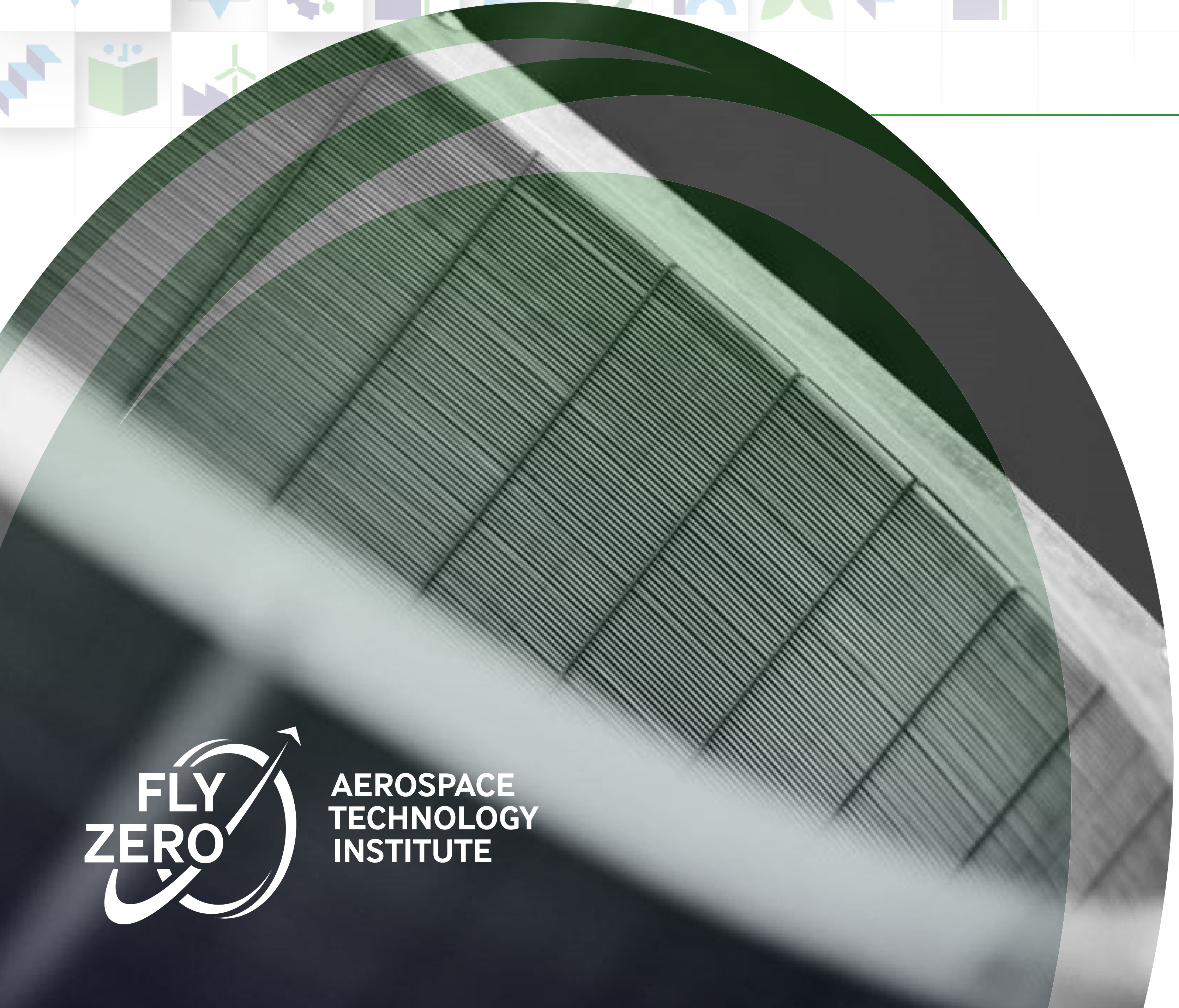
THERMAL MANAGEMENT

UK Capability and Overseas Landscape



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