Project Acorn

The UK's First Airside Hydrogen Refuelling and Operational Trial

Project Acorn led by:

easyJet Bristol Airport Jacobs

Summary Report | July 2024

Project Acorn Summary Report

Acknowledgements

Project Acorn Collaboration Partners

easyJet
Bristol Airport
Jacobs
UK Civil Aviation Authority
Cranfield Aerospace Solutions
Cranfield University
DHL
IAAPS Advancing Propulsion
MULAG
TCR

Technical Support

Fuel Cell Systems
Globe

With Gratitude for Support Provided by

Brighton & Hove buses.co.uk
Catapult Connected Places
Hamburg Airport
Hydrogen Innovation Initiative
Hydrogen South West
UKRI

Introduction

> Hydrogen offers huge potential to deliver zero carbon-emission aviation and to be a key enabler of the industry's transition to net zero, as low-carbon hydrogen has no operational CO_2 emissions and low or zero lifecycle CO_2 emissions.

In addition, hydrogen could complement sustainable aviation fuel (SAF) by offering a more energy efficient, and therefore cost effective, aircraft fuel than power-to-liquid SAF (PtL).

Hydrogen technology for aviation is currently in a development phase and there has been rapid progress over the past five years, for example with Rolls-Royce's hydrogen engine demonstrator, the Airbus ZEROe programme, and ZeroAvia successfully flying a retrofitted aircraft with a hydrogen propulsion system. However, to progress from where the industry is today to commercial flight at scale, a strong vision and clear plan is needed. The Hydrogen in Aviation Alliance (HIA) Milestone Delivery report, "Launching Hydrogen-Powered Aviation", recently outlined the steps that government and industry need to take to deliver this transition.

Hydrogen-ready technology
Enable the transition from research to development, and ultimately industrialisation, of world leading hydrogen propulsion and aircraft technologies in the UK

Hydrogen-ready CAA
A regulator that is well-funded and resourced, with the capacity to lead on certification, standard-setting and new regulation

Hydrogen-ready airports
A well-developed network of hydrogen-ready airports both in the UK and overseas

Transition fund and incentives
The support and incentives needed to get the sector over the hurdle of transition costs and investment in new infrastructure

Delivering aviation's hydrogen requirements
Ensuring that we can secure sufficient hydrogen for all sectors that need to decarbonise, including aviation

Hydrogen-ready skillsforce
Building the hydrogen skills needed to support the transition to this new technology

Figure 1: Hydrogen in Aviation — proposed changes across the aviation ecosystem

A key gap identified was the lack of any regulatory framework or operational guidance on the use of hydrogen at airports, with the critical path being hydrogen storage and refuelling in the restricted and highly regulated airside environment. Aviation hydrogen projects in the UK currently require navigation of fragmented legislation and regulation, as existing rules and policies were enacted before the emergence of hydrogen as a realistic fuel source, even though hydrogen has been regulated and used safely across different industries nationally and internationally for decades. These findings and the ambition to develop a regulatory framework for hydrogen's use in aviation led to the formation of Project Acorn.

Project Acorn involved a cross-sector collaboration of experts from across the aviation value chain and academia. The project set out to gather data and acquire knowledge to support establishing the first industry standards and procedures for the safe airside use of hydrogen. In particular, the project required CAA clearance for airside refuelling, which is a key requisite for the progression of hydrogen use in aviation. The project culminated in the airside trial at Bristol Airport in March 2024, which tested the use of a hydrogen baggage tractor within easyJet's daily operation. A video explaining the trial in more detail is available here.

