia with a fleet or narrowbody jet aircraft. TUI operate daily from Exeter to a range of European leisure destinations, predominantly in Spain, Greece and Turkey. Specific TUI operations to/from Exeter were identified to be used for the purpose of the trial. The airline provided operational support with regards to planning of aircraft and crew to support the trial.
Cranfield University	Cranfield University a leading UK University specialising in aviation and aerospace teaching and research. Zero Emissions Flight (ZEF) and Hydrogen for aviation representing a c focus for Cranfield, evidenced by high-profile R&D projects with major industry partners, including EnableH2, Project NAPKIN, LH2GT, and OneHEART. Most recently the University has also played an active role in pioneering H2 demnstrations, including Project ACORN (the first hydrogen refuelling trial of GSE at Bristol Airport), and the HIMATT (the first airside pushback of an aircraft using a hydrogen powered vehicle at an airport in the UK, held at Cranfield. Cranfield led work on the desk-based study, strategy and coordination of the trial, as well as writing of the project report.
ULEMCo (ultra low emission mileage company limited)	ULEMCo are a UK firm renowned for pioneering technology that supports the conversion of traditional liquid fuel vehicles to run on hydrogen. They have worked with operators to decarbonise transport emissions from HGVs, LGVs and other utility vehicles. This same approach makes the approach suitable for decarbonisation of airport equipment and GSE.

	ULEMCo provided technical expertise and resource in the conversion of the GPU to a dual fuel diesel/hydrogen powertrain, and provision of their existing hydrogen medium aircraft tow tug (MATT), powered by a hydrogen internal combustion engine (HyICE).
BOEING	Boeing is a major American multinational corporation that designs, manufactures, and sells aircraft, rockets, satellites and missiles worldwide. They are the sole supplier of aircraft to TUI, with Boeing 737-800 aircraft being used during the trial at Exeter. Boeing provided technical guidance for the trial, as well as support for arranging logistics and equipment.
MULAG	Mulag are a leading German manufacturer of specialist solutions for airport ground support equipment. Their H2 fuel cell baggage tractor was the first to be trialled at Hamburg Airport in 2019, and subsequently at Bristol Airport as part of Project ACORN. The same vehicle was supplied for use in the current project
Globe	Globe are a GreenTech company based in Stuttgart. They develop emission-free, digitally networked fuel cell systems for industrial applications. Globe supply, maintain and support the fuel cell used in the MULAG baggage tractor.
UK Civil Aviation Authority	The Zero Carbon Turn project formed part of the Civil Aviation Authorities (CAA) Hydrogen Regulatory Sandbox programme, which seeks to support stakeholders in testing hydrogen technologies, identify safety risks, and help develop the regulatory framework to support hydrogen aviation. 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 for the project.

3.4 Desk based study (Phase 1)

In the first phase of the project, a desk-based study was conducted using data provided by Exeter Airport to provide an emissions profile for their GSE operations. Specifically, this included an itemised list of operational GSE at the airport, fuel consumption/mileage/run-time for each piece of GSE over a 12-month period (September 2022 to August 2023), airline schedules and utilisation of GSE by different airlines at the airport. Fuel use for each piece of GSE was then converted to CO_2e, CO_2, CH_4 and NO_2 using the UK Government GHG conversion factors 2023, which are used for company reporting of greenhouse gas emissions in the UK and updated annually. GSE were also categorised according to whether they were used as part of regular aircraft operations and the category of GSE (belt loaders, pushback tugs etc.).

Overall, the study showed that just over 78,000 litres of diesel fuel was used for GSE operations in the 12-month period, which equated to nearly 200 tonnes of CO_2e. The majority of these emissions (61%) were derived from GSE routinely used to service aircraft, while non-aircraft GSE and GSE used upon request (for example, de-icing vehicles) represented 37% and 2%, respectively. Of the various GSE categories, Ground Power Units (GPUs) represented the single largest source of emissions, representing just under 39% of the total and nearly twice as much as the next highest category (Cars used for non-aircraft activities, 20.4%). Ground Power Units provide electrical power to aircraft while they are parked on stand. While preferable to the use of an aircraft's Auxiliary Power Unit, which burns jet fuel while on the ground to provide power, the use of mobile diesel-powered GPUs was identified as a key source of emissions at the airport. While fixed electrical ground power (FEGP) on each aircraft stand negates the need for diesel powered GPUs, but it is not universally available, especially at smaller airports where the use of mobile GPUs is more economical.

Unlike other GSE, which typically are used once per departure with a defined, repeatable action that varies little between carriers (for example, a pushback tug or belt loader), GPU operations (and fuel consumption) are dependent on the duration for which they are utilised. In other words, shorter turnarounds typically led to shorter GPU use (and less fuel use) than an aircraft that remained on the ground for longer periods. Of the other GSE categories, the refuelling vehicle, pushback tug and baggage belt loader were identified as having the most significant emissions profile (see Figure 1).

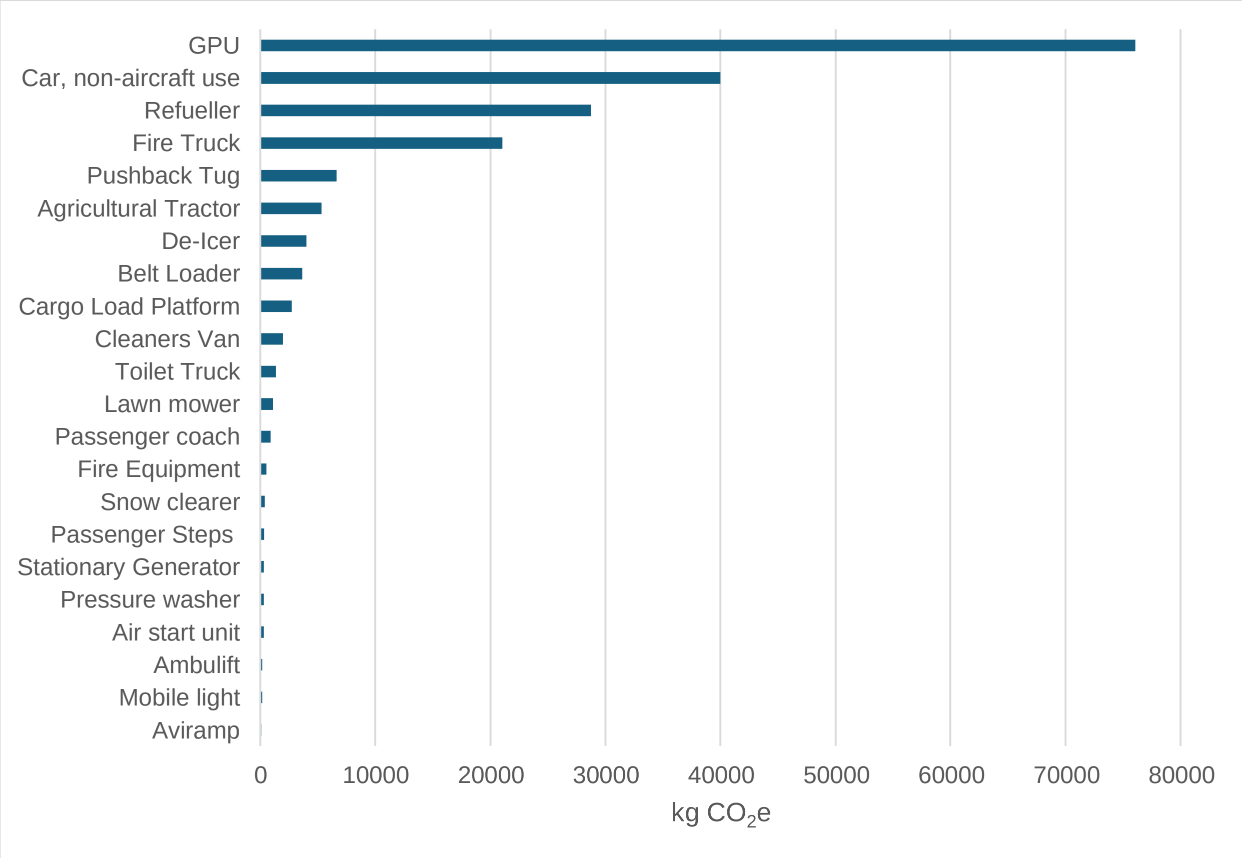


Figure 1: Emissions contributions of GSE categories, Sep 22 to Aug 23 at Exeter Airport

The desk-based study concluded with a forecast of emissions from GSE activity at Exeter to 2034, using growth forecasts provided by the airport. As shown in Figure 2, under a 'business-as-usual, do-nothing' scenario, emissions from GSE activity is forecasted to increase from 211,000 kgCO_2e (211 tonnes) to 293,000 kgCO_2e (293 tonnes) in 2034. This equates to an increase of just over 82,000 kgCO_2e (82 tonnes), or 38.9%.