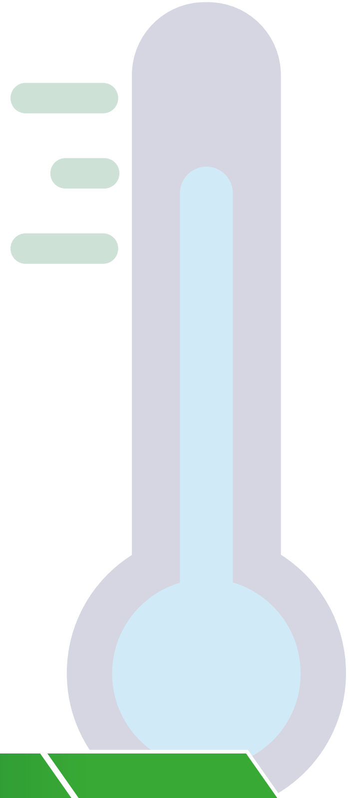


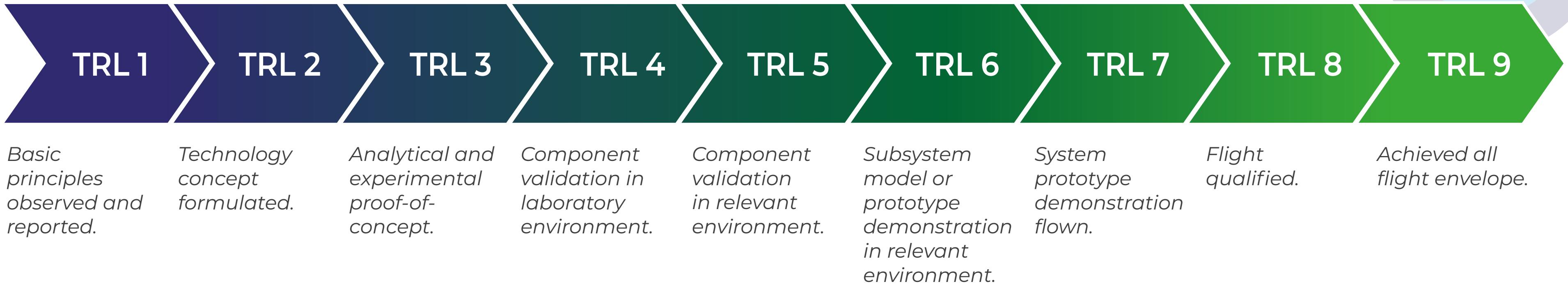


Figure 1 – Technology has been assessed against the NASA Technology Readiness Level (TRL) scale.