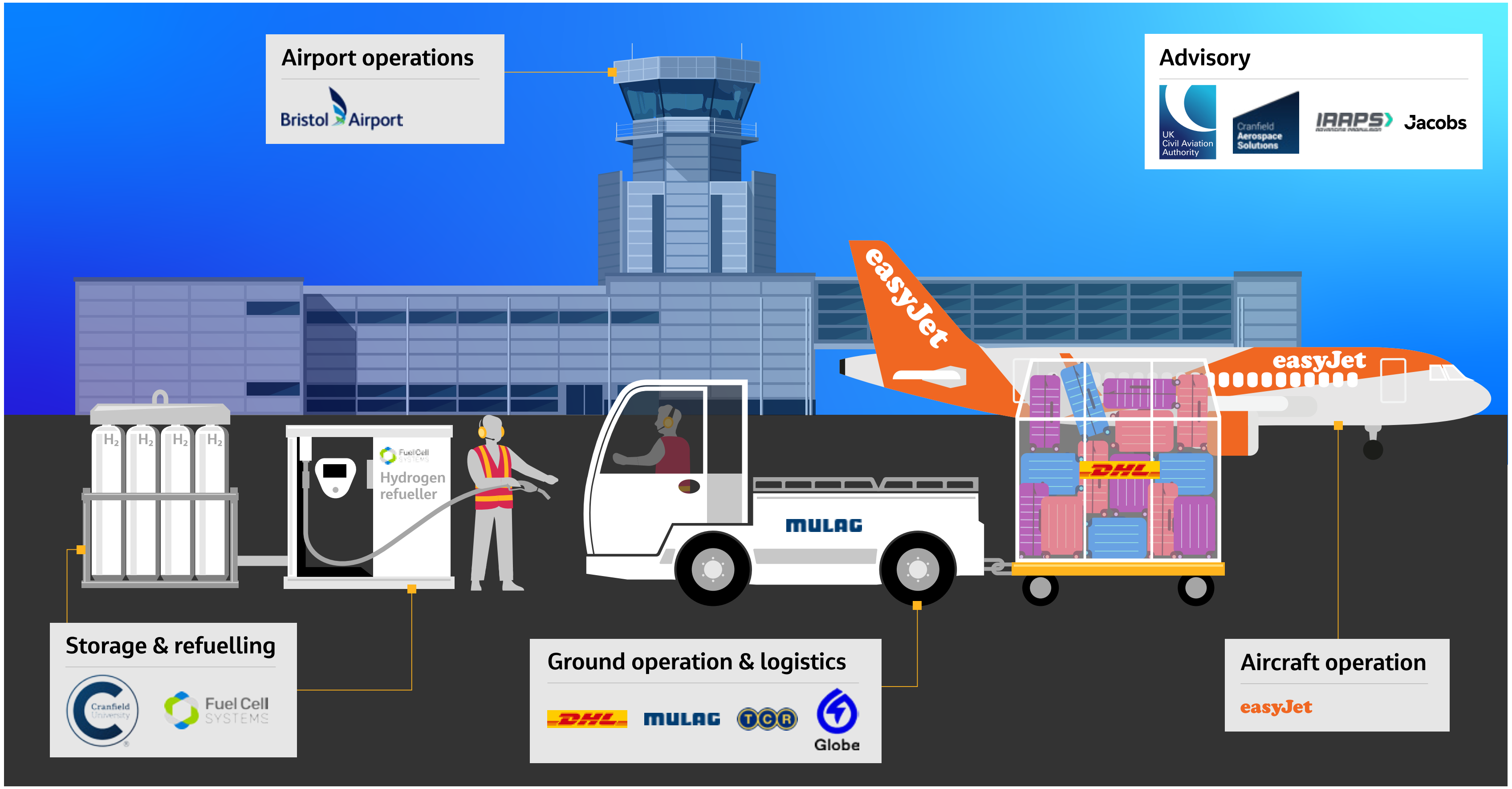
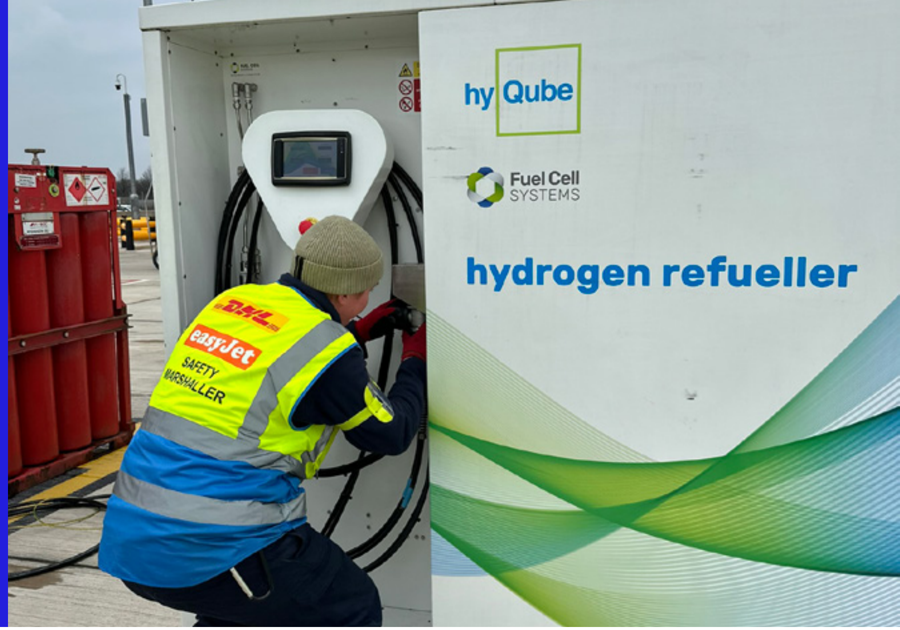


