



Hydrogen Capability Network



What Next for Hydrogen in Aviation?

September 2025

ABOUT THE AEROSPACE TECHNOLOGY INSTITUTE

The **Aerospace Technology Institute** (ATI) is an independent organisation that works alongside government and industry to transform UK aerospace through technology and innovation. The ATI is funded equally by the **Department for Business and Trade** (DBT) and by industrial recipients of project grants. ATI projects are chosen and overseen through close collaboration with Innovate UK and DBT.

As well as running this portfolio of R&T projects, the ATI conducts strategic research projects to help define and answer systemic questions of value to the UK aerospace sector. In 2022 the ATI published the findings of the **FlyZero** project, which concluded that liquid hydrogen is the most viable zero-carbon emission fuel with the potential to scale to larger aircraft.

The ATI Programme has made several investments in liquid hydrogen technologies to support the next generation of zero-carbon aircraft.



Department for
Business & Trade

Funded by the Department for Business and Trade.

Front cover image © ATI - FlyZero's LH₂ fuel cell-powered, zero-carbon emission, regional aircraft concept.

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FlyZero's LH₂ powered, zero-carbon emission aircraft concepts.

EXECUTIVE SUMMARY

Over 24 months, the **Hydrogen Capability Network (HCN)** has engaged industry, academia, regulators and liquid hydrogen suppliers to identify challenges, coordinate research, and recommend actions that will enable zero-carbon emission flight.

Liquid hydrogen (LH₂) is the most promising zero-carbon emission fuel for large commercial aircraft, as identified in the ATI's **FlyZero** project. While gaseous hydrogen aircraft are beginning to fly at sub-regional scale, achieving zero-carbon flight for larger commercial aircraft will require major advances in LH₂ technologies, infrastructure, and skills - many of which do not currently exist at scale in the UK. The report sets out recommendations in four core areas:



▶ **Bolstering the UK's Research**

through investment in fundamental research areas: cryogenic materials, thermofluids, and health and safety.



▶ **Developing key technologies in the UK**

prioritising the development of the cryogenic hydrogen storage and fuel system to anchor IP and manufacturing capability within the UK's supply chain.



▶ **Developing UK based Infrastructure**

and test facilities at all scales, increasing availability and lower cost of testing to accelerate development of experimental data.



▶ **Growing the UK skills base**

through a coordinated LH₂ community, growing capability and knowledge through research and technology development.

The opportunity for the UK is significant, not only to win future work share, but also to protect existing UK-based manufacturing in the future. The UK is well-placed to lead in this emerging global market, but only if it continues to invest, collaborate, and create a coordinated long-term strategy ensure alignment between research, testing, infrastructure and skills.

+ HCN FINDINGS

1

The **cryogenic hydrogen storage and fuel system** is the technology which requires the most innovation. Out of all the technologies considered (see *Figure 5*), the cryogenic hydrogen storage and fuel system is the most crucial for future LH₂ powered aircraft, whether they are powered by gas turbines or fuel cells.

2

Although **Liquid Hydrogen is the most viable solution**, the technology is unproven, and uncertainty remains.

- ▶ **Industrial R&T** - Progress is being made for a number of the technology bricks, but the lack of fundamental research and data is slowing down advancements. Cryogenic components are urgently required to be developed but SMEs face barriers such as lack of data, high testing costs and uncertainty in technology exploitation timeframes and return on investment.
- ▶ **Market Forces** - Without certainty on technical viability, it's challenging for levers to be applied to influence market forces to adopt LH₂ technology. Without certainty on the market viability, there is no guaranteed offtake to scale and reduce costs of LH₂ fuel production and provide commercial/operational price levers.
- ▶ **Market Failures** - The UK currently lacks test facilities, supply of LH₂, and fundamental LH₂ research. These market failures require incentives, funding or offtake guarantees through government support. Unlocking these obstacles holistically will allow the UK to develop its LH₂ capability at pace.



3

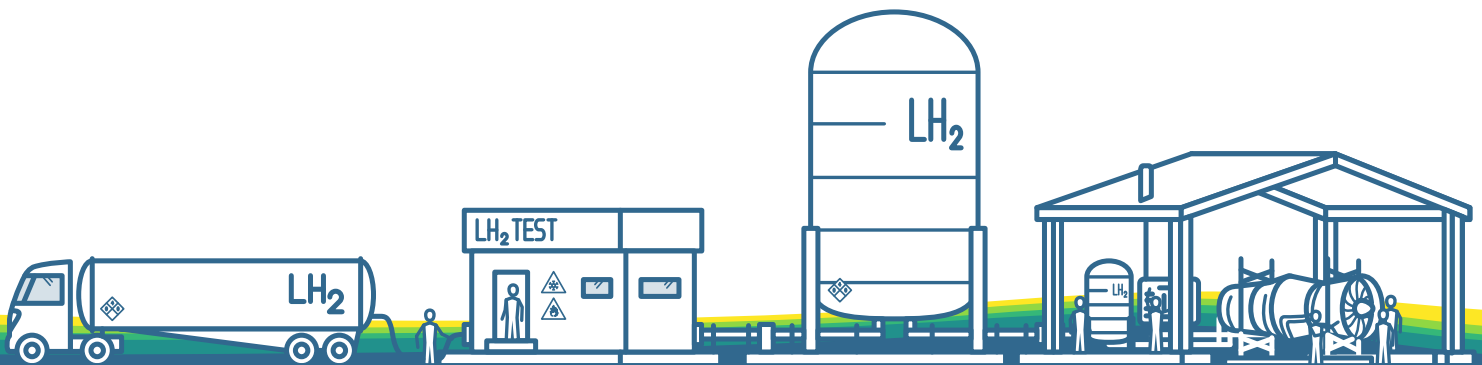
There are **fundamental science knowledge gaps for liquid hydrogen**. The critical topics needing advancement in understanding are material behaviour, thermofluid behaviour and health and safety for liquid hydrogen. Research in these areas has grown exponentially over the last five years, with China and the USA leading in recent research publications and patent applications. This lack of knowledge is beginning to impact industrial R&T progress.

