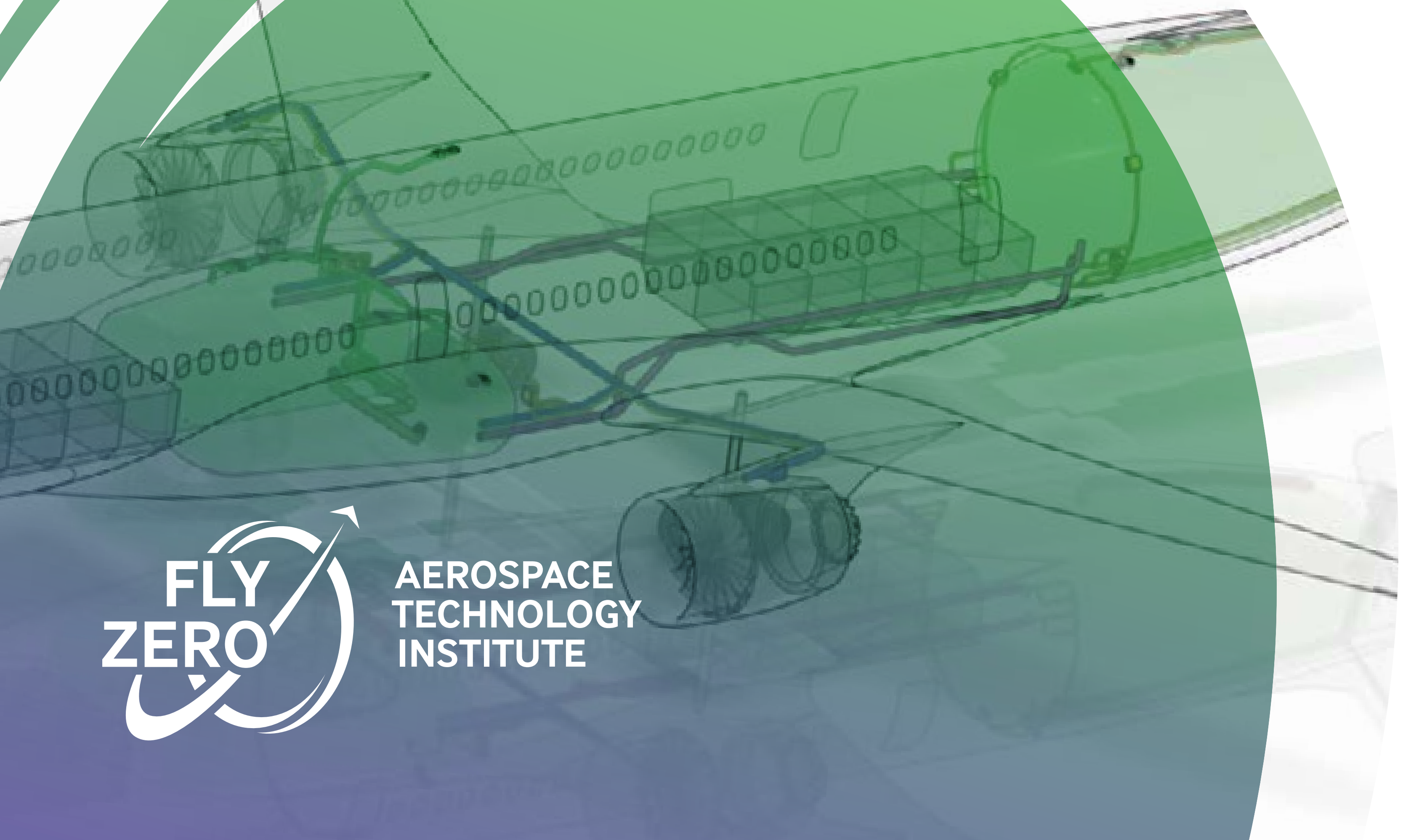
# CRYOGENIC HYDROGEN FUEL SYSTEM AND STORAGE

UK Capability and Overseas Landscape



FLY ZERO

AEROSPACE TECHNOLOGY INSTITUTE

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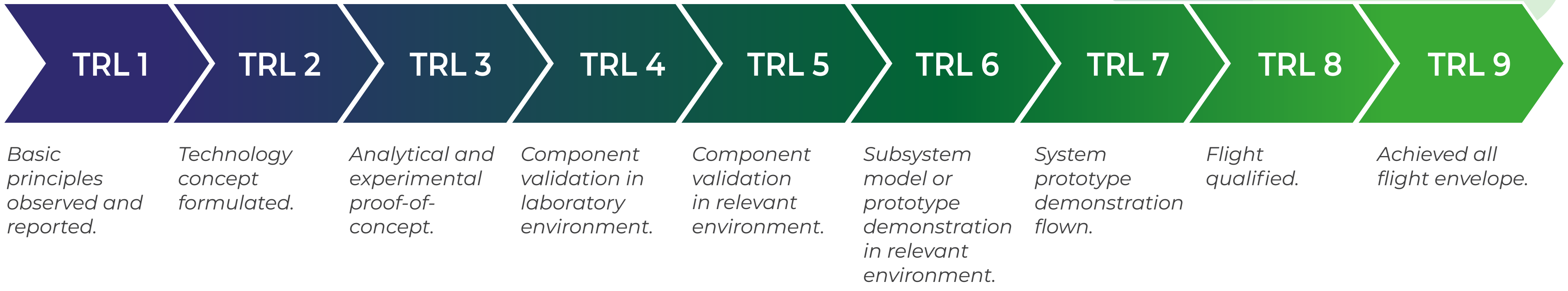