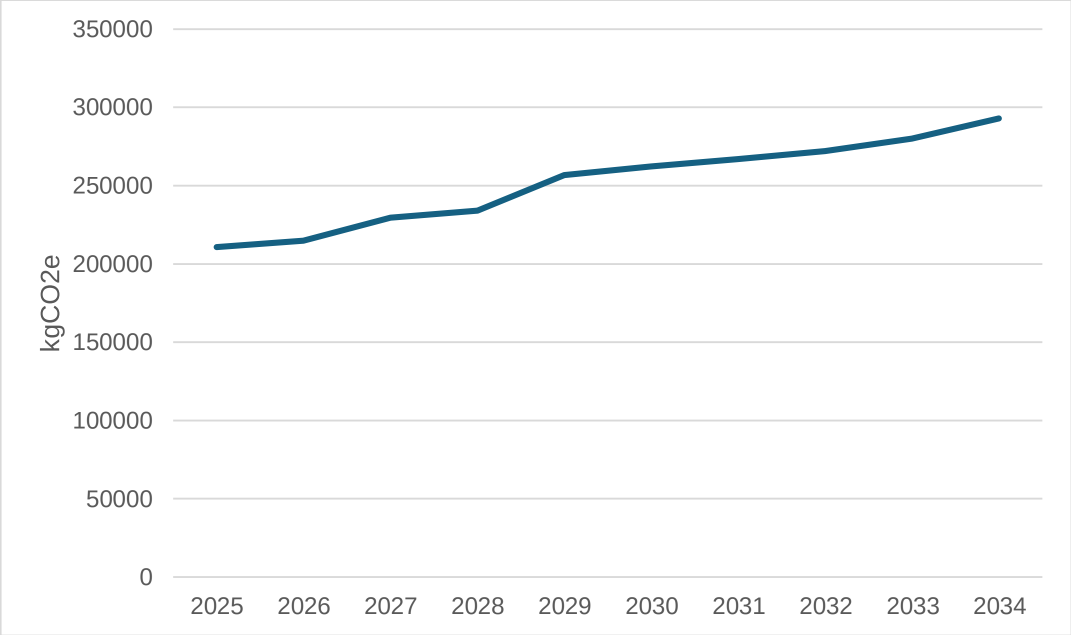


Figure 2. Overall emissions forecasts (kgCO_2e) from GSE activity at Exeter Airport 2025 to 2034 under a 'business and usual-do nothing' scenario.

The results of the desk-based study informed decisions about the design of the physical trial phase, and provided context for assessing the potential impacts (emissions savings) of decarbonising ground-based operations at the airport. Namely, the study highlighted

- The disproportionate impact of emissions from GPUs (and the need to mitigate these emissions).
- The increasing impact of ground-based emissions at airports if left unchecked and without intervention.

3.5 Trial outline (Phase 2)

Following the desk-based study, work in Phase 2 was conducted to plan a series of demonstrations at Exeter Airport, incorporating the refuelling and use of three pieces of H2 powered GSE,

- GPU
- Pushback tug
- Baggage tractor

These demonstrations would be utilised as part of operational aircraft turnarounds at Exeter. These GSE will all be retrofitted vehicles and will showcase different technology pathways for Hydrogen, namely; hybrid dual fuel (hydrogen-diesel) for the GPU, hydrogen internal combustion for the pushback tug, and hydrogen fuel cell configuration for the baggage tractor. The purpose of this approach was to demonstrate the varying pathways for decarbonisation of GSE using various hydrogen technologies, to generate specific learnings about the use of these technologies (relative merits, specific considerations, comparisons with traditional technologies), and to collect operational data for use in the future desk-based studies.

Further, the demonstrations sought to build upon previous demonstrations and projects using H2 GSE at airports in the following ways, which aimed to advance knowledge and the case for introduction of hydrogen at airports.

- The first time that multiple pieces of H2 fuelled GSE had been used simultaneously and in combination to support an operational turnaround at an airport.
- The first time an H2 fuelled vehicle (the GPU) had been physically connected to a commercial aircraft at a UK airport.
- The first time that green hydrogen had been used for a H2 trial at a UK airport.
- The first time a commercial aircraft had been pushed back using a H2 fuelled vehicle.

The trial was planned to take place for a duration of 1 working week (5 days) in the Autumn of 2024. This was later re-arranged to the Spring of 2025, as described in Section 5.

4. Hydrogen technology and equipment

The Zero Carbon Turn Project required the use of H2 equipment and technologies across the supply chain; from production and distribution to storage, refuelling and end-use. Details of this is shown schematically in Table 1 below, and in the following sections.

Table 1. Hydrogen supply chain, equipment and technologies relevant for the purpose of the trial

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.	HyQube 350 refueller	GPU (hybrid) Pushback tug (H2 ICE) H2 Baggage tractor (H2 fuel cells)
				  

Images: for illustration purposes only

4.1 Production and Distribution

The trial employed the use of gaseous hydrogen only. This was produced, stored and transported to Exeter by an external supplier. The supplier was selected on the basis that they could supply green hydrogen (i.e. derived via electrolysis using renewable energy, as opposed to grey hydrogen which uses natural gas a feedstock), and the location relative to the airport (to minimise emissions from transport and delivery costs).

Calculations were made regarding the forecasted use of hydrogen for the trial period using published data and results from previous hydrogen trials and tests undertaken by the project partners. Subsequently, 2 MCPs each containing approximately 16.7kg of hydrogen were acquired (33.4kg in total), for a period of two weeks.

The production facility from where the hydrogen was acquired is accredited to ISO14687 Type 1, Type II Grade D specification, as per hydrogen test report Ref. D240724 PG H2 DT RGC12071 A, issued on 23rd Sep 2024. This standard assures the minimum quality characteristics of hydrogen fuel for various applications, with Type 1 Grade D referring to hydrogen for use in PEM fuel cells in on-road vehicles, requiring high purity hydrogen (equivalent to 99.99% purity).

The MCPs were delivered to Exeter Airport on a delivery truck. This required the use of a forklift truck certified to lift a maximum of 2 tonnes (already located at the airport) to lift the MCPs from the delivery vehicle into position. This reduced delivery costs compared with delivery from a ‘HIAB’, or crane mounted truck.

As the delivery vehicle needed to go airside at the airport to unload the hydrogen, it was necessary to gather information about the delivery vehicle (make and registration) prior to the delivery date. It was also necessary for the driver to bring photographic identification (valid passport or driving licence) with them on the day of delivery so they could access the controlled airside area. On the day of the delivery, EXT provided a short security and safety brief to the driver of the delivery vehicle prior to going airside, and then provided an escort to and from the delivery location. A member of the Exeter airport team then unloaded and positioned the MCPs with the forklift.

4.2 Storage

The hydrogen was stored in the two MCPs at EXT in the designated area adjacent to Hangar 10 and Stand 7, as shown in the annotated Figure 3 below. The site was selected to be practicable in terms of access, suitable for access and power supply (for the HyQube), away from an active operational area and as remote as practicable from potential hazards, other aircraft and buildings (see further discussion in Section 5.2, Risk Assessment.