- ▶ **Investment in fundamental research** for cryogenic hydrogen is required to anchor industrial R&D in the UK. This will generate data, knowledge and skills.
- ▶ **Experimental testing** is required to fill data gaps and generate datasets for model development, validation and certification. Testing must be standardised and repeatable.
- ▶ This is **required at pace** to ensure that fundamental knowledge is established, which enables cryogenic technologies to be developed (see *Figure 3*). This needs to be **led by industrial requirements** while allowing academic innovation. Data dissemination is critical to advancing capability in the sector.

4

Open access LH₂ test facilities are required, to reduce duplication, ensure LH₂ supply and maximise collaboration. There is a shortage of permanent LH₂ test facilities in the UK, especially for small scale testing to advance fundamental research within academia and component development within the supply chain.

- ▶ Developing test facilities is expensive due to limited supply chain and high costs of certified hardware. LH₂ fuel is expensive and not produced at volume in the UK requiring bulk deliveries. Consequently, requiring larger facilities to factor in expensive insulated storage tanks and smaller facilities to factor in cost of liquefaction capex, which remains inefficient.
- ▶ The regulations, guidelines and standards for the development, design, and safe operation of test facilities are still maturing, and there is a shortage of skilled LH₂ practitioners.



- ▶ LH₂ testing is expensive, exacerbated by the need for more early concept development testing due to lack of validated models (based on experimental data) and more testing required due to lack of standardised testing procedures (repeatability). When standards are developed, testing may have to be duplicated if non-compliant and data cannot be replicated.
- ▶ Offtake uncertainty: Making a commercial case for test facilities and LH₂ production is difficult due to a combination of factors resulting in demand uncertainty and no guarantee of offtake and future market.

5

LH₂ is difficult to test with - Testing needs to be in a controlled, safe environment. Maintaining safety during the early years of R&D testing is critical. Health and safety understanding of hazards and human factors needs more research and guidelines.

This combined with the shortage of skilled practitioners supports a conclusion that testing should initially be consolidated to fewer facilities.

6

Expertise is in short supply globally - There needs to be a blend of attracting new talent to the UK sector and growing organically through R&T and testing.



To deliver this, coordination is vital.



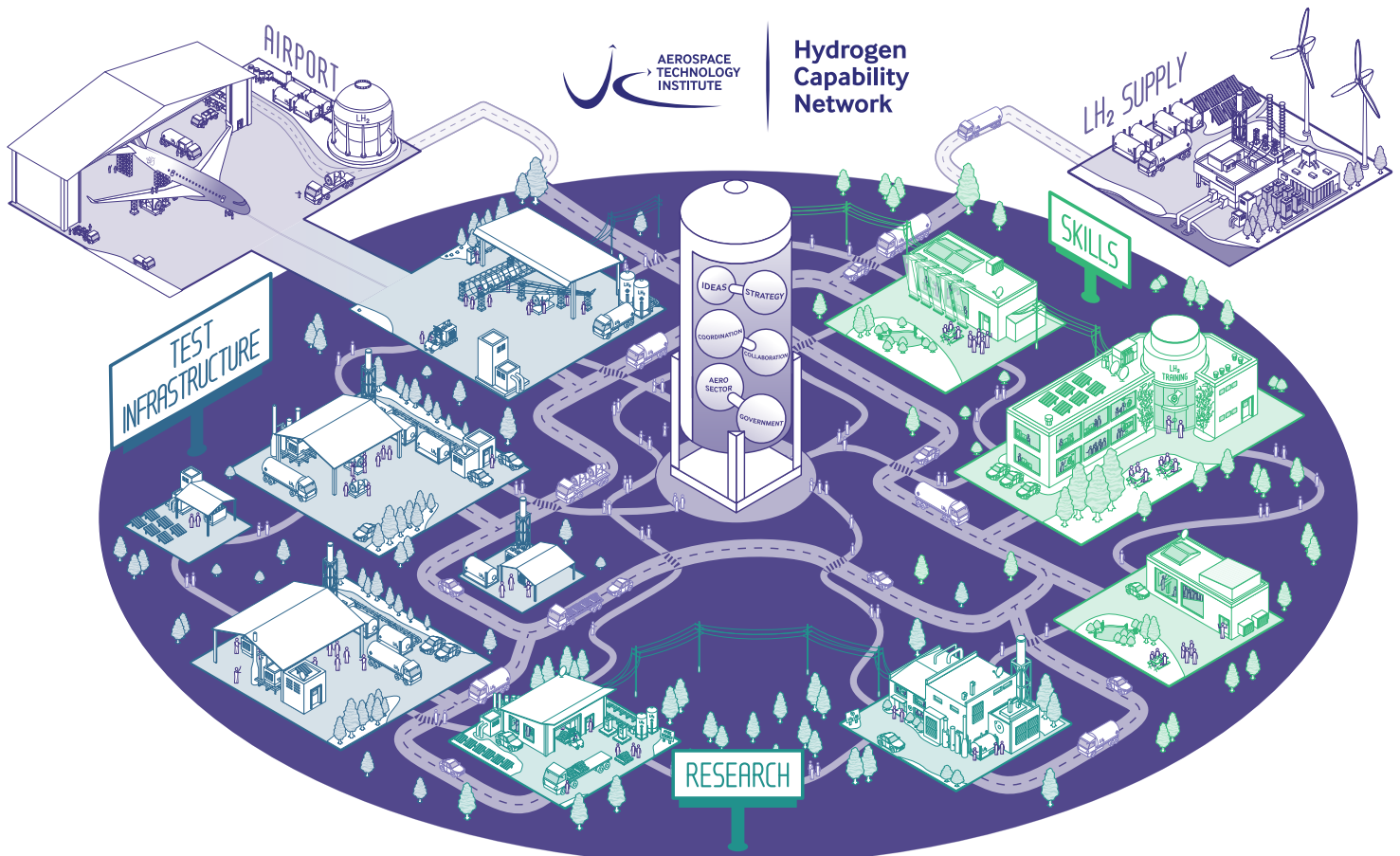
For the UK to maintain and build its global position in aerospace in the face of the disruption that LH₂ brings, an independent, industry-linked body is required to make strategic coordination decisions, convene research and appropriate technology demonstrations, ensure rapid knowledge dissemination and maintain a UK community.