Figure 2: Project Acorn cross-sector industry and academia collaboration



Safety considerations

Safety is the number one priority for the aviation industry, and while there are risks handling hydrogen in an airport environment, in its daily operation the industry is well versed in safely managing substances such as jet fuel, natural gas, and hydraulic fluids. However, as hydrogen as a fuel is new to the aviation industry, the specific risks must be understood and mitigated to ensure that any residual risks are reduced to acceptable levels, and aligned with existing aviation safety and operational frameworks. Due to its small molecular size, hydrogen presents specific challenges, as risks materialise differently to other commonly used substances in aviation. To ensure the safe operation of Project Acorn, a detailed safety assessment was undertaken and is outlined later in this report.

Hydrogen property	Associated risks	Advantages over other gaseous fuels
Lighter than air	Propensity to leak, which may lead to ignition and/or explosion	Rises and disperses rapidly. Fire consumes itself faster than other fuels
Very low ignition energy and fast detonation	Propensity to ignite and explode	Higher oxygen requirement for explosion
High flame temperature and wide flammability	Propensity to ignite and explode when mixed with oxygen	Fire consumes itself faster than other fuels

Figure 3: Properties of hydrogen

Trial overview

To support the operation of the hydrogen baggage tractor (HBT), hydrogen was stored in multi-cylinder pallets (MCPs) and distributed via a HyQube refuelling system.

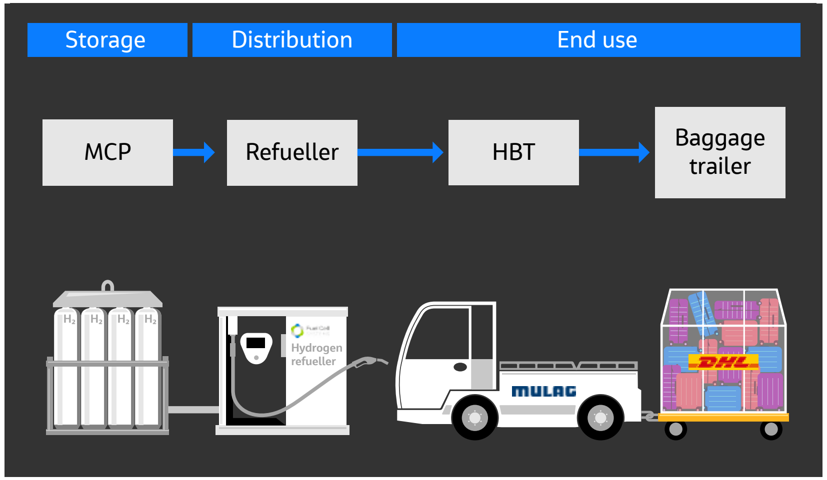


Figure 4: Trial configuration

Storage	Gaseous hydrogen (max 60kg) at 175 bar stored in multi-cylinder pallets (MCPs) on a remote stand, distant from main airport operation
Distribution	HyQube 350 bar refuelling system attached to the storage system
End use	Mulag Comet 4FC Hydrogen Baggage Tractor (HBT) refuelling airside, used to transport passengers' bags between easyJet aircraft and Bristol Airport's baggage loading area

The HyQube refueller design incorporates multiple built-in safety features to mitigate hydrogen-specific risks and complies with the ATEX European Directive for controlling explosive atmospheres.