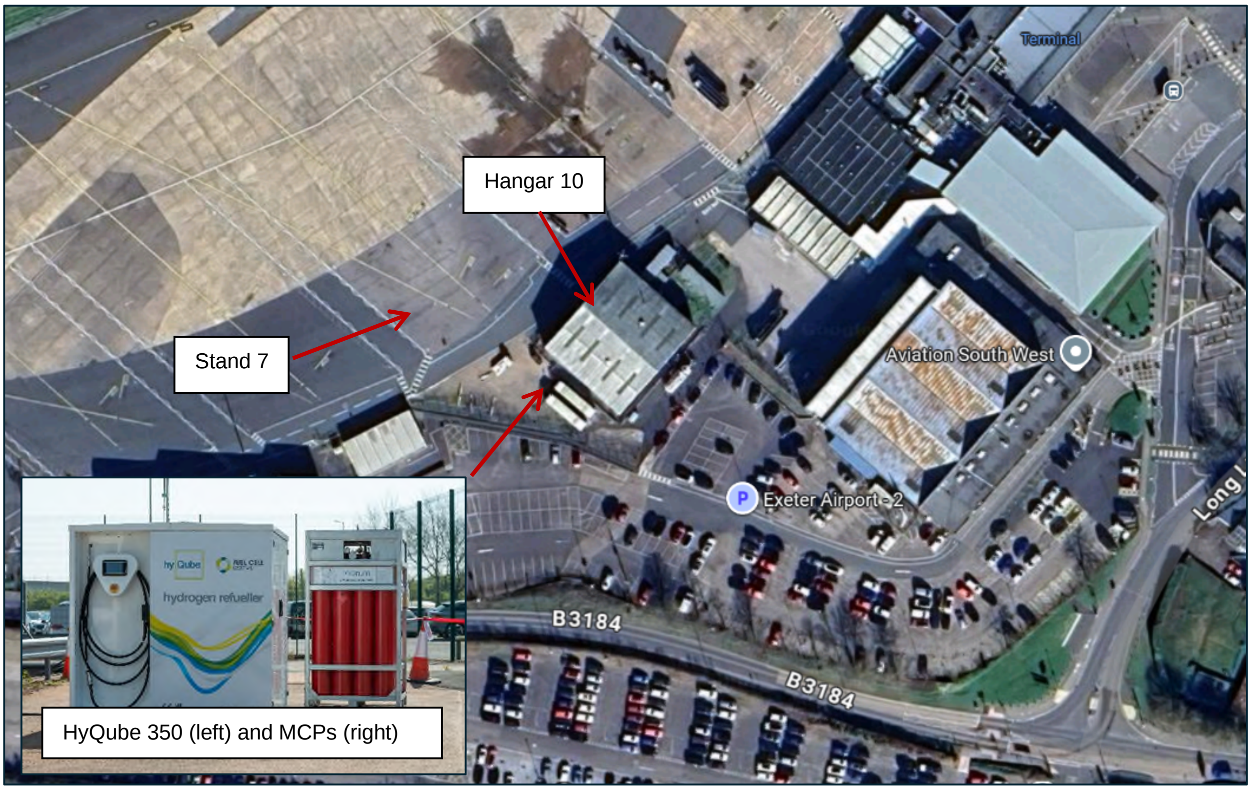


Figure 3. Location of MCP storage and HyQube 350 during trial (Source: annotated image from Google Maps)

4.3 Refuelling

Refuelling of the three H2 powered GSE was undertaken by using Fuel Cell Systems' HyQube 350 refueller (Figure 3).

The refueller is a modular, semi-permanent solution with a compact design and high energy efficiency, which made it highly suited to this trial. The unit used during the trial is the same unit that has been deployed at Cranfield University since 2021, and the same model as the one used for the ACORN project at Bristol Airport. The specifications of the HyQube 350 are shown below (Table 2).

Table 2. HyQube 350 specifications and requirements

Dimensions	1.8 x 1.8 x 1.8 m	
Hydrogen compressor	Fully integrated	
Electrical requirement	32A 400V 50Hz 3P+N+E	Connection to be made using commando socket – must be 5 pin variant with neutral and earth.
Hydrogen inputs	3	
Storage connections	0	
Min/Max input	90 bar/350 bar	Supply hose standard lengths are 5m or 10m with Staubli HCB quick connect for connection to the HyQube and a BS no.4 for connecting to an MCP.
Filling nozzle options	350 bar	
Earth connection	max 0.1 Ohm resistance	M12 threaded brass rod provided as connection point on the HyQube.
ATEX	Clear space above the HyQube	There is an ATEX zone 1m above the HyQube at the vent outlet (1.6m radius, 11m tall).

4.4 End-use

The ZCT project utilised three pieces of hydrogen fuelled GSE. Uniquely, each of these operate with a different powertrain and configuration, representing the three main ‘pathways’ for adoption of hydrogen at airports.

4.4.1. Hydrogen Internal Combustion Engine (HyICE) Medium Aircraft Tow Tug (MATT)

The HyICE is a converted Schopf F59 aircraft tow tug converted to run on a novel series-hybrid powertrain with a hydrogen engine (see Figure 5). The conversion was conducted prior to the start of the project by ULEMCo as part of the ZeHYDA Project (Zero Emissions Hydrogen Demonstration in Airport applications at RAF Leeming and Teesside International Airport).

Figure 5. Hydrogen Internal Combustion Engine (HyICE) Medium Aircraft Tow Tug (MATT)

The specifications and performance of the tug remain the same as the conventional diesel-powered version, with the following exceptions (see Table 3).

Table 3. HyICE MATT specifications (differing from base F59)

Item	Specification	Compliance
HyICETM Powertrain Including:		
Zero-emission Modified Ford 3.3L V6 engine	· output 18kW · constant speed 3000rpm	
Advanced Electric Machines HDSRM300	· 325Nm peak Torque as motor 65 kW · continuous rated power 90% efficiency · as a generator at 3000rpm	BS EN 60068-2-64 (vibration) BS EN 60068-2-27 (shock) ISO 16750-3 (vibration and shock tests) BS EN 60068-2-1 (cold temperatures) BS EN 60068-2-2 (dry heat) BS EN 60068-2-30 (damp heat cycle) • BS EN 60529 (ingress dust) • BS EN 60529 (ingress water IP67)
Semikron SKAI2HV Inverters		IEC 62477-1(2012-07)
High C rate 16kWhr, 450VNom battery module		
Electronic control Unit (ECU)		ISO 9000 / ISO 9001 ISO 26262
Braking system	· Regenerative (in conjunction with existing hydraulic service brake)	See AEM above
Hydrogen containment	· Roof mounted 2 x 94L Type III 350bar Hydrogen Cylinders, approximately 5kg H2 capacity	EC79.2009
Refuelling Nozzle	· WEH® Receptacle TN1 H_2 35 · MPa	EC70.2009 SAE J2600:2002
HMI	· Murphy Gauge PV450	Electromagnetic Compatibility: 2004/108/EC J1113/2, 4, 11, 21, 26 and 41 EN61000-6-4 • EN 61000-6-2
Electrical Charging	· 240V	
Dimensions	· (H) 2.6M	

In March 2024 the tug was employed at Cranfield University as part of the Hydrogen Innovation Initiative Medium Aircraft Tow Tug (HIIMATT) trial, where the tug was used as part of a simulated push back of the National Flying Laboratory (NFLC) SAAB 340b in the Ground Operations Laboratory.

As part of the Zero Carbon Turn project, the tug was used to move TUI aircraft (exclusively 737-800's) to and from aircraft stands and the taxiway and to re-position aircraft between stands. This was conducted while the aircraft were empty (no passengers, baggage, and minimal fuel onboard). Engineers were on board the aircraft to 'ride the breaks', in the case of needing to take control in the event of a malfunction or emergency.

4.4.2 Hydrogen dual-fuel GPU (HyGPU)

The HyGPU is a converted Houchin 690 LS393 ground power unit (GPU) owned and operated by Exeter Airport (see Figure 6). The conversion of the vehicle was conducted by ULEMCo and funded by the Connected Places Catapult via the Transport Research Innovation Grants (TRIG) programme.

The GPU was used to power the onboard electrical systems (lighting, air conditioning etc) on the TUI aircraft during the trial. The hydrogen was stored in a 'Portabull' unit (the green unit shown in Figure 6), which connects directly to the GPU when in operation. The Portabull has a maximum capacity of 7.2kg of hydrogen at 350 bar.

Figure 6 The HyGPU and Portabull in position on Stand 7

The system allows Hydrogen to replace a percentage of the diesel fuel in a diesel engine. The engine always starts and warms up on 100% diesel, 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) and depends on requested engine torque output and engine speed. If the Hydrogen supply is interrupted for any reason, the engine will revert to 100% diesel operation with no change to the operation or performance of the unit. For the purposes of the project, this means that the GPU could remain in use at Exeter in the weeks prior and beyond the trial week running on diesel 'as normal'. By the same token, this means if and when hydrogen becomes available permanently at the airport, the GPU can be utilized with hydrogen again.

While the operation of the GPU entails a degree of CO_2 emissions, and hence should be considered a 'lower carbon' alternative rather than a truly 'zero carbon' option, it presents the most flexible and lowest cost conversion option of the three GSE used in the trial.

4.4.3 Hydrogen Fuel Cell Baggage Tractor (HBT)

The Hydrogen Fuel Cell Baggage Tractor (HBT) is a hydrogen fuel cell variant of the Comet 3 towing tractor, manufactured by MULAG, a major global supplier of airport GSE (Figure 7).

Figure 7 Hydrogen Fuel Cell Baggage Tractor (HBT)

The HBT was used to load, transport and unload passenger baggage at Exeter during the trial. It is powered with a GLOBE XLP80 hydrogen fuel cell system. The fuel cell utilises a stack of individual proton-exchange membrane (PEM) fuel cells. Once in operation, the fuel supply valve on the hydrogen storage tank opens and hydrogen is fed into the anode of the fuel cell. Here, the hydrogen molecules are split to produce protons (H^+) and electrons (e^-). The protons pass through the electrolyte towards the cathode, whilst the electrons pass through an external circuit to generate electricity. This electricity is supplied to the battery to power the electric motor of the vehicle. At the cathode, surrounding oxygen reacts with the protons and electrons to produce water (H_2O), which is the only by product of the reaction. This excess water is captured and stored in a tank in the back of the HBT.

Overall, the system contains a hydrogen storage tank, a fuel cell fuel cell stack, a battery, an air filter, and a water tank. These are located and housed inside a 15 mm thick stainless-steel case and installed in the centre of the vehicle.

The other key specifications of the HBT are shown below in Table 4.