HYDROGEN CAPABILITY NETWORK

The **Hydrogen Capability Network (HCN)** was launched in April 2023 funded by the **Department for Business and Trade**, to progress key recommendations from **FlyZero** which will enable the aerospace sector to deliver liquid hydrogen research & development (R&D). The HCN has worked with sector stakeholders to determine the recommendations and interventions required to protect and grow the UK aerospace sector for future liquid hydrogen aircraft.

From April 2025, the work of the HCN was integrated into the main ATI organisation and the project was concluded. The ATI will focus on the technology findings of the HCN, which will help shape technology strategies, investment priorities and industry support. In other areas, such as research and skills, the ATI will aim to influence and advise relevant organisations where possible. Relationships and partnerships focusing on cryogenic hydrogen established during the project have been led by the ATI following the conclusion of the HCN.

The HCN's aim has been to ensure that there is collaboration, coherence and efficiency for the aerospace sector to enable hydrogen research and development. The HCN has been working on behalf of the sector through a network of stakeholders and delivery partners.



IMPACT OF THE HCN ON THE UK AEROSPACE SECTOR

HCN Project Highlights



1000+ Individuals
Engaged from across the sector



7 Secondees
from Industry & academia



32 Presentations
at Conferences/events



13 Workshops
Led or co-led



16 Reports Published
(~600 pages of content)



20+ International
groups engaged

Over 24 months...



155 Delegates
Attended our
Cryogenic Research
Conference



**Launched the
HCN Network Map**
informed by inputs from the
hydrogen community



Developed the
Chymes Proposal,
focussed on material
testing & standards



Developed plans for a
**National Hydrogen
Centre** with the Health &
Safety executive in Buxton



**Cryogenic Research
Commissioned**
for a global
landscaping exercise



**Convened the
sector** on technology
requirements & LH₂
supply & demand



**Worked with
multiple partners**
and initiatives across
the UK & beyond



Supported the
AGP & Hydrogen
Skills Alliance
strategies

 **Figure 1 - The impact of the HCN over 24 months.**

Stakeholders across the sector acknowledge the challenges associated with adopting LH₂, as well as the need for timely knowledge, data, and technology development. They also note that collaboration across boundaries is essential. As such, the work of the HCN has been welcomed across the sector, as it has enabled collaboration across multiple areas of the hydrogen value chain which don't usually come together and increased the recognition of the importance of open-source data and standards. The HCN convened aerospace manufacturers, academics, regulatory bodies and hydrogen producers to establish priorities and undertake research where required. The HCN's **Cryogenic Research Conference** in January 2025 and many workshops over 24 months demonstrate the impact of the HCN, and the need for an organisation such as the ATI as an independent expert body to coordinate and convene multiple parties. Participants have dedicated time preparing and attending workshops and have reiterated how useful the outputs have been to them and their organisations. Events have often been organised in collaboration with other initiatives and organisations such as the **Civil Aviation Authority (CAA)** or the **ATI Hub**, which has led to a more diverse audience and greater knowledge sharing.



 **Figure 2 - Images from the HCN's Cryogenic Hydrogen Research Conference – January 2025.**



Figure 2 (cont.) - Images from the HCN's Cryogenic Hydrogen Research Conference – January 2025.

CONTEXT

The HCN's conclusions agree with those from FlyZero^[7] and provide more detail on the importance of the recommendations for collaboration, given the challenges identified. The FlyZero project concluded that liquid hydrogen is the most viable zero-carbon emission fuel with the potential to scale to large commercial aircraft.

Since the publication of the FlyZero reports in 2022, the aerospace sector has progressed its understanding of the opportunities and limitations associated with liquid-hydrogen fuelled aircraft. The ATI have also worked with the **Natural Environmental Research Council (NERC)** to introduce aligned competitions on advancing the understanding of climate science and non-CO₂ impacts.

In parallel, hydrogen has become more visible as a route to decarbonising different hard-to-abate sectors. Various projects across the globe have seen hydrogen being used as an energy vector to power buses, trains, and distribution centres. Even when gaseous hydrogen has been identified as the end use, there is growing awareness that LH₂ is a more suitable solution to transport and store the hydrogen due to its higher energy density and lower pressure requirements. **Plug Power's** (USA) hydrogen plant^[2] in Woodbine, Georgia is already producing LH₂ and transporting it by road to Amazon, Walmart and Home Depot distribution centres to be used to power H₂ forklifts.

Although liquid hydrogen may eventually power large commercial aircraft, there are several challenges around cryogenics that need to be overcome across all parts of the hydrogen value chain. Today's production of LH₂ is limited to a small number of large-scale global producers; none of these are currently located in the UK. This means LH₂ must be transported on road by tankers to reach the UK. Storage of LH₂ also comes with challenges as the liquid must remain at extremely cold temperatures (-253°C), otherwise it begins to 'boil-off'. Cryogenic hydrogen interacts differently when in contact with traditional aerospace materials and behaves differently as it flows and changes state, which means a greater understanding of material and thermofluid properties is required before components are tested and ultimately used with the fuel.

As the aerospace sector begins looking at hydrogen as a route to zero carbon emissions, companies are starting to tackle these challenges from different angles.

+ HYDROGEN-POWERED AIRCRAFT ARE FLYING TODAY

ZeroAvia (USA and UK) is developing hydrogen-electric propulsion systems for zero-emission flight. Their approach focuses on retrofitting a Dornier 228 before progressing to fully hydrogen-powered designs. In 2025, ZeroAvia are well into their flight test campaign and plan to submit for certification by the close of this year^[3]. In June 2024, **Joby Aviation's** (USA) hydrogen-electric technology demonstrator aircraft completed a 523-mile flight above Marina, California^[4]. This followed on from Joby's subsidiary **H2FLY** (Germany), who completed the world's first piloted flight of an electric aircraft powered by liquid hydrogen in September 2023^[5].

Alongside this, **Universal Hydrogen** (USA) successfully flew a hydrogen-powered Dash 8 test aircraft in 2023 but ended up facing financial difficulties and ultimately ceased operations in early 2024. The fall of Universal Hydrogen highlights the difficulties in securing investment and developing technologies in a sector with long returns, as well as the challenges of relying on an ecosystem and infrastructure which is still in its infancy. This is perpetuated throughout the supply chain where there are significant gaps in critical components and capability.