- ✓ Hydrogen vent line
- ✓ ATEX rated
- ✓ Fused and isolated electrical connections
- ✓ Leak detection and alarm system
- ✓ System shuts down if leak detected
- ✓ Control panel with pin number

Figure 5: HyQube hydrogen refueller key safety features

Similarly, the hydrogen baggage tractor design also incorporates multiple built-in safety features to mitigate hydrogen-specific risks.

- ✓ Leakage sensors
- ✓ Cooling air outlet
- ✓ Collision protection
- ✓ Pressure control
- ✓ Error protection
- ✓ Emergency stop buttons

Figure 6: Hydrogen baggage tractor key safety features

Trial development and execution

The development and execution of the trial followed the following steps.

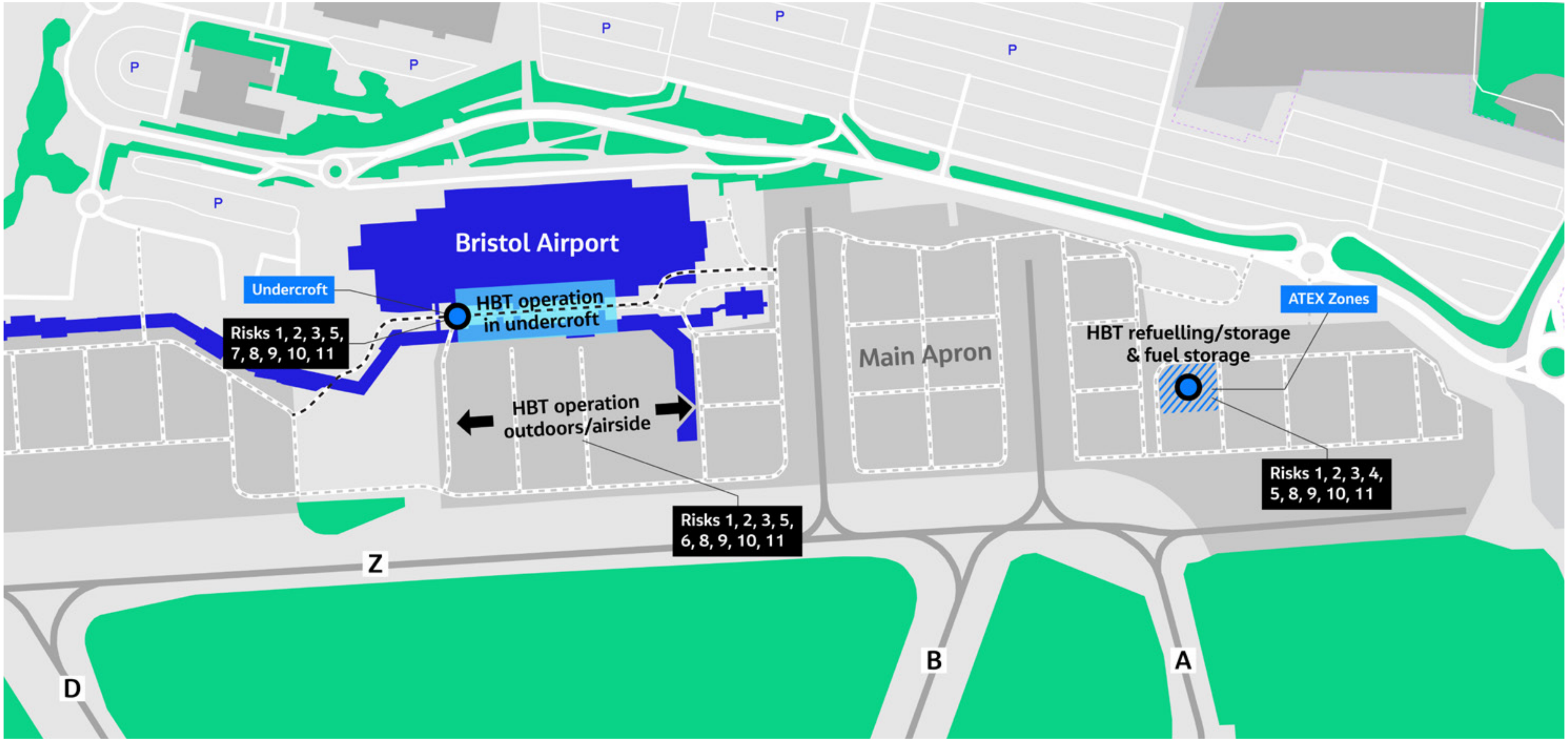
1.	**CAA Innovation Team engaged**	CAA Innovation Team engaged as collaborator on Project Acorn from kick-off to provide continuous guidance.
2.	**Safety consultant engaged**	HSE Buxton engaged to review risk assessment.
3.	**Local council engaged**	North Somerset Council engaged to ascertain permissions and any specific permits needed to carry out hydrogen trial at Bristol Airport.
4.	**CAA Aerodrome Team engaged**	The CAA Aerodrome Team responsible for aerodrome compliance and safety engaged.
5.	**Airport DSEAR Assessment updated**	Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) assessment for Bristol Airport updated to include the storage of hydrogen airside.
6.	**Refuelling electrical equipment ATEX rating confirmed**	All electrical equipment and fittings confirmed ATEX rated by suppliers (Fuel Cell Systems Ltd and MULAG).