Table 4. Hydrogen Fuel Cell Baggage Tractor (HBT) specifications

Specification	Value
Maximum Power	70 kW (for 5 seconds) / 35 kW (for 300 seconds)
Continuous Power	9 kW
Maximum Speed	30 km/h
Maximum Efficiency	63%
Hydrogen Tank Material	ISO 9809-1 Certified Stainless-Steel
Hydrogen Tank Quantity	1.631 kg
Hydrogen Pressure	350 bar
Hydrogen Temperature	15°C
Refuelling Time	< 3 minutes at 350 bar
Battery Type	Lithium Nickel Manganese Cobalt (NMC)
Battery Energy Storage Capacity	11.88 kWh
Fuel Cell System	1,880 kg
Fuel Cell System Dimensions	102.5 x 85.2 x 75.9 cm
Dimensions and weight	
Length	3.18 metres
Width	1.32 metres
Height	1.92 metres
Dead weight (inc. fuel)	4,000kg
Ground clearance	130mm

5. Safety and Approvals process

5.1 Regulatory context

At the present time there is no comprehensive regulatory framework covering hydrogen production, transportation and storage. Nor are there specific frameworks and regulations governing the use of hydrogen for aviation, given the novelty of the technology. As with the small but growing number of other trial activities involving hydrogen at airports, it was necessary to consider and draw insight from fragmented and piecemeal legislation and standards from a variety of sectors where hydrogen is already more established.

Specifically. the trial planning was guided by, and demonstrated compliance with, the following regulations and standards relating to the storage and handling of gaseous hydrogen.

BS ISO 14687:2019 Hydrogen Fuel Quality

The standard specifies the minimum fuel quality characteristics of H2 fuel distributed for vehicular and stationary applications. Namely, that fuel cell grade hydrogen (for use in the MULAG) requires higher purity hydrogen of 99.999% purity. This will be used for the MCP fuelling the MULAG (fuel cell) baggage tractor and HiiMATT tug.

BS EN 17127:2020 Outdoor hydrogen refuelling points dispending gaseous Hydrogen and incorporating filling protocols

The standard specifies the minimum requirements to ensure the interoperability of hydrogen refuelling points, including refuelling protocols that dispense gaseous hydrogen to road vehicles (e.g. Fuel Cell Electric Vehicles) that comply with legislation applicable to such vehicles. Compliance with this standard ensures that the refuelling equipment and process used for the demonstrations is suitable and safe for the three pieces of equipment being used.

NFPA 2 – Hydrogen codes, Ch7

This code provides fundamental safeguards for the generation, installation, storage, piping, use and handling of hydrogen in compressed gas (GH2) form or cryogenic liquid (LH2) form. The proposed activity was guided by compliance with GH2 requirements, namely;

- Minimum separation distances of activity from stored hydrogen.
- An emergency plan including hazard identification and labelling, emergency procedures is in place and available in case of an incident, including lists of personnel designated and trained in using the equipment.

BCGA CP33. Bulk storage of gaseous hydrogen

The code refers to safe storage of bulk (i.e. large) quantities of hydrogen. While the relatively small quantities of hydrogen used for the proposed demonstrations would not typically be considered large enough to be considered as 'bulk' storage, the more stringent codes were adhered to ensure safe operations. Namely;

Location of hydrogen installation - Where fencing is provided the minimum clearance between the fence and the installation shall be 0.6 m to allow free access to and escape from the enclosure in the case of an emergency. Timber or other readily combustible materials should not be used for fencing. The height of the fencing should be at least 1.8 m for reasons of security.
Any gates should be outward opening and wide enough to provide for an easy access and exit of personnel.

In lieu of established aviation regulation on handling hydrogen, demonstrating compliance with this regulation was key in supporting the CAP791 application to the CAA, described in the following section.

5.2 CAP791- Procedures for changes to aerodrome infrastructure

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.'

Subsequently, an application for CAP791 approval was prepared by the consortium and submitted to the CAA on 19th December 2024. This included the following documentation, as shown in Table 5 below:

Table 5. Documentation submitted for CAP791 application

Document/information	Description
SRG2011 Application of Proposed Change at a UK Certified Aerodrome form	Overall application form covering the CAP791 application, submitted and signed by the accountable manager at Exeter Airport.
Airfield Safety Plan (Doc no: CIMS/EX/AO/6/2024)	A document to summarise the project and the impact of the activities on the operational condition of the aerodrome. It considers as guidance GM AMC ADR.OPS.B.070 and the actions and/or mitigation measures that were adopted to maintain aerodrome safety.
RA8365	Risk Assessment covering the operation of the HyGPU.
RA8366	Risk Assessment covering the operation of the HyICE MATT.
RA8384	Risk Assessment covering the handling and operation of the H_2 MCPs.
RA8385	Risk Assessment covering the operation of the HBT.
RA8483	Risk Assessment covering the handling and operation of the HyQube.
TUI RA 20241129	Risk assessment/Management of Change documentation prepared by TUI relating to the use of H2 equipment for their aircraft.
H2ICED DF Training Booklet (HyGPU)	Training booklet prepared by ULEMCo for operation of the HyGPU.

Following review of the application by the CAA and a subsequent request for clarification and additional information, two further documents were submitted by the consortium, in addition to a revised Airfield Safety Plan (see Table 6 below). The CAP791 application was then approved by the CAA on 17th January 2025.

Table 6. Additional documentation submitted for CAP791 application, following initial review.

Document/information	Description
Operational Prompt 1122- Electric Hybrid Vehicles	Hazard/Risk information and control measures for electric and hybrid vehicles, prepared by and for Exeter Airport Fire and Rescue Service.
Cylinders- aide memoir	Hazards, Risks, Actions and Considerations relating to pressurised gas cylinders, prepared by and for Exeter Airport Fire and Rescue Service.

5.3 Safety Case and Risk Assessments

The safety assessment for the ZCT project required project and equipment specific risk assessments to be produced and submitted as part of the overall CAP791 application (see Section 5.1).

Understanding lessons learned from previous trial activities and partners with a history of handling of hydrogen was identified as key to helping develop the safety case for the ZCT project. However, it should be noted that these previous trials or activities were required to submit a CAP791 application, as was the case here.

5.3.1 Lessons from previous hydrogen trials and activities

Project ACORN- In March 2024, Project ACORN (led by easyJet) undertook the first airside refuelling and operation of hydrogen GSE at Bristol Airport. Cranfield University and MULAG were both consortium partners in the ACORN project and could bring knowledge and lesson from the ACORN project directly to the current work. Specifically, the continuity of equipment being used (HyQube 350, H2 MCPs and MULAG HBT) were relevant for the current work. Members and partners from the ACORN project not involved with ZCT were also contacted on an ad hoc basis regarding elements of the safety case preparation and were helpful in providing insights and advice.

Hydrogen Innovation Initiative Medium Aircraft Tow Tug (HIIMATT) - In March 2024, ULEMCo and Cranfield University collaborated to design and deliver the first airside pushback of an aircraft using a hydrogen fuelled vehicle. This involved the use of the HyICE MATT (used here for ZCT) to conduct a simulated pushback of the National Flying Laboratory Centre (NFLC) SAAB 340B aircraft in the Ground Operations Laboratory at Cranfield. The risk assessments and safety case prepared for this trial was directly beneficial to the preparation of the risk assessments for ZCT, given the continuity of the equipment being used.

Cranfield University - Cranfield University have hosted and operated a HyQube 350 (indeed, the same one used at Exeter for the ZCT trial) and hydrogen MCPs since 2021. This activity required a safety case and risk assessment to be prepared and approved, which again were directly beneficial for the preparation of the safety case for this project.

5.3.2 CAA

The CAA provided useful insights to the safety case development via their oversight as part of the CAA Hydrogen Challenge- Sandbox process. This took the form of engagement at regular project consortium and planning meetings, including specialists from the CAA inspection teams.

5.4 Risk Assessment

While separate risk assessments were prepared for each piece of equipment used in the trial, there were areas of commonality across the various activities with regards to risk and hazard mitigation, which are summarised below in Table 7.

Table 7. Risk assessment categories and control measures

Risk	Control Measures
Hydrogen Leak.	Trial conducted in an external environment only Training of staff Storage and flow of Hydrogen complies with EC R79/UNR134 Sensors and automatic shut off/venting if a leak is detected.
Ignition of leaking hydrogen.	Potential sources of ignition minimised by placing and operating equipment in a controlled area, outside and as far as practicable from other equipment and infrastructure. Sensors and automatic shut off/venting if a leak is detected. DSEAR 2002 regulations referred to as guidance.
Explosion	In built safety features and detection sensors on equipment. Limiting the quantity of hydrogen stored and used on-site. Training and familiarisation of staff using the equipment.
Collision with other vehicles, aircraft or equipment.	Hydrogen components/systems on equipment are designed to regulation EC 79/2009 and EU R134/204 ensuring that components are suitable and fit for the lifetime of the vehicle. Low quantities of hydrogen stored on vehicles at any one time. Vehicles will be operated only by trained personnel holding an airside driving permit, and/or with an escort. 'Kill-switches' located on equipment to stop the flow of hydrogen in an emergency. A 2m exclusion zone around equipment at all times. Hydrogen tanks are either located away from area likely to be impacted by a collision and/or are protected by reinforced cases.
External fire in location or surroundings.	All equipment located and stored airside with strict regulation and policies regarding minimising sources of ignition (no smoking, vaping etc). Kill-switch/automatic venting of hydrogen if temperature/pressure increase beyond safe limits.
Disconnection of refuelling hose during refuelling.	Breakaway connectors fitted to vehicles will seal immediately upon disconnection of the hose. Only trained and certified users will operate the vehicles.
Collision/interference by guests attending the Live Day	Visitors will be escorted in small groups by trained airport staff and will not be permitted to touch or handle the equipment. A safe exclusion zone will be always kept around the equipment.