These companies are targeting entry into service dates in the late 2020s for their first regional and sub-regional retrofit platforms. This allows them to generate revenue, develop capability and build infrastructure before turning their attentions to a clean-sheet design afterwards. Emissions from regional aircraft only account for about 7%^[6] of the total aviation emissions, and this share is reducing as the fleet of narrowbody aircraft grows. However, the efforts being made in the regional space will mature and de-risk some of the critical technologies required to achieve zero-carbon flight for larger aircraft.

 **FlyZero's LH₂ airport apron refuelling concept.**



+ HYDROGEN AIRCRAFT OF THE FUTURE

Larger aircraft manufacturers are also developing hydrogen technologies. **Rolls-Royce** successfully ran their *AE 2100* on green hydrogen in November 2022^[7]. The UK-based engine manufacturer have three ATI supported projects; *HYEST*, *RACHEL* and *LH2GT*^[8] which are developing and testing key system technologies and integrated powerplant architectures for liquid hydrogen gas turbines. **Pratt & Whitney's** *HySIITE* concept uses a novel water vapor recovery and steam injection system to enable up to a 35% improvement in energy efficiency^[9].

The **Airbus ZEROe** programme has the objective of developing a hydrogen-powered commercial aircraft, which initially targeted an entry into service in 2035. In February 2025, Airbus postponed the timeline for the ZEROe aircraft by 5 to 10 years citing slower-than-expected advancements in essential technologies, infrastructure, a lack of support on fundamental hydrogen research and slow progress on regulatory frameworks. Nonetheless, in March 2025, Airbus' chief executive Guillaume Faury said he considers hydrogen as the "energy of the future" when addressing the Airbus Summit^[10] in Toulouse.

GKN Aerospace's *H2FlyGHT*^[11] and *H2GEAR* projects have allowed the company to develop IP in power and propulsion architecture for hydrogen powered aircraft. However the opportunity to exploit these technologies have now been pushed to the right.

 **FlyZero's LH₂ powered, zero-carbon emission aircraft concepts.**



These recent developments in the sector reflect FlyZero's 'regional first'^[12] scenario, where companies address the regional market, with little impact on emissions. The Climate Change Committee's (CCC) 7th Carbon Budget^[13] forecasts that by 2040 the aviation sector will be the UK's highest emitting sector. The CCC highlights demand management as the biggest lever for CO₂ reductions, however this has consequential impacts to the aviation sector, the UK economy and projected market growth. The scale up of SAF and zero carbon emission technology development must both be pursued.

Meanwhile, the 2030s is forecast to be dominated by upgraded narrowbody platforms, powered by SAF, delaying the arrival of a zero-carbon narrowbody aircraft. The economics of developing a new narrowbody aircraft means that companies cannot afford parallel investments into a zero-carbon platform.

A delayed entry into service of larger zero-carbon aircraft provides an opportunity for the UK sector to grow capability and supply chain, to win workshare on future platforms and protect current workshare in key products. But to achieve that, a coordinated approach is required on fundamental research, development of infrastructure and acceleration of testing with LH₂.

✔ *FlyZero's LH₂ fuel cell-powered, zero-carbon emission, regional aircraft concept.*



ACTION IS REQUIRED NOW TO ENABLE ZERO-CARBON EMISSION AIRCRAFT IN THE FUTURE

The rest of this paper highlights the challenges associated with developing hydrogen technologies over the coming years. *Figure 3* illustrates why action is needed today to accelerate the sector's progress to net zero.

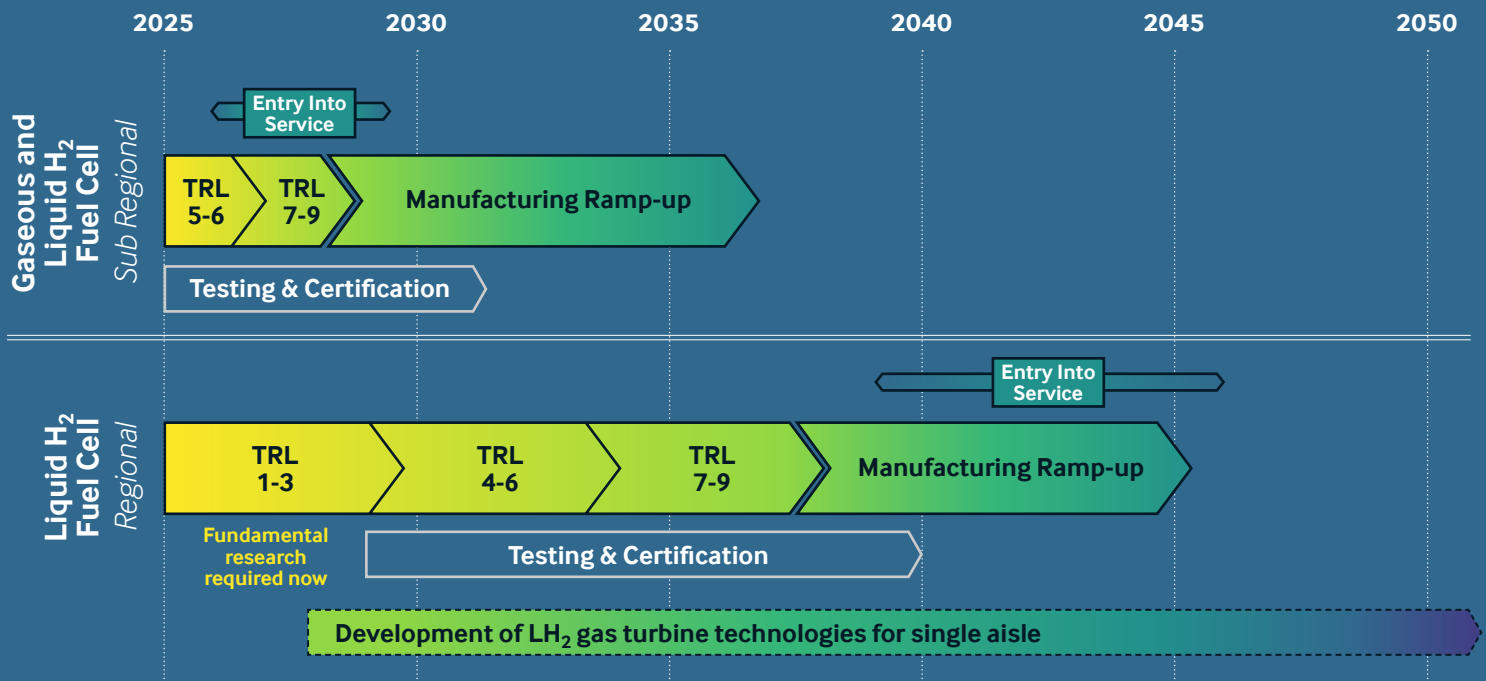


Figure 3 - Timelines of hydrogen aircraft development.