7.	**Insurance confirmed**	Confirmed that airport and ground handler insurance agreements cover the planned activity, including that of third parties contracted to assist with the work.
8.	**Operational Process Review (OPR)**	Industry standard procedure for risk assessment and mitigation completed.
9.	**Training plan for operatives in place**	Formal training plan for DHL operators, Airside Operations, and Fire and Rescue Department.
10.	**Emergency services sign-off**	Airport and local emergency services, and local authority informed and conducted site visit for awareness of new site risks, ahead of airport sign-off.
11.	**Safety consultant review and feedback**	Feedback from HSE followed by refinements to risk assessment.
12.	**CAA final review**	Risk assessment reviewed by CAA Aerodrome Team.
13.	**'Shake-down' trial**	Landside trial in controlled environment at Cranfield University to test and troubleshoot hydrogen equipment.
14.	**Landside training**	Operator training and familiarisation for key stakeholders in controlled environment at Cranfield University and Safe System of Work (SSOW) provided.
15.	**Airside trial Phase 1**	Airside equipment checks and test operation at Bristol Airport. Communications/briefing document to all airside operations personnel.
16.	**Airside trial Phase 2**	Full airside operation serving easyJet aircraft turnaround at Bristol Airport.
17.	**Airside trial wash-up**	Feedback and lessons learnt from airside trial with partners/key stakeholders.
18.	**Knowledge sharing**	Sharing of key insights across the industry to feed into the creation of industry safety guidance and regulatory framework.