6. Trial outline and operations planning

The airside trial took place between Thursday 24th April and Friday 2nd May. Two days were allocated for training (shaded green in Table 8), with one day (Saturday 26th, shaded blue) allocated as a training contingency day in the case this could not be completed due to technical issues with the equipment, crew absences, or very poor weather. Two contingency days were also allocated at the end of the trial week (Thursday 1st and Friday 2nd May) for similar reasons. This plan was shared with ground crew and fire crew at Exeter Airport, as well as with the flight operations team at TUI for dissemination to crew on the affected flights during trial period.

6.1 Equipment delivery and logistics

Delivery vehicles and their drivers were escorted airside when delivering/collecting equipment, and drivers underwent a short verbal safety briefing upon arrival. To ensure this went smoothly, delivery schedules were staggered so only one piece of equipment was due to be delivered on any particular day. This avoided the risk of multiple deliveries arriving at the same time, which would have likely caused delays. Additionally, a pdf was created with basic delivery instructions and key points of contact at Exeter and shared with the companies due to deliver the equipment (see Figure 8.

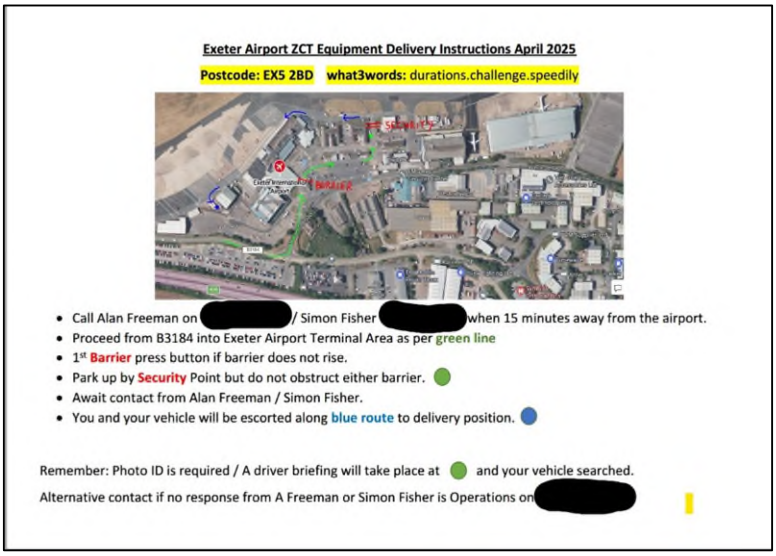


Figure 8. Delivery instructions shared with delivery companies (phone numbers redacted.

Table 8. Trial schedule

Date	Flight number	GSE	Comments
Thur 24 Apr	TOM6462, TOM6463	HYGPU HBT HyICE MATT	Ground Crew Training Day 1 ARRIVAL STAND 7, CONNECT HyGPU MULAG FOR ARRIVALS BAGGAGE, REPOSITION EMPTY A/C FROM STAND 7 TO STAND 5 FOR NEXT DAY DEPARTURE USING TRAINED STAFF ONLY. LESSONS LEARNED RECORD FOR LIVE TRIAL.
Fri 25 Apr	TOM6584	HYGPU HBT HyICE MATT	Ground Crew Training Day 2 MULAG FOR BAGGAGE DELIVERY TO A/C AND A/C STEPS REMOVAL USING TRAINED STAFF ONLY (STAND 5) (POSSIBLE RECONFIGURE HyGPU TO STAND 5).
Sat 26 Apr	N/A	None	Normal operation, training contingency day.
Sun 27 Apr	TOM6700, TOM6701	HYGPU HBT HyICE MATT	ARRIVAL STAND 7 , CONNECT HyGPU , MULAG FOR ARRIVALS BAGGAGE, REPOSITION EMPTY A/C FROM STAND 7 TO STAND 5 FOR NEXT DAY DEPARTURE USING TRAINED STAFF ONLY (TBC DUE STAFF TRAINED AVAILABILITY)
Mon 28 Apr	TOM6170F, TOM6171	HYGPU HBT HyICE MATT	PUSHBACK1 AT 08:30 L WITH NO FUEL AND ENGINEER ONBOARD AND TOW BACK TO STAND 5. PUSHBACK2 AT 09:45 L WITH FUEL AND CREW AND CATERING ONBOARD FOR LIVE DEPARTURE. RECORD WEIGHTS OF AIRCRAFT AND HyICE MATT PERFORMANCE.
Tue 29 Apr (Live Day)	TOM6200, TOM6242, TOM6200	HYGPU HBT HyICE MATT	DEPARTURE STAND 7 , CONNECT HyGPU , MULAG FOR DEPARTURES BAGGAGE, REMOVAL OF DEPARTURE STEPS. PUSHBACK FROM STAND 7
Wed 30 Apr	TOM6334	HYGPU HBT HyICE MATT	MULAG DEPARTING BAGGAGE TO AIRCRAFT. POSSIBLE HyICE MATT PUSHBACK WITH FUEL, CREW, CATERING AND BAGGAGE AND TOWBACK ONTO STAND 5. RECORD HyMATT PERFORMANCE
Thur 1 May	tbc	tbc	Contingency day
Fri 2 May	tbc	tbc	Contingency day

6.2 Flight schedule considerations

Careful consideration was given to selecting which TUI flight operations would be used to test the equipment during the trial and for the Live Day (shaded purple), where guests would be invited to Exeter to witness the demonstration of the equipment in person. A key consideration here was the scheduled length of the turnaround time at Exeter (i.e. how long the aircraft was due to be on the ground before departing). This was critical given that the ‘pushback’ of the aircraft would in reality be a simulated pushback, once all passengers and cabin crew had disembarked and bags removed. The necessity to operate with an empty aircraft ensured that the weight of the aircraft did not exceed the towing capacity of the HyICE MATT. According to Boeing, the Maximum Take-off Weight of a B737 is just under 80 tonnes. The maximum towing capacity of the HyICE is 70 tonnes. Consequently, it was important to select an operation where there would be sufficient time for passengers and crew to disembark, bags to be removed, conduct the push-back of the aircraft from the stand, pull-back onto stand, then load bags, board passengers and crew, and depart on the scheduled departure time.

Consequently, flight TOM6242 arriving from Palma de Mallorca at 1145 and departing to Tenerife at 1325 on Tuesday 29th April was identified as the best candidate for the Live Day demonstration, given the scheduled 1h 40min turnaround time.

7 Training and familiarisation

It was necessary to train the ground crew and personnel at Exeter Airport in the safe operation of the equipment to be used during the trial. To achieve this, a safety briefing and familiarisation sessions were conducted with selected personnel from the airside ground operation team at Exeter Airport in the week prior to the trial. This training was conducted by certified personnel from the respective equipment providers, namely;

Safety Briefing:

Exeter Airport

Training:

HyGPU and HyICE - ULEMCo

HyQUBE 350 (including the MCPs) – Fuel Cell Systems

MULAG HBT – Globe Fuel Cell Systems

7.1 Safety briefing

Before training on each piece of equipment commenced, a general introduction and safety briefing was conducted by the Airport Services Manager at Exeter Airport. This included;

- Introduction and purpose of the trial
- Arrangement and activities for the trial activities
- Key properties of hydrogen relevant to safety
- General hazard mitigation
- Key difference between hydrogen and liquid fuels (both diesel and A1 Jet Fuel).
- Proper use of PPE

After the safety briefing, a short individual assessment consisting of 10 multiple choice questions was held covering the topics from the briefing. Answers were then shared with the group immediately, and any incorrect answers provided were addressed and discussed as a group.

7.2 Training

Following the safety briefing, training and familiarization sessions were held. A specific training syllabus was designed for each piece of equipment, and members of the ground crew were tested regarding their competency for using them in a safe manner (example, see Figure 8). The training included a general introduction and overview of the main components and configuration, operation, and key safety features. The training concluded with a supervised operation where each member of the team used the equipment under close supervision by the training lead.