Figure 3 shows the timelines associated with developing gaseous and liquid hydrogen powered aircraft. The first generation of sub-regional, gaseous hydrogen aircraft are being flight tested today, as well as some smaller LH₂ aircraft. These platforms pave the way for testing and technology development of larger commercial aircraft in the future. It highlights the importance of taking action now in building knowledge and capability in fundamental research, testing facilities and the supply chain to be prepared for future generations of zero carbon platforms.

The next generation of hydrogen aircraft will likely combine liquid hydrogen fuel with fuel cells as the propulsion source. These platforms are now expected to enter service in the 2040s. To achieve those timelines, action is required now, particularly in underpinning fundamental research to enable technologies to be developed in time. The HCN has studied what those priority research areas are, and other key areas required to support.

HCN Focus Areas

This report summarises each of the focus areas of the HCN and is the last of 16 published reports, the themes of which are highlighted in *Figure 4*. These reports have detailed analysis and findings, and the following sections provide a summary of those findings for the UK sector regarding research, technology, test infrastructure and skills.

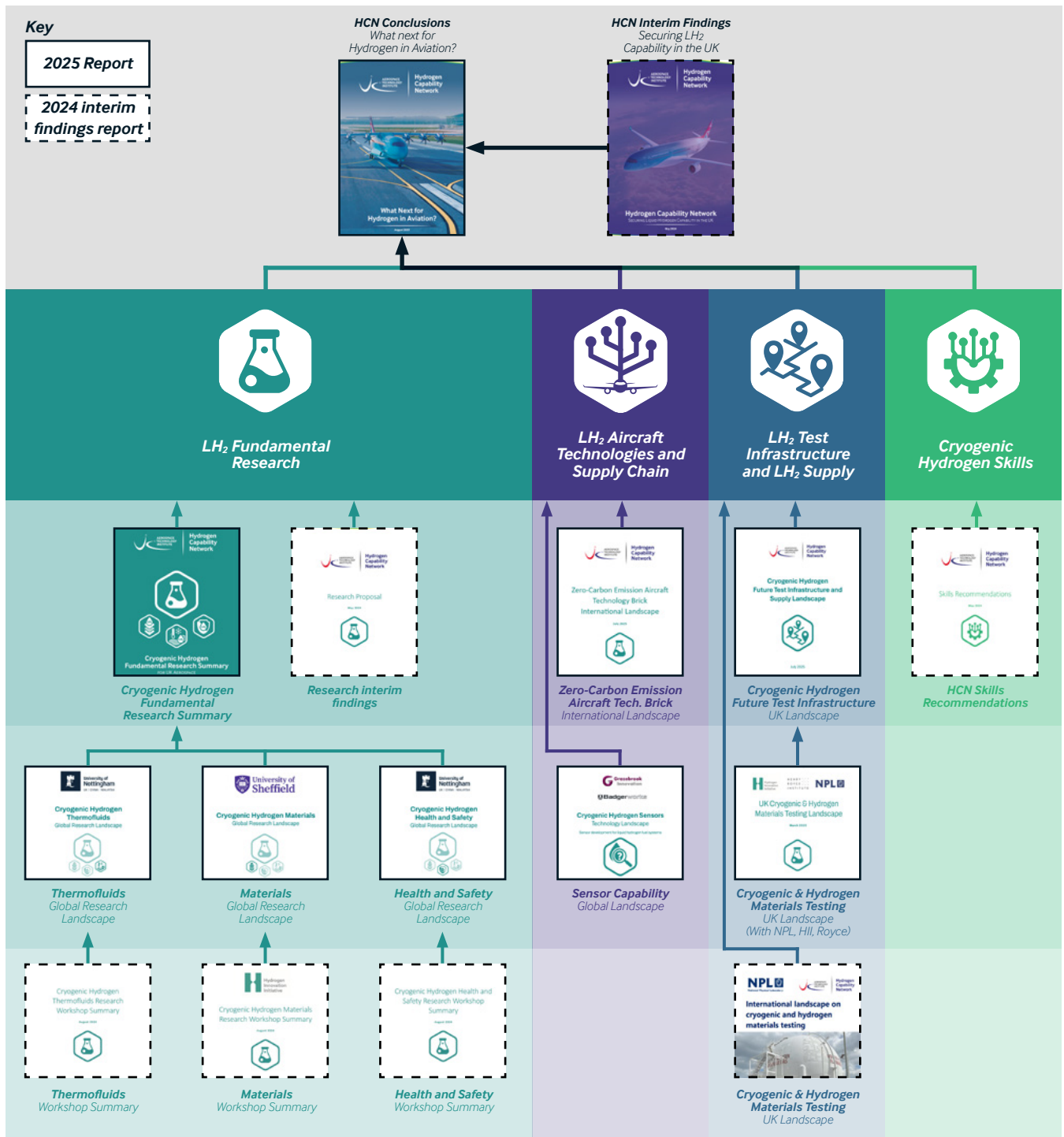


Figure 4 - HCN Reports and key themes studied.