*Figure 1 – Technology has been assessed against the NASA Technology Readiness Level (TRL) scale*

# UK CAPABILITY

## Fuel storage will consist of multiple large, insulated tanks. Material types being evaluated for the tank wall are metallics, composites and multi-material hybrids. This will drive supply chain choice.

The thermal cycling of the tank as it is filled and drained will determine its life, which, in turn, will dictate the tank replacement strategy. Sustainability will be a significant consideration in material choice. H2GEAR is a UK technology collaboration demonstrator led by GKN Aerospace consisting of a hydrogen fuel cell system and cryogenically cooled super-conducting motor/drive providing insight in this area.

FlyZero has assessed the global technology readiness level as TRL3.


*Tank concepts developed, early planning for manufacturing developments in place.*

*Figure 2 – Global TRL levels for fuel storage*

The hydrogen fuel distribution systems, including systems for fill, vent, feed, pressurise and drain, are made up of components including valves, pumps, expanders, connectors, couplings, ventilation, pipes, etc. These components will need to be redesigned for liquid hydrogen aviation applications. The fuel distribution system will need to be able to handle hydrogen in the liquid and supercritical phases. High tolerance sealing surfaces capable of absorbing the effects of thermal expansion across a wide temperature window will be required. FlyZero has identified cryogenic high-pressure pumps as a particular challenge with read across from the space sector as an opportunity. The numerical models for the system will need to be developed and validated by tests using suitable software. Additionally, development and approval of industrywide aerospace standards and specifications for the hydrogen fuel system was identified as a key requirement, in parallel with those currently governing and guiding the specification design, and testing of tanks, pumps and other fuel system units for kerosene operation (e.g. SAE AIR1408B, SAE AIR7975, and SAE ARP1401B). These standards will need to consider the specific characteristics of hydrogen fuel and address the full lifecycle, including refuelling, defuelling, purging, venting, pressurising, insulating, coupling, sealing, pumping, monitoring and controlling the fuel supply. The opportunity to develop a cryogenic centre of excellence in the UK was also raised by the supply chain as a good way to anchor UK jobs.

# UK CAPABILITY

The data required to establish materials capability across this group of technologies has been identified as a key knowledge gap. The materials used for existing cryogenic component and systems manufacture in other industries will need to be evaluated and tested for compatibility with hydrogen across the temperatures and pressures in which it will be stored and transferred in aerospace applications. There are currently no UK facilities capable of conducting large-scale mechanical tests at cryogenic temperatures and in a hydrogen environment. Creating one would mean significant infrastructure investment. Achieving ambitious entry into service dates for hydrogen powered aircraft (late 2020s for sub-regional and 2030s for larger aircraft), will require aggregating existing materials data for preliminary design and then conducting mechanical testing in parallel during the later stages of the programme.

Based on the consultation activity FlyZero has assessed that there is a range of technology readiness levels between 2 and 3.


*Liquid hydrogen pump, fill, vent and control valves all at concept stage with plans to scale up from ground based component manufacturing for aerospace qualified components.*

*Figure 3 – Global TRL levels for fuel system*

Airbus is developing solutions for its ZEROe demonstrator. Airbus's Filton site is its main location for fuel systems design globally. Major suppliers with a UK base with relevant competence include Eaton, Cobham Mission Systems, Parker Hannifin and Meggitt. The UK also has capability in cryogenic systems within the industrial sector (e.g. Parker Hannifin) and space sectors. There are a number of developing collaborations between aerospace incumbents, the industrial and space sectors.  The UK has capability to develop cryogenic fuel systems for future aerospace applications.

To ensure the functionality requirements of components for a liquid to gaseous hydrogen system can be met, critical manufacturing competencies will also need to be established in both the component suppliers and further down the supply chain. With the ongoing level of consolidation in this sector, such as Eaton's acquisition of Cobham Mission Systems and the Parkers acquisition of Meggitt, it is important to ensure key manufacturing opportunities are clearly understood and anchored in the UK. Tank manufacture capabilities exist with CCP Gransden for carbon filament winding of hydrogen tanks, the National Composite Centre are developing these technologies. In the UK Impression Technologies are developing manufacturing forming capabilities that are directly applicable to liquid hydrogen storage tanks. There is strong academic support available through Queens University Belfast, on hydrogen tank liners, and Ulster University with an understanding of explosion proof hydrogen tank expertise.