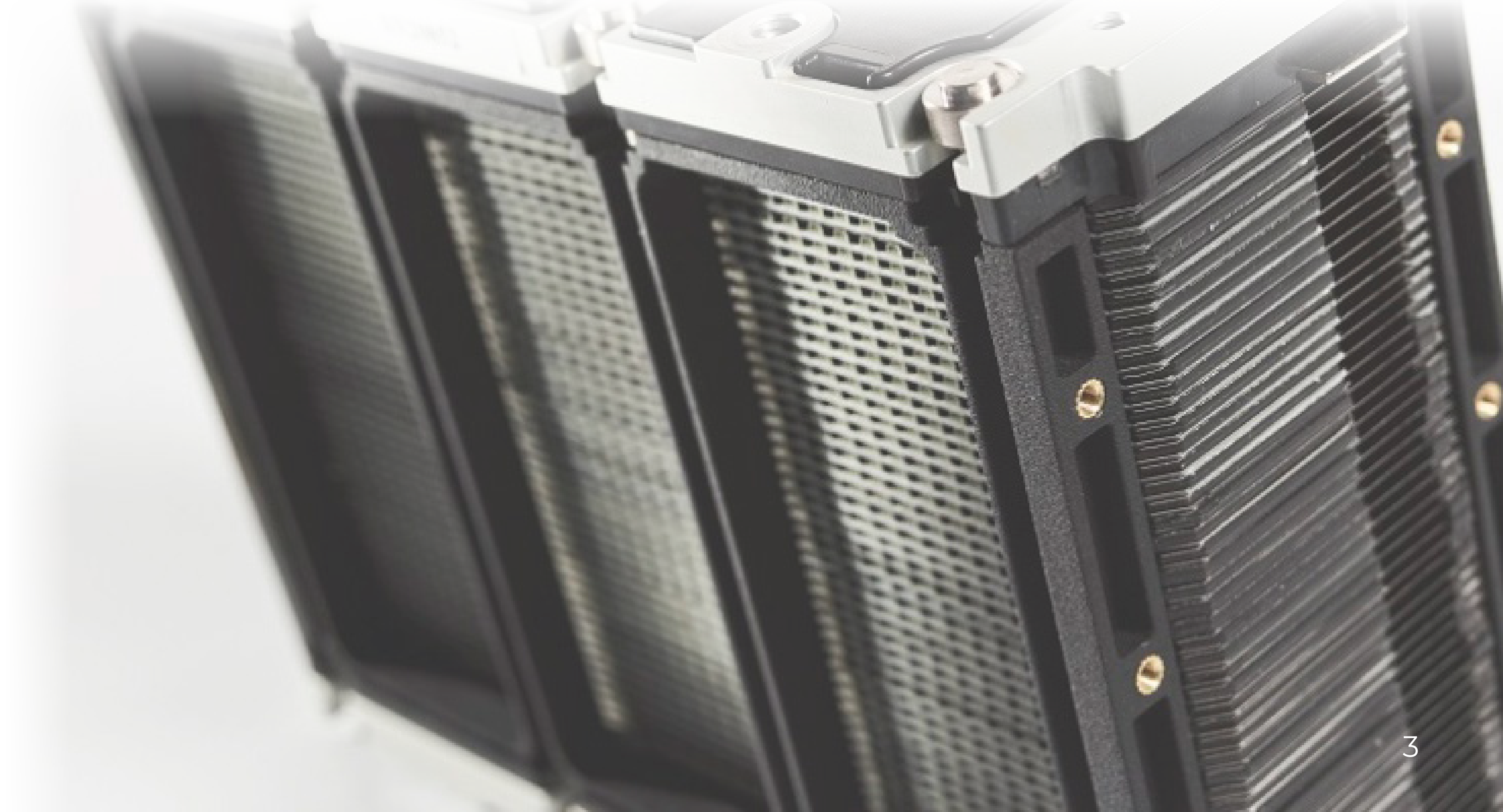
UK CAPABILITY

Fuel cell thermal management

Novel air radiator heat exchanger designs coupled with a commercially attractive manufacturing method presents a potential area of high opportunity for the UK. Globally, the heat exchanger technology relevant to fuel cells has been demonstrated on a test rig to TRL5.

Air radiator heat exchanger demonstrated on rig, initial evaluation of manufacturing planning for rate production underway.

Figure 2 - Global TRL levels for air radiator heat exchanger.



UK CAPABILITY

Gas turbine thermal management

The thermal management challenge for hydrogen gas turbines is associated specifically with the thermal management of the hydrogen fuel, enabling the hydrogen to be heated from cryogenic temperatures to temperatures enabling both efficient combustion and reduced fuel consumption. Some of the hydrogen heating can be achieved from the need to cool oil, requiring a direct fuel to oil exchanger (FOHE). Further heating of the hydrogen can be achieved with a recuperator, making direct use of the hot gas turbine exhaust. Supercritical hydrogen will flow through these products and drive a number of the common challenges identified (hydrogen fuel system and tanks) including materials, sealing and unit testing.

The availability of cryogenic testing facilities for gas turbine heat exchangers is a clear gap in current capability. The scope of verification will be similar to current testing of aerospace heat exchangers, but testing at cryogenic temperatures will be challenging with new facilities required. Tube-shell and plate-fin heat exchanger designs will need to demonstrate their compatibility with hydrogen. An active assessment of how additive manufacturing may enable more complex geometries that are not currently achievable is also required. The combination of additive manufacturing with novel geometry supports weight reduction.

Fluid heat exchangers assessed at TRL3 for cryogenic hydrogen systems due to lack of testing at low temperatures, under conditions representative of aircraft operations.

Figure 3 - Global TRL levels for fluid heat exchanger.

Fluid heat exchangers for cryogenic hydrogen systems are assessed to be at TRL3 globally for aerospace applications due to lack of testing with hydrogen and under conditions representative of aircraft operations, limited materials data combined with the requirement to develop sealing technology (see **Figure 3**). Examples of UK capability in design and manufacture for aero heat exchanger technology include Meggitt, Reaction Engines, HS Marston (a division of Collins Aerospace), and HiETA.