LH₂ FUNDAMENTAL RESEARCH - GLOBAL LANDSCAPE AND UK PRIORITIES

The HCN has been working with experts from academia, industry and adjacent sectors to identify the priority research areas for LH₂ in aerospace, and what is needed specifically to develop this knowledge in the UK. The HCN commissioned three global landscaping studies, working closely with universities and research institutions, to understand the global landscape for fundamental research for:



Material Behaviour in Cryogenic Hydrogen Environments

Global Research Landscape

led by the University of Sheffield
with support from Oxford Research
and Development Limited



Cryogenic Hydrogen Thermofluids Behaviour

Global Research Landscape

led by the University of Nottingham



Cryogenic Hydrogen Health & Safety

Global Research Landscape

led by the University of Nottingham
with support from the
Health and Safety Executive (HSE)

For each topic, findings were based on publicly available information, including historical seminal texts and recent publications. The research highlighted the significant increase in cryogenic hydrogen related research over the past five years, with USA and China far ahead of other countries. It also showed that LH₂ related patent applications have increased fivefold since 2018, indicating the conversion of fundamental research into pre-commercial R&D for LH₂ related technologies.

Each study relied on engagement with experts from across the aerospace sector through a series of workshop sessions and the involvement of an advisory board. These led to the generation of the detailed sub-topics that are of critical importance to advancing the fundamental understanding of LH₂, and development of heat maps for each sub-topic which established industry priorities and the timeframes for which they had to be tackled. Some common themes have emerged across all topics, which have been captured on the following page.

Standardisation of test procedures and expansion of experimental data

There is a strong need for standardised equipment, methods, and test procedures across all three areas to ensure consistency and comparability of data. This will allow independent experiments from diverse research groups to be compared to each other. More experimental data is required to fill the significant gap in data for cryogenic hydrogen environments as the usefulness of existing data is limited by the lack of standardised test procedures, making comparisons difficult. As additional test infrastructure becomes available in the UK, increased data and experimentation will be crucial for developing and validating models and advancing technology development. Testing with LH₂ is expensive, so a focused effort on standardisation would be globally beneficial, preventing the need for costly repetitive experiments.

Fundamental research and understanding

Further experimentation and modelling are required to progress knowledge of cryogenic hydrogen. This includes developing fundamental understanding of material behaviour, including physical and mechanical properties and the impact of long-term hydrogen exposure and thermal cycling. Similarly, for thermofluid behaviour, a greater understanding is required in phase transitions and heat transfer. Health and safety protocols need to be developed in parallel, through understanding liquid hydrogen in various scenarios, including leakage, dispersion, and ignition. Specifically, more research is required on hazards, the causes, impacts and in particular human factors in hazard scenarios. Fundamental research in these areas is beneficial for the UK, as breakthroughs may lead to spinouts creating new supply chain companies. An example of this is **H2Fly** which spun out of the **University of Ulm** and the **German Aerospace Centre (DLR)** in 2015 before being acquired by USA's **Joby Aviation** in 2021^[14].

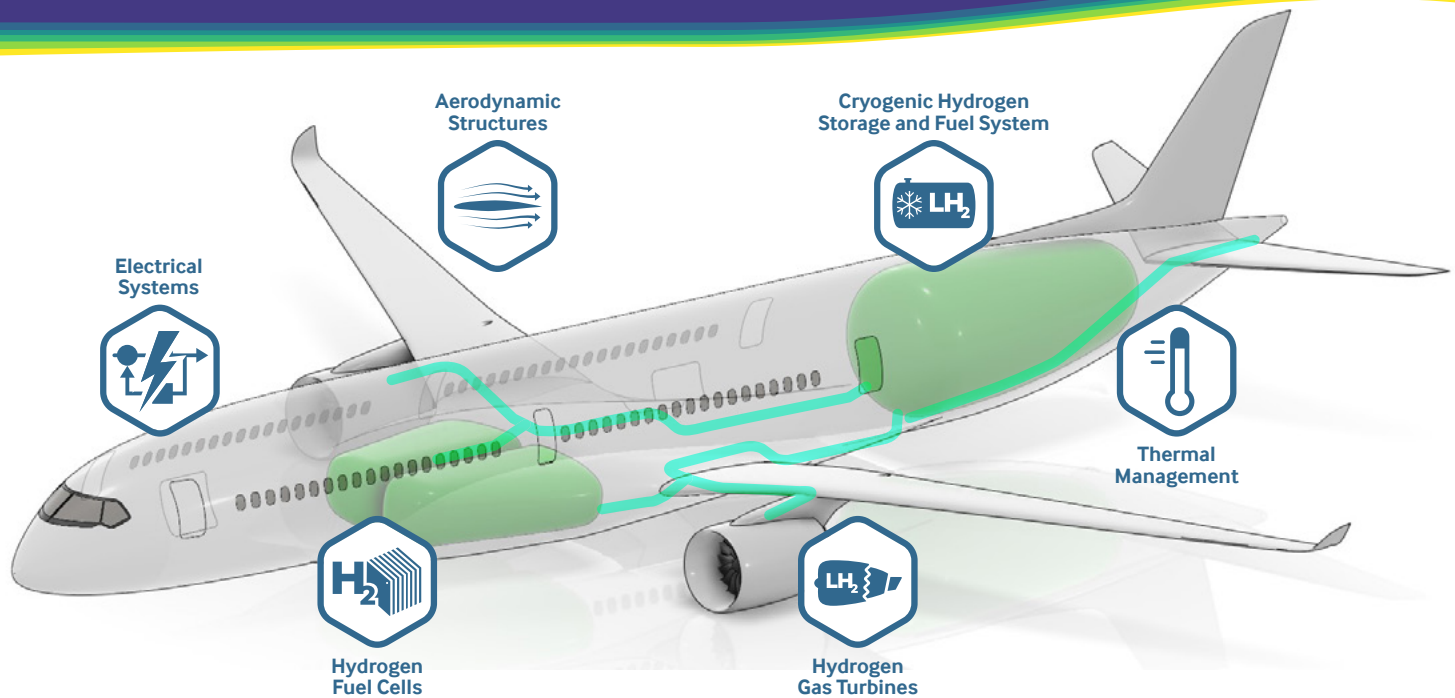
Investment in test facilities

Specialised test facilities are required to undertake experimental testing to generate data. Due to the nature of testing with LH₂ and the scarce supply of the fuel, these test facilities are essential for creating a safe testing environment, progressing industry priorities and progressing product design and certification. Established facilities overseas include **DLR's** Lampholdhausen site, **NASA's** facility in Stennis, and **Washington State University's** HYPER lab. To compete with countries with established facilities and existing space capability, the UK needs to build capability at pace to enable testing, build cryogenic knowledge and build experience of handling LH₂. Facilities are needed at smaller scales to support academic research and at larger scales to support product and system testing.