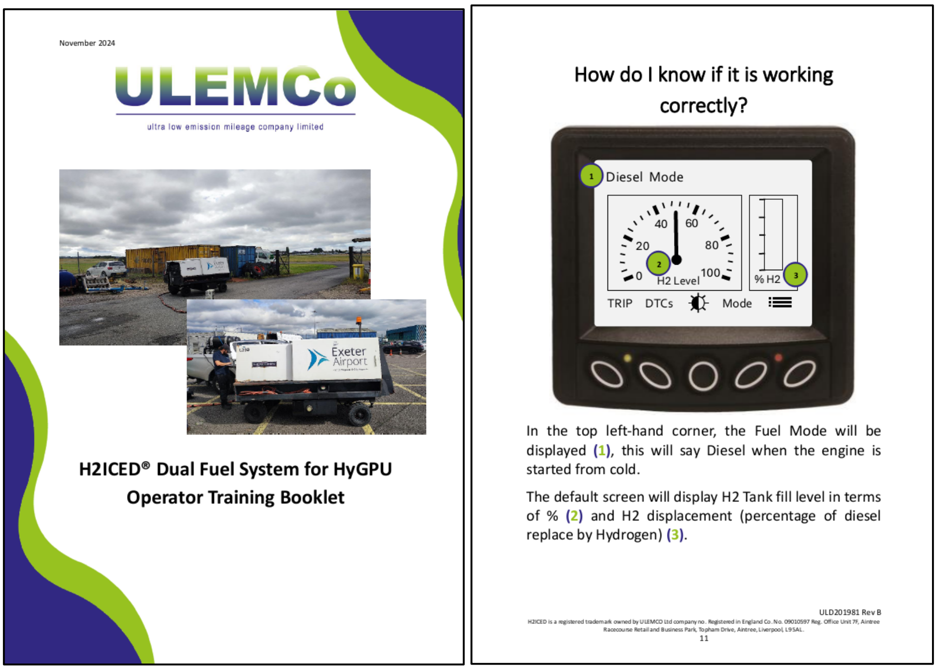
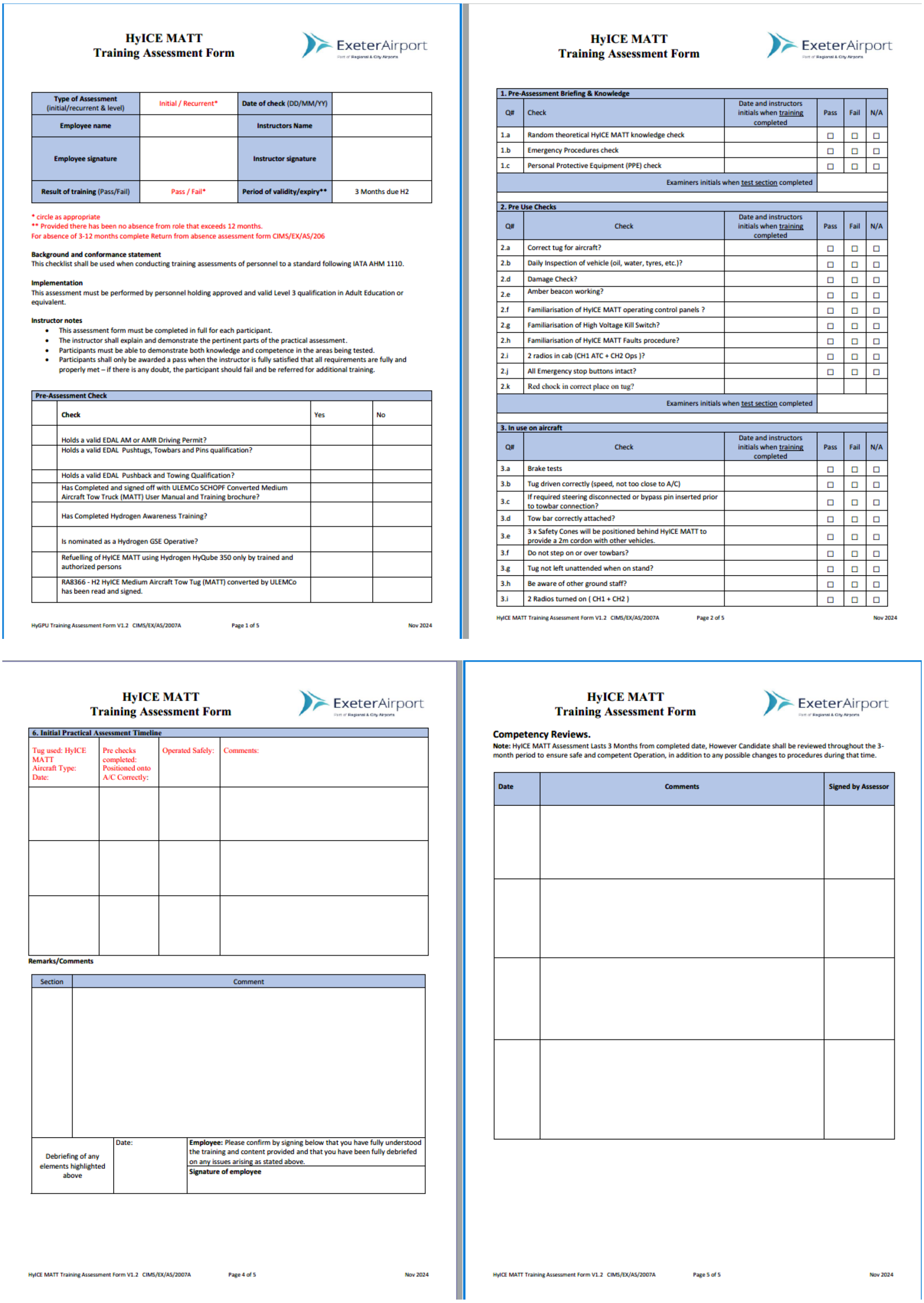


Figure 8. Example of training booklet provided by ULEMCo for operation of the HyGPU.

Figure 9. Training and familiarisation of the 'Portabull' (left) and HyQUBE 350 (right)

Formal certification for completion of the training was conducted via a signed physical and digital certificate for each individual. Only personnel who have completed and passed both the safety briefing and training for each piece of equipment were permitted to operate them during the trial. Additionally, only team leaders were authorised to operate the HyQUBE350 and conduct the refuelling process, given the increased complexity and safety implications of this activity. Extracts from the training assessment form used for the HyICE MATT is shown below in Figure 10.



HyICE MATT
Training Assessment Form

Type of Assessment (initial/recurrent & level)	Initial / Recurrent*	Date of check (DD/MM/YY)	
Employee name		Instructors Name	
Employee signature		Instructor signature	
Result of training (Pass/Fail)	Pass / Fail*	Period of validity/expiry**	3 Months due H2

* circle as appropriate
** Provided there has been no absence from role that exceeds 12 months.
For absence of 3-12 months complete Return from absence assessment form CIMS/EX/AS/206

Background and conformance statement
This checklist shall be used when conducting training assessments of personnel to a standard following IATA AHM 1110.

Implementation
This assessment must be performed by personnel holding approved and valid Level 3 qualification in Adult Education or equivalent.

Instructor notes

- This assessment form must be completed in full for each participant.
- The instructor shall explain and demonstrate the pertinent parts of the practical assessment.
- Participants must be able to demonstrate both knowledge and competence in the areas being tested.
- Participants shall only be awarded a pass when the instructor is fully satisfied that all requirements are fully and properly met – if there is any doubt, the participant should fail and be referred for additional training.

Pre-Assessment Check			
	Check	Yes	No
	Holds a valid EDAL AM or AMR Driving Permit?		
	Holds a valid EDAL Pushtugs, Towbars and Pins qualification?		
	Holds a valid EDAL Pushback and Towing Qualification?		
	Has Completed and signed off with ULEMCo SCHOPF Converted Medium Aircraft Tow Truck (MATT) User Manual and Training brochure?		
	Has Completed Hydrogen Awareness Training?		
	Is nominated as a Hydrogen GSE Operative?		
	Refuelling of HyICE MATT using Hydrogen HyQube 350 only by trained and authorized persons		
	RA8366 - H2 HyICE Medium Aircraft Tow Tug (MATT) converted by ULEMCo has been read and signed.		