Oxford University's Thermofluids Institute is a recognised leader in the field of fluid and thermal management research in the UK. Other universities with thermal management expertise include Imperial, Loughborough, Cambridge, Southampton and Manchester. However expertise is needed in modelling and managing the thermal effects and in materials development. There is also work underway in UK research organisations including the High Value Manufacturing Catapult and TWI to exploit latest manufacturing technologies for this commodity; automated laser welding and additive manufacturing techniques are both actively being pursued.

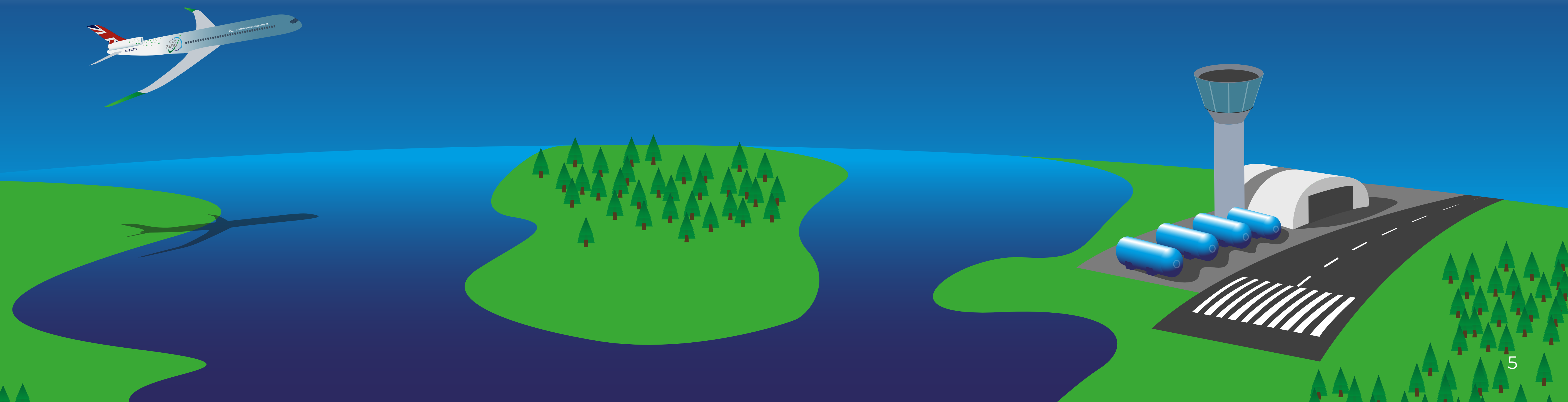
OVERSEAS LANDSCAPE

Outside the UK, the leading countries in fluid and thermal management are Germany and the USA.

Liebherr in Germany provides heat exchanger systems for rail applications, as well as having aerospace products.

In the USA, a NASA-led electric powertrain flight demonstration (EPFD) programme is developing thermal management solutions to support megawatt-class powertrain system ground and flight demonstrations.

In Germany, the DLR is developing thermal management capability through fuel cell demonstrator aircraft such as the BALIS project and H2FLY. There are options to develop heat exchanger technology in adjacent sectors and then apply the principles in aerospace, for example the increased use of cooling schemes in electric vehicles to enhance motor performance.



KEY MESSAGE

The UK is a world leader in thermal management. To anchor the technology in the UK, a suitable test environment is required to develop new heat exchanger technologies.

The FlyZero team saw evidence of UK companies electing to test in the US where the regulatory environment allows testing facilities to be licensed and established more quickly. This area needs to be addressed to ensure new and innovative technology development remains anchored in the UK.

Understanding the long-term effects of thermal cycling and hydrogen exposure on the mechanical properties of heat exchanger materials is a further challenge which again drives a requirement for facilities that can accommodate extended test cycles at elevated and cryogenic temperatures.

The new design freedoms afforded by new manufacturing processes such as additive manufacturing also bring new challenges for qualification and lifing of these 3D printed structures, especially in a hydrogen environment.