LH₂ AIRCRAFT TECHNOLOGIES AND SUPPLY CHAIN - INTERNATIONAL LANDSCAPE

The HCN reviewed UK and international capabilities in six key technology bricks relevant to zero-carbon aircraft. This study follows on from the work carried out in the FlyZero project^[15] in 2022 and provides an update on where progress has been made and where the opportunities lie for the UK. These technology bricks are highlighted in *Figure 5* below.



 **Figure 5 - Key Technology Bricks for Zero-Carbon Flight.**

The study assessed technology development across the world but focussed on five countries with the most consistent level of research and investment across all six technology bricks and where the countries have information available in the public domain: Japan, France, Germany, the United States and the United Kingdom. From the global research landscaping activity, we can see that China is active in LH₂ research from publications and patent applications but for industrial R&D there is less information publicly available. Six different comparators have been used to compare each country's levels of advancement in the different technology bricks:

- Current aerospace sector capabilities (in conventional aircraft technology) and market presence.
- Test infrastructure relevant to supporting the technology brick.
- Low-TRL academic capability and ongoing research.
- Mid-TRL research and development funding commitment and projects underway.
- National or non-governmental body policies and roadmaps.
- Current cross-sector capabilities in the technology brick.

The cryogenic hydrogen storage and fuel system was identified as a critical area for development, requiring significant technological advancements. This is due to technical challenges associated with the phase change of hydrogen from liquid to gas, from the point of storage to the point of use (either in a gas turbine or fuel cell). The UK has strong expertise in fuel systems for conventional aircraft, but it lacks in cryogenic test infrastructure and low-TRL research as there has not been significant industry around LH₂ in the UK previously. There is strong existing mid-TRL support and industrial interest around LH₂ fuel systems, but the underpinning LH₂ and research understanding is not present in the UK to the same extent as it is in other countries such as Germany, Japan, and the USA, who have successful space programmes to bolster their LH₂ systems knowledge.

Thermal Management has been identified as being closely linked with LH₂ fuel systems and essential for managing heat across system. The other technology bricks require less disruptive changes. The development of these technology bricks for the next generation of ultra efficient aircraft, puts them on a good trajectory to be mature for future zero-carbon aircraft.

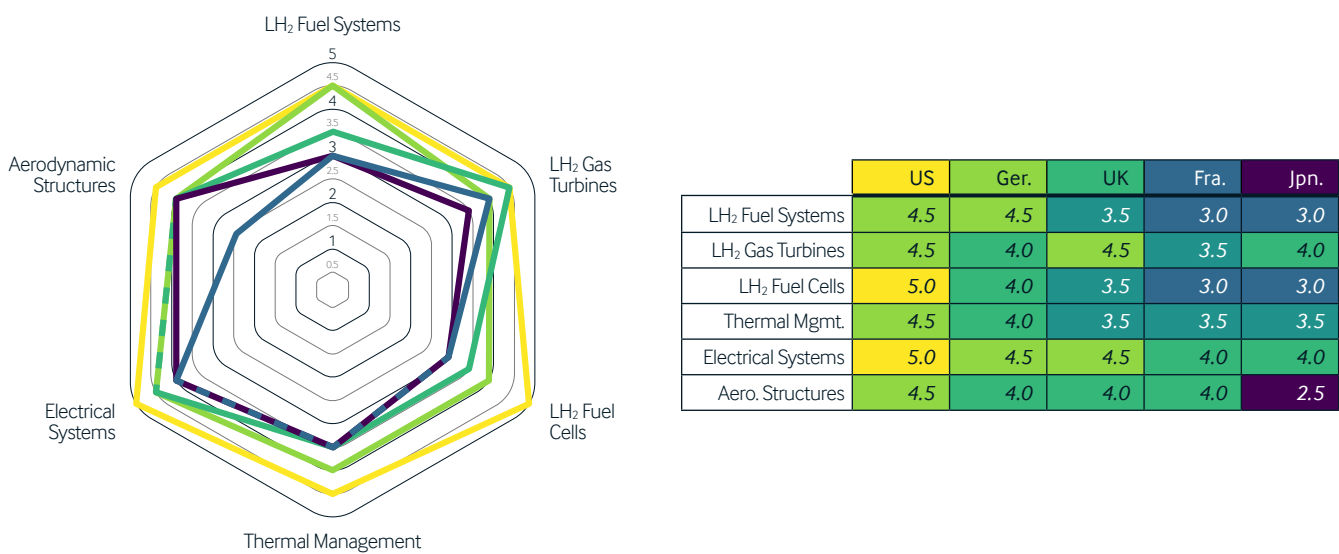


Figure 6 - Comparison of zero-carbon technology bricks by country.

Figure 6 shows that the UK is strong in many of the zero-carbon technology bricks, with potential to be a leader in this space if fundamental research and test infrastructure is bolstered. There is strong competition from USA, Germany, France and Japan most of whom have historic space programmes, funded research programmes (across TRLs), or test facilities which allow them to develop these technologies easier.