HyGPU Training Assessment Form V1.2 CIMS/EX/AS/2007A Page 1 of 5 Nov 2024

HyICE MATT
Training Assessment Form

1. Pre-Assessment Briefing & Knowledge					
Q#	Check	Date and instructors initials when training completed	Pass	Fail	N/A
1.a	Random theoretical HyICE MATT knowledge check		☐	☐	☐
1.b	Emergency Procedures check		☐	☐	☐
1.c	Personal Protective Equipment (PPE) check		☐	☐	☐
		Examiners initials when test section completed			
2. Pre Use Checks					
Q#	Check	Date and instructors initials when training completed	Pass	Fail	N/A
2.a	Correct tug for aircraft?		☐	☐	☐
2.b	Daily Inspection of vehicle (oil, water, tyres, etc.)?		☐	☐	☐
2.d	Damage Check?		☐	☐	☐
2.e	Amber beacon working?		☐	☐	☐
2.f	Familiarisation of HyICE MATT operating control panels ?		☐	☐	☐
2.g	Familiarisation of High Voltage Kill Switch?		☐	☐	☐
2.h	Familiarisation of HyICE MATT Faults procedure?		☐	☐	☐
2.i	2 radios in cab (CH1 ATC + CH2 Ops)?		☐	☐	☐
2.j	All Emergency stop buttons intact?		☐	☐	☐
2.k	Red chock in correct place on tug?				
		Examiners initials when test section completed			
3. In use on aircraft					
Q#	Check	Date and instructors initials when training completed	Pass	Fail	N/A
3.a	Brake tests		☐	☐	☐
3.b	Tug driven correctly (speed, not too close to A/C)		☐	☐	☐
3.c	If required steering disconnected or bypass pin inserted prior to towbar connection?		☐	☐	☐
3.d	Tow bar correctly attached?		☐	☐	☐
3.e	3 x Safety Cones will be positioned behind HyICE MATT to provide a 2m cordon with other vehicles.		☐	☐	☐
3.f	Do not step on or over towbars?		☐	☐	☐
3.g	Tug not left unattended when on stand?		☐	☐	☐
3.h	Be aware of other ground staff?		☐	☐	☐
3.i	2 Radios turned on (CH1 + CH2)		☐	☐	☐

HyICE MATT Training Assessment Form V1.2 CIMS/EX/AS/2007A Page 2 of 5 Nov 2024

HyICE MATT
Training Assessment Form

6. Initial Practical Assessment Timeline			
Tug used: HyICE MATT Aircraft Type: Date:	Pre checks completed: Positioned onto A/C Correctly:	Operated Safely:	Comments:

Remarks/Comments

Section	Comment	
Debriefing of any elements highlighted above	Date:	**Employee:** Please confirm by signing below that you have fully understood the training and content provided and that you have been fully debriefed on any issues arising as stated above. **Signature of employee**

HyICE MATT Training Assessment Form V1.2 CIMS/EX/AS/2007A Page 4 of 5 Nov 2024

HyICE MATT
Training Assessment Form

Competency Reviews.
Note: HyICE MATT Assessment Lasts 3 Months from completed date, However Candidate shall be reviewed throughout the 3-month period to ensure safe and competent Operation, in addition to any possible changes to procedures during that time.

Date	Comments	Signed by Assessor

HyICE MATT Training Assessment Form V1.2 CIMS/EX/AS/2007A Page 5 of 5 Nov 2024

Figure 10. Extracts from HyICE MATT training assessment form

8 Airside Trial and Live Day

As mentioned in Section 6.2, a Live Day was scheduled for Tuesday 29th April for invited guests to witness the demonstration at Exeter Airport. The day was organised to incorporate presentations from the project consortia (Figure 11), a 'show-and-tell' demonstration and overview of each piece of equipment (Figure 12), and concluding with viewing of the equipment being used as part of the TOM6242 operation (Figure 13).

Given the demonstrations were airside, guests were asked to bring photo ID (passport or driving licence) with them on the day. Guests were escorted airside by members of the Exeter Airport 'Green Team'. Additional safety provisions were made to ensure that guests remained in a secure and monitored area at all times and could not access other areas of the airfield.

Figure 11. The Live Day commenced with short presentations from the project consortia

Figure 12. Guests were given short demonstrations in small groups

Figure 13. The day concluded with the turnaround of TOM6242

9 Data analysis

Operating and usage data was collected from the equipment employed in the trial for analysis. Additionally, selected qualitative feedback was collected from ground crew regarding their use and experience of the HyICE; this is detailed below.

9.1 HyICE MATT

The HyICE was used on five occasions to move different TUI aircraft off/on stand during the trial period. Since the drivetrain is a series-hybrid, the main source of energy is from the high voltage system, the hydrogen engine is used as a range extender and directly charges the battery. Typically, the engine activated once per pushback, charging the battery from 50% to 60% state of charge. This took between 7.5-8 minutes, the average consumption of the engine is 2.98kg/hour, which equates to 397g per “charge”. This charging strategy is designed to maximise the life of the battery; however, the engine would be more, or less active based on the duty cycle of the MATT.

A summary of the use and consumption of the MATT is shown below. The data shows the average hydrogen consumption as there will be instances where the state of charge does not fall below 50% until part-way through the activity and a full “charge” cycle is not completed.

Average duration of use per activity (min)	**Average H_2 consumption per activity (g)**	**Average H_2 consumption per minute of activity (g)**	**Total H_2 consumed (g)**
9m25	43g	4.7g	215g

Qualitative feedback was also collected from the ground crew following each use of the HyICE. This was conducted so that any issues or challenges could be identified and rectified during the trial, if necessary. The intention was also to allow for any issues to be linked to the quantitative data collected from the specific push-back or activity, in the case that a fault or deviation from normal operations were detected. This was also important to determine how the weight of the aircraft affected the performance of the tug, if relevant. This activity also had the dual benefit of engaging ground-crew in the trial as an important source of data. No major concerns were identified throughout the trial, as shown below in Table 9.

Table 9. Trial schedule and feedback from ground crew

Date	Stand	Trial activity	Comments	Aircraft weight
24/4	7	Arrival Stand 7, connect HyGPU, MULAG for	Noticed slope on departure from 7 but OK when used to	46,084kg

		arrivals baggage, HyICE MATT reposition empty aircraft from Stand 7 to Stand 5 for next day departure.	vehicle. Repositioning to tow required guidance for towbar.	
25/4	7	Arrival Stand 7, Connect HyGPU, MULAG for arrivals baggage, HyICE MATT reposition empty aircraft from Stand 7 to 5.	Stand 7, need to be aware of slope. Two mode used and no problem pulling up the slope.	45,809kg
28/4	5	Pushback at 0800 with no fuel and engineer onboard and two back to Stand 5.	Towed back onto stand without using TOW mode. All ok but driver noticed it needed more power.	42,809kg
28/5	5	Pushback at 0945 with fuel and crew for catering onboard for live departure	No issues encountered.	53,409kg

9.2 HyGPU

Data was collected for the HyGPU during the turnaround on the 28 April as part of the Live Day. This yielded the following results.

Total operating time: 30 minutes

Total H_2 consumed: 213g (426g/hr)

Approx diesel savings: 1.38 L/hr

These figures are lower than were observed during the calibration exercise undertaken prior to the trial (detailed below). Here, the unit was tested under various settings, ranging from 0kW to 60kW, with H_2 consumption recorded for each. From this, it was then possible to calculate the equivalent diesel saving for each setting.

Table 10. HyGPU calibration results

Power (kW)	H2 consumption (g/min)	Equivalent diesel saving (L/hr)
0	17.8	3.46
15	20.3	3.95

30	23.6	4.59
45	21.9	4.26
60	11.2	2.18

Exeter Airport note that GPUs are most commonly operated at 30kW. However, during calibration testing significant speed instabilities were observed when reducing the load from 60kW, with the engine prone to 'hunting.' This issue manifested as unpredictable spikes in the engine's speed (rpm). The issue was due to the older and mechanically driven GPU used in the trial. Newer units tend to be electrically controlled via the engines ECU (Electronic Control Unit). This would have allowed for communication with the hydrogen system to allow for quicker detection and rection to changes in load. The older mechanically controlled systems, as used here, do not allow for this communication and 'hunting' may occur as a result during changes of load.

To counter this problem, a reduction in the quantity of H_2 was applied. While this addressed the problem, it also meant that the ability to use an optimal calibration to maximise diesel displacement was compromised. It is thought that this is a specific issue inherent to the GPU unit, rather than a problem with the dual-fuel conversion process. However, it will be necessary to conduct further tests with the GPU under varying conditions to assess to what extent this is the case, and how issues such as this could be rectified in the future.

9.3 MULAG HBT

The MULAG HBT was in operation between the 23/4 to 30/4. Unfortunately, the telematics data on the tug was found to have been non-operational after the trial had concluded, so it was not possible to determine the total distance covered or number of operations. However, data collected from the fuel cell operation found that the fuel cell was operational for a total of 83 minutes (1h23), and consumed 379g of H_2 (equivalent of 273g/hr).

9.4 HyQube 350 refueller and Hydrogen MCPs

On completion of the trial it was recorded that a total of 4.5kg of hydrogen had been consumed, considerably more than the total H_2 consumed by the equipment during the trial (807g). This is because hydrogen was vented to the atmosphere during the installation, commissioning and for training of the equipment. This is a key safety feature, and hence was demonstrated numerous times. Under 'normal' operating conditions it would not be necessary to operate and demonstrate the equipment in this way, and as such the losses of hydrogen would be reduced.

It is also worth noting that the 4.5kg that were used is still considerably lower than the original 32kg that were ordered. This discrepancy was due both to an overly conservative estimate of how much hydrogen would be needed during the trial, and a lower than anticipated utilisation of the equipment during the trial itself. Data from additional trials conducted over longer periods will be needed to provide clearer estimates of hydrogen consumption in 'real-world' conditions.