# OVERSEAS LANDSCAPE

## Outside the UK, the countries that are leading the development of hydrogen fuel systems and tanks are France, Germany, USA, Canada, Japan, and South Korea.

Germany has covered the creation of green hydrogen and its use - including hydrogen storage and distribution for aviation - under its national hydrogen strategy. The development of a hydrogen fuel cell powered regional aircraft demonstrator is the core of the BALIS project, which will also cover on-aircraft hydrogen fuel system and tanks. The aim of the BALIS project is to develop and test a fuel cell powertrain with an output of approximately 1.5 megawatts.

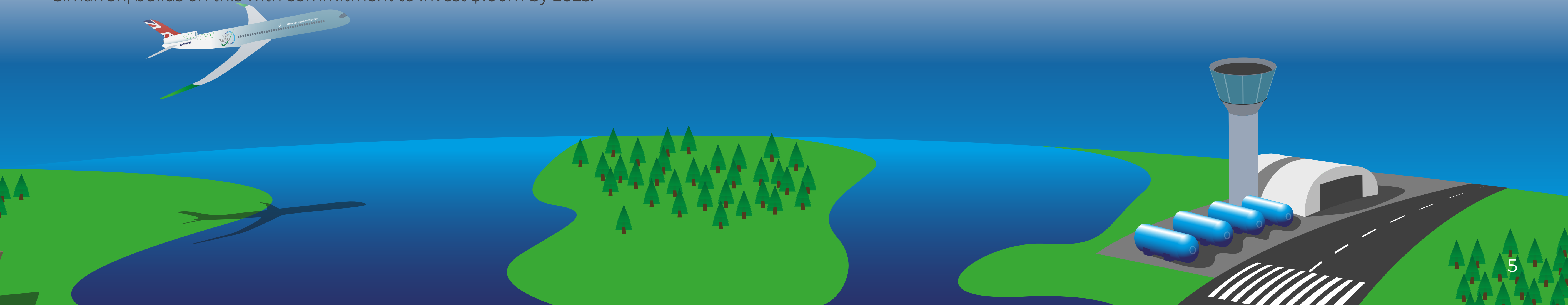
Airbus has established zero-emissions development centres in Germany (Bremen), France (Nantes) and most recently in Spain. All three centres will investigate hydrogen tanks, covering between them both metallic and composite solutions.

The USA is actively developing hydrogen storage and distribution technologies within the US Department of Energy-led HydroGEN consortium. Additionally, Boeing has manufactured and pressure tested a 4.3 meter diameter composite cryogenic tank, similar to what would be used in space applications. This is estimated to be 30% lighter than a metallic alternative.

Canada's National Research Council (NRC) Low-emission Aviation programme features specific streams on aircraft technology integration and hydrogen applications.

Japan has a world-leading position in hydrogen with strong activity in its industrial sector. Novel fuel storage in aerospace is a key element of Japan's national strategy towards net-zero, with industry-leading hydrogen development programmes with potential to translate into strong hydrogen storage and hot section gas turbine capability.

In South Korea, Hanwha Solutions' acquisition of TK-Fujikin in 2019 marked their entry into hydrogen tanks. Their subsequent acquisition of NASA composite tank manufacture start-up, Cimarron, builds on this with commitment to invest $100m by 2025.



# KEY MESSAGES


## The UK is well placed to develop a cryogenic hydrogen capability for aerospace applications. Airbus's site in Filton is its main site for fuel system design.

UK companies have cryogenic components available commercially today for land-based industrial applications, and the UK has capability within its space sector. UK suppliers are actively participating in the development of aerospace cryogenic capability with OEMs on strategic technology programmes. However, the UK does not currently have the same depth of expertise on cryogenics as exists in other countries, particularly those that have hydrogen space launch capability. Developments in this technology area can be used across multiple sectors, including energy and marine.

The UK should support the creation of an open access centre of excellence for hydrogen systems design, integration, prototyping and test, including cryogenics in order to rapidly build skills, to accelerate technology development and provide an anchor for industrial development in the UK. This capability could be a national asset and could potentially be shared with other sectors. FlyZero's final reports to be delivered in 2022 will highlight the requirements for infrastructure.

Investment is needed to create and adapt UK test capability and capacity. This test capability needs to cover the generation of basic material mechanical property data all the way through to component and system testing when operating at cryogenic temperatures.

Nationally and internationally, there are limited standards and regulations on the use of liquid hydrogen for aerospace applications. There is an opportunity for the UK to influence standards and regulations for e.g., refuelling and tank design.

# 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 Storgage Technical Report**
Ref. FZO-PPN-REP-024
**Storage System 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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***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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