Risk Assessment

The risk assessment was led by trained operational personnel from easyJet, DHL (easyJet's ground handler at Bristol Airport) and Bristol Airport. Learning from other organisations with more experience in using hydrogen safely, such as Brighton and Hove Buses, Hamburg Airport, Cranfield University, IAAPS and HSE, provided the first step to help prioritise and shape the key considerations, which form part of the risk assessment.

The following measures helped to mitigate the risks:

- Pre-trial training and 'shake-down' to troubleshoot issues, familiarise, train and build confidence prior to moving the equipment airside.
- Built-in safety features on the refueller and hydrogen baggage tractor to mitigate the hydrogen-specific risks.
- Leveraging the benefit of learning from other industries and organisations that have more experience in the safe use of hydrogen.
- Airside reconnaissance with key partners, including the CAA, during the risk assessment development helped to visualise how the trial would work in practice.
- Parking of the refueller at a remote stand, away from aircraft and the main terminal, with a designated safety zone.
- Majority of the activity conducted outdoors, with the exception of hydrogen baggage tug operation in the 'undercroft' baggage loading area.
- Quantity of stored hydrogen limited to a maximum of 60kg.



Key / Risk category

1 / Fire & explosion	**5** / Hydrogen leaks	**9** / Defective equipment
2 / Incorrect emergency response	**6** / Airside operation	**10** / Lack of appropriate training
3 / Handling & storage	**7** / Confined space operation	**11** / Lack of awareness of trial
4 / HBT tank pressure >438 bar	**8** / Vehicle collision, tilting	

Figure 7: Risk map

Risk Map Reference Number ›	1	2	3	4	5	6	7	8	9	10	11
Risk Category ›	Fire & explosion	Incorrect emergency response	Handling & storage	HBT Tank pressure >438 bar	Hydrogen leaks	Airside operation	Confined space operation	Vehicle collision, tilting	Defective equipment	Lack of appropriate training	Lack of trial awareness
Risk Mitigation											
ATEX zoning – refueller parked remotely, 5m in-use ATEX Zone from HBT fuel filler	■				■						
Limiting the quantity of hydrogen stored to 60kg maximum	■		■								
Compulsory training and Safe System of Work (SSOW) to all operatives and safety briefing for Rescue and Fire Fighting Service (RFFS)	■	■	■	■	■	■	■	■	■	■	
HBT safety features	■			■	■			■	■		
RFFS firefighting risk card	■	■								■	■
MCP Swap-over completed by competent individual			■		■						
1m electrical device exclusion zone around the fuel dispenser	■				■						
Refueller safety features	■			■	■				■		
HBT parking location included in Temporary Airport Instruction (TAI)		■	■		■	■	■				■
Landside vehicle familiarisation	■	■	■							■	
Airside vehicle familiarisation	■	■	■			■	■			■	
DSEAR assessment fuel storage review	■		■		■	■					
HBT operational area mainly outdoors	■					■	■				
Portable (wearable) hydrogen detectors	■				■		■		■	■	
Airport Duty Manager communications		■				■					■

Figure 8: Risk mitigations matrix

Trial outcome

The objectives of Project Acorn were successfully met:

- ✓ **Demonstrated safe refuelling of hydrogen airside for the first time at a major UK airport**
  Project Acorn refuelled airside over a period of five days in a live operational environment.

- ✓ **Zero safety incidents**
  There were no near misses or safety incidents reported for Project Acorn — the only user system warning related to the EV battery level being low.

- ✓ **Mitigations covered the activity risks sufficiently**
  The Safety Assessment was submitted to the CAA for review and was accepted.

- ✓ **Effective handling of the hydrogen baggage tractor for easyJet's, DHL's and Bristol Airport's operations**
  The DHL handlers' feedback (outlined in more detail in the full technical report) was positive, and indicated the use of the hydrogen baggage tractor had been effective by enabling them to carry out their shifts as normal.

- ✓ **Successful collaboration with partners across the supply chain**
  Project Acorn involved multiple partners and many other industry stakeholders, which provided the advice and guidance integral to the success of the trial.

- ✓ **Dissemination of the trial results**
  A large amount of coverage via news outlets, social media, industry and company websites was generated following the trial and on the completion of the trial report, which has led to interest in further activity across the industry.

- ✓ **Enable partners and industry to support the future development of a regulatory framework**
  Data and experience gathered during the trial has provided a solid base to support the development of a regulatory framework for the industry's wider use of hydrogen.

Lessons learnt

Full lessons learnt are summarised in the accompanying technical report. However, Project Acorn identified two specific areas of focus needed to support and accelerate further trials:

1. A centralised body to take on the role of the national coordinator, providing strategic guidance, funding support and help to assemble the right consortia of project partners.

2. Investment in hydrogen logistics including ADR (dangerous goods) certified transport vehicles, multi-cylinder pallets (MCPs) and qualified personnel to transport low-carbon hydrogen from production sites to test locations.

Next steps

> Project Acorn showed that hydrogen can be safely used for airside refuelling of ground support equipment, and in a live and fully functioning airport operation.

This trial provided a vital step towards understanding the safety cases and risk mitigations required to underpin safety regulations for hydrogen refuelling. Data from this trial will now be used to support Cranfield University in more accurately modelling the airside use of hydrogen, including storage, demand forecasts and infrastructure requirements.

Project Acorn also created the opportunity for the CAA to build experience with hydrogen and to support the process of developing the required regulation. In addition, the CAA trialled a new way of working, participating in the project from launch, both as a collaborator and as a regulator. Such collaborative ways of working will be critical to ensuring that regulation not only complements but enables the transition to hydrogen-powered aviation.

It is also important, as identified by the Hydrogen in Aviation Alliance, that the UK CAA and other regulators are adequately resourced to support the development of future regulations and operational procedures.