9.5 Environmental benefits for ground operations at Exeter Airport

As mentioned previously, hydrogen offers an attractive fuel source for airports to support decarbonisation of ground-based operations. Thus, the final phase of the analysis concerned returning to the desk-based study (see Section 3.4) to estimate the potential environmental benefits if the three GSE technologies showcased here were implemented at the airport permanently.

To achieve this, it was necessary to assume a phased-implementation scenario where diesel GSE was progressively converted to run on hydrogen. This approach recognises that it would be financially and operationally impractical to convert all of the equipment at the same time. Hence, the implementation scenario assumed that;

- 1 diesel powered GPU would be converted to dual-fuel diesel/hydrogen per year from 2026. There are currently 5 GPUs in the fleet at Exeter, meaning all GPUs would be converted by 2030.
- On average, converted HyGPUs would achieve a 20% fuel displacement and saving of CO_2 compared to fully diesel GPUs for the duration of their operation.
- 1 diesel aircraft tug would be converted to run on HyICE per year from 2026. There are 4 tugs in the fleet at Exeter, meaning all tugs would be converted by 2029.
- All baggage tractors remain electrically powered (all baggage tractors at Exeter are currently electrically powered).
- The size of the current GSE fleet remains constant to 2030.
- No other diesel powered GSE are converted to hydrogen or battery electric alternatives (i.e. only GPUs and tugs are affected).
- All tugs and GPUs were operated equally (for example, if 5 GPUs emitted a total of 100kg of CO_2, it is assumed each individual GPU emitted 20kg).

Using these assumptions, annual CO_2 emissions savings were estimated based on the ‘business as usual do nothing’ forecast presented in Figure 2. A summary of this is provided below in Table 11.

Table 11. Estimated emissions savings from H2 GSE deployment to 2030

Year	BAU emissions CO_2 (kg)	Combined annual CO_2 savings (kg)	Combined annual CO_2 savings (%)	Cumulative CO_2 savings (kg)
2026	214,824	4,382	2.04	4,382
2027	229,505	7,022	3.06	11,404
2028	233,978	9,546	4.08	20,950
2029	256,780	10,913	4.25	31,863
2030	262,282	11,146	4.25	43,009

As can be seen, annual CO_2 savings of around 4% can be obtained via gradual implementation and introduction of H_2 into the GSE fleet at Exeter. These figures equate to between 4,000kg (in 2026) and just over 11,000kg (by 2030). Cumulatively, this approach would save just over 43,000kg of CO_2 by 2030. For means of comparison, this figure is slightly higher than the annual CO_2 emissions from the second most polluting category of GSE at the airport (car, non-aircraft use, 39,800kg CO_2). It is worth nothing here that this scenario reflects a situation where no other vehicles are converted or switched to cleaner alternatives; clearly, more rapid integration of clean vehicles into the fleet would yield increased emissions savings.

Equally, greater emissions savings would also be accrued if the rate of diesel displacement of GPUs could be increased or, better still, eliminated entirely. Currently, a 20% displacement of diesel is assumed. Given that GPUs are the largest single source of GSE emissions at Exeter, improving on this would have significant benefits in terms of emissions (i.e. it may be more practical and cost effective to focus on improving the efficiency of GPU emissions, rather than seeking to convert or upgrade other categories of GSE).

10 Key learnings, achievements and next steps

10.1 Key learnings

Overall, the aim of the project was to:

- **Develop awareness and capability around handling hydrogen airside at an airport to support planning and decision making via an airside demonstration of hydrogen powered GSE.**

The project has built important knowledge and developed experience of handling hydrogen at Exeter Airport during the trial, and also with the wider airport community via dissemination of project findings and key learnings after its completion. This activity, combined with the desk-based work, as helped inform decision making at Exeter Airport and added to critical ‘real-world’ experience of handling hydrogen at airports.

This was fulfilled via the following objectives;

- **Develop knowledge and understanding of training and familiarisation of airport ground crew.**

A training and competency programme was developed and delivered to ground crew at Exeter Airport, informed by the desk-based study and previous and ongoing research activities. This will help inform future practice to support both future H2 trials and handling hydrogen at airports in the future.

- **Generation of data sets relating to hydrogen refuelling time, consumption and activity during the trial, relevant for future desk-based studies and planning of trials.**

While valuable data was generated during the trial which will be beneficial to future trials and planning activity, the need for longer and more varied use of hydrogen at airports (and the data this would generate) are needed to provide more detailed and rigorous assessments to support planning and decision-making.

- **Draw learnings regarding safety case development, risk assessment preparation and the CAP791 process.**

The trial provided critical learnings around the CAP791 process, safety case development and safety case development. It will be important to develop a mechanism or platform to share this information and best practice to support other trials and programmes like this in the future. One specific area which we feel would benefit the development of hydrogen trials is an amendment of the current CAA CAP791 process to specially account for hydrogen trials like this. The current CAP791 mechanism does not account for this type of activity (nor was it originally designed to do so), so it is encouraging that the CAA have identified this as an area of priority for future development.

- **Practical and logistical learnings on trial development and delivery.**

As with any activity like this that is conducted for the first time, the practical and logistical learnings are often as valuable as the theoretical or scientific contributions of the project. In this case, the early and clear coordination of the project team meant that the trial ran smoothly overall with only minor interruptions. A focus on developing and sharing clear, practical information and communication was a key factor in the project being a success.

10.2 Key achievements

The project demonstrated novelty in a number of key areas, helping to develop both scientific understanding and applied decision making around how to safely and efficiently deploy hydrogen at airports. Specific firsts and areas of achievement include;

- The first concurrent use of multiple pieces of different hydrogen fuelled equipment at an airport. Previous trials and have been conducted with either one piece of equipment, or multiple pieces of the same type of equipment.
- 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 green hydrogen (produced via electrolysis using renewable energy) at an airport in the UK. Previous trials have used commercially purchased grey hydrogen, derived from fossil fuels, or from other non-green sources. For hydrogen to be considered a sustainable and zero emissions fuels, it is vital that only green hydrogen is used.
- The first application of a hybrid hydrogen/diesel dual-fuel piece of equipment at an airport. While this represent a lower emissions pathway, rather than being fully zero emissions, it does represent a pragmatic and lower cost alternative to reduce emissions from older equipment without the need for expensive or lengthy fleet renewal. As a supporting interim measure or ‘stepping stone’ to fuller hydrogen adoption, this represents an important step.
- 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.

10.3 Next steps

While the success of the project represents an important milestone with regards to handling hydrogen at airports, it has also further highlighted (if it were needed), the significant remaining gaps in understanding. Addressing these many gaps will be needed to help develop the necessary regulatory framework, standards and best practise to support hydrogen adoption at airports. Specific areas to address include, but are not limited to:

Handling of H_2 under different 'real-world' operating conditions.

Existing trials have taken place under tightly defined timelines; usually over the course of a matter of hours or a few days. A longer duration of future trials, or those targeted to occur at specific times, would allow for testing under a variety and operating conditions, including varying weather conditions, ambient temperatures, and during hours of darkness. This is important to build data, knowledge and understanding of using H2 in different 'real-world' conditions, and how the technical performance and related safety aspects may vary. For example, it is well known that charging performance and range of electric vehicles is impaired in very cold weather. 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 to get to temperature, reduced battery performance, or even potentially causing damage to the membranes of fuel cells).

Comparing operational models for storage and refuelling of H2 GSE.

Existing hydrogen trials have focussed on a small-scale static storage of hydrogen on the airfield, with GSE accessing this area when needing to refuel. While this is suitable for small scale operations and under trial conditions, this may prove challenging at scale and/or busier environments. Mobile, on-stand and other concepts could be trialled to optimise operational efficiency and safety. This activity also has value in that it is likely that hydrogen aircraft would be fuelled on-stand in this way (i.e. with a mobile refuelling solution).

Developing a platform for sharing of information and best practice

Throughout the project the consortium has variously sought information, advice and resources from other consortia and organisations who have previously undertaken similar hydrogen trials. Equally, since completing this project, we have been approached by organisations who are now in the process of planning their own hydrogen trials and projects. While initially a small group of organisations and individuals, it is clear that the community of hydrogen airports (or at least airports keen to explore hydrogen) is growing. As such, to ensure coordination of research activity that is additive, rather than repetitive of what has gone before, there is a need for a more formalised community of hydrogen for airports. This will allow for networking and consortia building, as well as sharing of information, practical knowledge and best practice to a wide and engaged audience. This in turn will help support future trials and activities and develop knowledge and practice to support hydrogen adoption. Without this, projects will continue to develop in a largely piecemeal and uncoordinated fashion, with key learnings being shared only with the wider community on an ad-hoc basis or not at all. This would risk failing to capitalise on the good work of trial activities like the current project, and the potential for hydrogen as a zero emissions alternative for the sector overall.