RELATED FLYZERO FURTHER READING

The ATI FlyZero project developed its technology roadmaps through a combination of broad industry consultation and assessment of technologies by experts. Technology assessment was carried out both by the FlyZero team and by approximately 50 industrial and academic organisations that partnered with FlyZero to support delivery. During the project, FlyZero developed three concept aircraft and used this exercise to gain a deep understanding of requirements and challenges for systems and technologies, which have been reflected in the roadmaps. Further detail of these technologies and developments can be found in the following reports, available to download from **ati.org.uk**

FlyZero

Zero-Carbon Emission Aircraft Concepts
Report
Ref. FZO-AIN-REP-0007

Technology Roadmaps
Report
Ref. FZO-IST-MAP-0012

Workforce to Deliver Liquid Hydrogen Powered Aircraft
Report
Ref. FZO-IST-PPL-0053

Hydrogen Aircraft

Aerodynamic Structures
Technical Report
Ref. FZO-AIR-REP-014
Roadmap
Ref. FZO-AIR-MAP-0015
Roadmap Report
Ref. FZO-AIR-COM-0016
Capability Report
Ref. FZO-AIR-CAP-0066

Electrical Propulsion System
Technical Report
Ref. FZO-PPN-REP-0028
Roadmap
Ref. FZO-PPN-MAP-0029
Roadmap Report
Ref. FZO-PPN-COM-0030
Capability Report
Ref. FZO-PPN-CAP-0070

Thermal Management
Technical Report
Ref. FZO-PPN-REP-017
Roadmap
Ref. FZO-PPN-MAP-0018
Roadmap Report
Ref. FZO-PPN-COM-0019
Capability Report
Ref. FZO-PPN-CAP-0067

Fuel Cells
Technical Report
Ref. FZO-PPN-REP-0031
Roadmap
Ref. FZO-PPN-MAP-0032
Roadmap Report
Ref. FZO-PPN-COM-0033
Capability Report
Ref. FZO-PPN-CAP-0071

Hydrogen Gas Turbines & Thrust Generation
Gas Turbine Technical Report
Ref. FZO-PPN-REP-020
Thrust Devices Technical Report
Ref. FZO-PPN-REP-021
Roadmap
Ref. FZO-PPN-MAP-0022
Roadmap Report
Ref. FZO-PPN-COM-0023
Capability Report
Ref. FZO-PPN-CAP-0068

Cryogenic Hydrogen Fuel System & Storage
Fuel System Technical Report
Ref. FZO-PPN-REP-024
Fuel Storage Technical Report
Ref. FZO-PPN-REP-025
Roadmap
Ref. FZO-PPN-MAP-0026
Roadmap Report
Ref. FZO-PPN-COM-0027
Capability Report
Ref. FZO-PPN-CAP-0069

Cross-Cutting

Aircraft Systems
Ref. FZO-AIR-POS-0013

Airports, Airlines, Airspace - Operations & Hydrogen Infrastructure
Ref. FZO-CST-POS-0035

Advanced Materials
Ref. FZO-IST-POS-0036

Lifecycle Impact
Ref. FZO-STY-POS-0034

Sustainable Cabin Design
Ref. FZO-AIR-POS-0039

Compressed Design and Validation - Culture and Digital Tools
Ref. FZO-IST-POS-0038

Advanced Manufacturing
Ref. FZO-IST-POS-0037

ABOUT FLYZERO

Led by the Aerospace Technology Institute and backed by the UK government, FlyZero began in early 2021 as an intensive research project investigating zero-carbon emission commercial flight. This independent study has brought together experts from across the UK to assess the design challenges, manufacturing demands, operational requirements and market opportunity of potential zero-carbon emission aircraft concepts.

FlyZero has concluded that green liquid hydrogen is the most viable zero-carbon emission fuel with the potential to scale to larger aircraft utilising fuel cell, gas turbine and hybrid systems. This has guided the focus, conclusions and recommendations of the project.

This report forms part of a suite of FlyZero outputs which will help shape the future of global aviation with the intention of gearing up the UK to stand at the forefront of sustainable flight in design, manufacture, technology and skills for years to come. To discover more and download the FlyZero reports, visit **ati.org.uk**

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FlyZero contributing companies: *Airbus, Belcan, Capgemini, easyJet, Eaton, GE Aviation, GKN Aerospace, High Value Manufacturing Catapult (MTC), Mott MacDonald, NATS, Reaction Engines, Rolls-Royce, Spirit AeroSystems.*

These roadmaps have been developed with a view to accelerate zero-carbon technology development and maximise the potential future value for the UK. They are unconstrained by the availability of funding.

Department for
Business, Energy
& Industrial Strategy

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