Project Acorn has taken a small but critical step towards hydrogen's use at scale in aviation, both in the air and on the ground. Decarbonising aviation will require liquid hydrogen storage and refuelling capability at airports, and liquid hydrogen-powered narrowbody aircraft operating at scale. There are undoubtedly many challenges ahead but activity is progressing along this journey and at pace, including a collaboration between the Sustainable Aviation Test Environment (SATE) and Cranfield Aerospace, as well as planned trials at Exeter Airport and Toulouse Airport.

The learning from Project Acorn can be used as an example of how the future testing of hydrogen, at a wider scale, can be conducted.

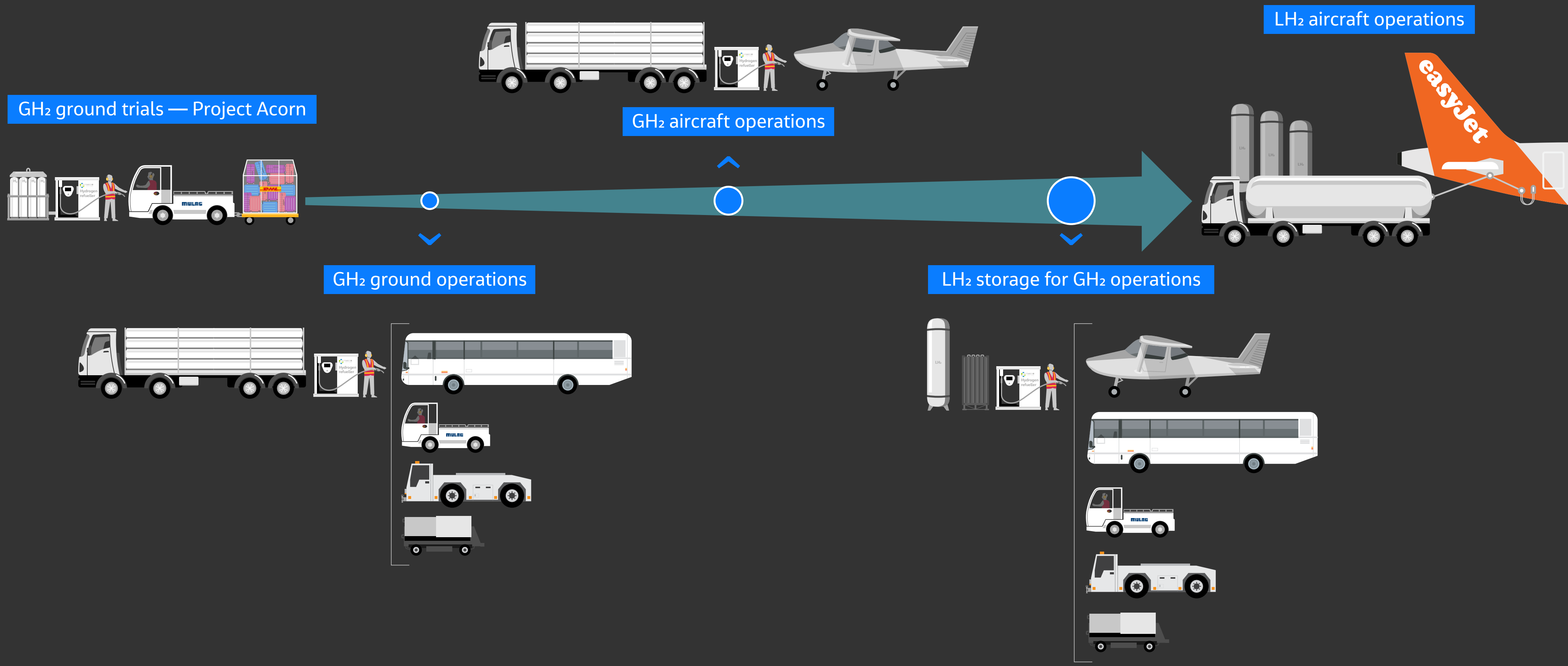


Figure 9: Hydrogen airport roadmap from trials to future aircraft operations

For enquiries about this report, please contact:

Chris Pickard
Director of Sustainable Aviation, Jacobs
E: Chris.Pickard@jacobs.com

Lahiru Ranasinghe
Head of Net Zero, easyJet
E: Lahiru.Ranasinghe@easyJet.com

Hannah Pollard
Head of Sustainability, Bristol Airport
E: Hannah.Pollard@bristolairport.com

Jacobs

Challenging today.
Reinventing tomorrow.