Sensors

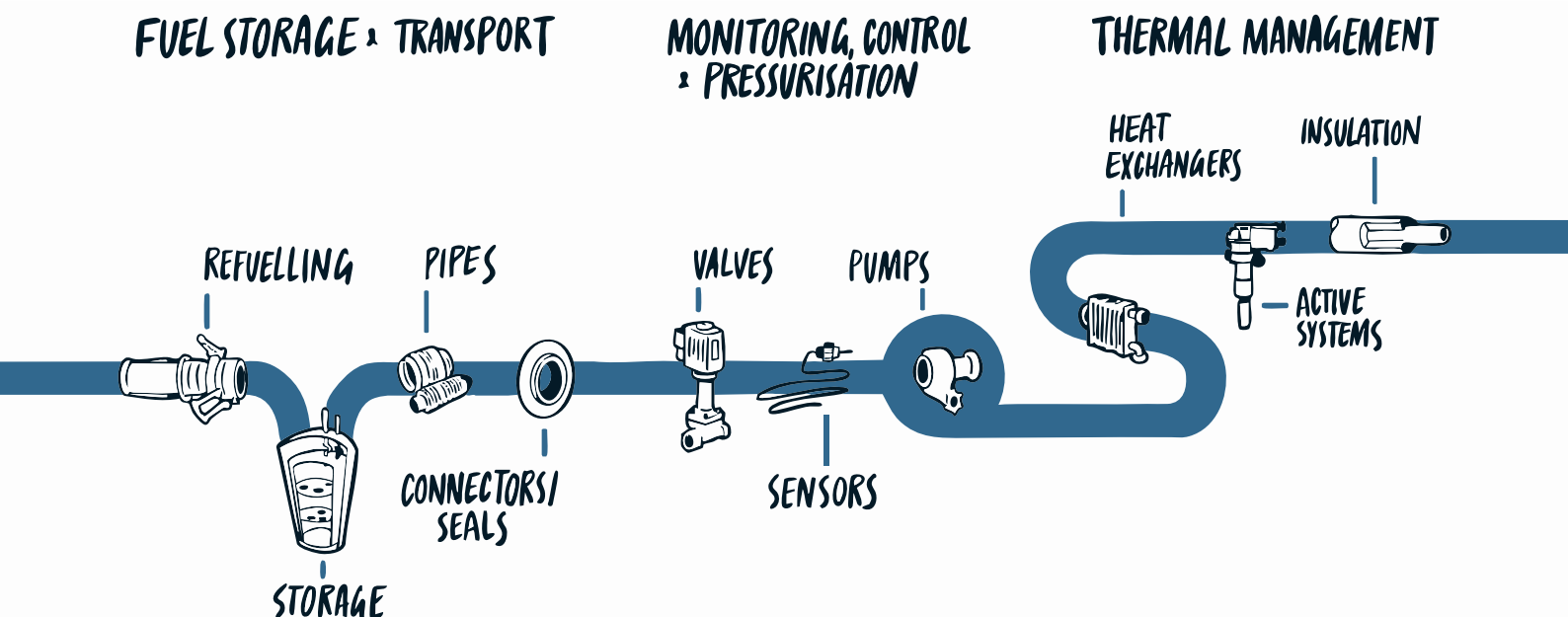
Beyond the technology bricks mentioned above, the HCN also identified the importance of developing reliable and certifiable sensors which can be used on LH₂ powered aircraft. As LH₂ technologies develop, a broad range of sensing technologies will be required to operate in conditions that are radically different from those used on current aircraft.

In the short term, reliable sensors will be required to support the testing and development of other LH₂ technologies. Sensors will allow engineers to measure how components behave under cryogenic conditions, including the measurement of temperature gradients, pressure drops and thermal stresses. They will also be crucial in detecting safety risks early, such as identifying risks or detecting microcracks.

Commercially available sensors exist for many of the phenomena required for LH₂ aircraft, though work is needed to convert and certify relevant sensing technologies for LH₂ aircraft applications. This includes ensuring sensors work throughout the life of a cryogenic aircraft and taking a holistic approach to develop whole systems with integrated and multi-functional sensing. Ultimately, sensors will enable the validation of cryogenic components in a safe manner and will be crucial in enabling LH₂-powered flight in the future.

Supply Chain

The HCN has identified the need to support the UK supply chain through targeted technology development of hydrogen components and products. Through engagement with aerospace manufacturers, the HCN identified key technologies which need to be developed within the UK supply chain, as this capability is limited globally, and existing components do not meet aerospace requirements. *Figure 7* shows some of the components which make up the cryogenic hydrogen storage and fuel system.



 **Figure 7 - Cryogenic hydrogen storage and fuel system.**

For most of these critical components, the supply chain does not exist due to a lack of fundamental research in the key topics mentioned above. However, there are additional challenges which are limiting the supply chain from developing these components.

Several organisations with existing expertise and products for cryogenic hydrogen management have highlighted that the return on investment (ROI) from long-term aerospace technologies is not sufficient to justify R&D. Alongside this the other barriers discussed in this report are impacting SMEs, such as validated models and materials datasets, availability of test infrastructure and cost of testing.

Additionally, direction on priority technologies and components from OEMs has not reached the supply chain. OEMs and Tier 1 suppliers are also looking to leverage existing overseas supply chains, increasing the risk of overseas migration for key technologies.

Coordination across the value chain will ensure that the UK supply chain is adequately informed of priority technology and research areas. Additionally, funding for the UK's supply chain to develop these technologies at pace will increase the possibility of winning future market share. Supporting the supply chain's access to research at an early stage will build their capability and hence allow them to develop products for this market. Spin-outs are also likely to come from and be supported through fundamental research, some of whom could be the component suppliers of the future.

LH₂ TEST INFRASTRUCTURE AND LH₂ SUPPLY



The HCN has been working with experts from the aerospace and hydrogen gas production sectors to establish a roadmap of UK facilities of all scales, which will be needed to fulfil the experimental and testing requirements of industry and academia. The study also considered the various methods for supplying LH₂ to these facilities.

A survey was conducted to capture the supply and demand for LH₂ from end users across the aerospace sector. This was followed by a workshop held in March 2025 to gather insights from participants in the development of LH₂-fueled aircraft. The workshop also provided an opportunity for those working in different parts of the value chain to present and share methods and best practices on supplying, storing and handling LH₂. The study and workshop established the following findings and potential solutions for the UK.

Demand

Predicting long term demand of LH₂ is difficult due to the uncertainty of technology development and test campaigns. Over the next 2-3 years, demand of LH₂ remains small in the UK – in the order of 1 to 30 kg/day.

Facilities

Universities and SMEs are seeking to build their own LH₂ test capability and are seeking funding to develop these facilities. Little currently exists to support fundamental materials and thermofluid research and testing. The development of a centralised laboratory capable of testing thermofluid and material properties, would provide users with a space for testing across all TRLs and would encourage the development of relevant standards. Figure 8 provides an overview of the proposed UK LH₂ facilities and when they will become available.

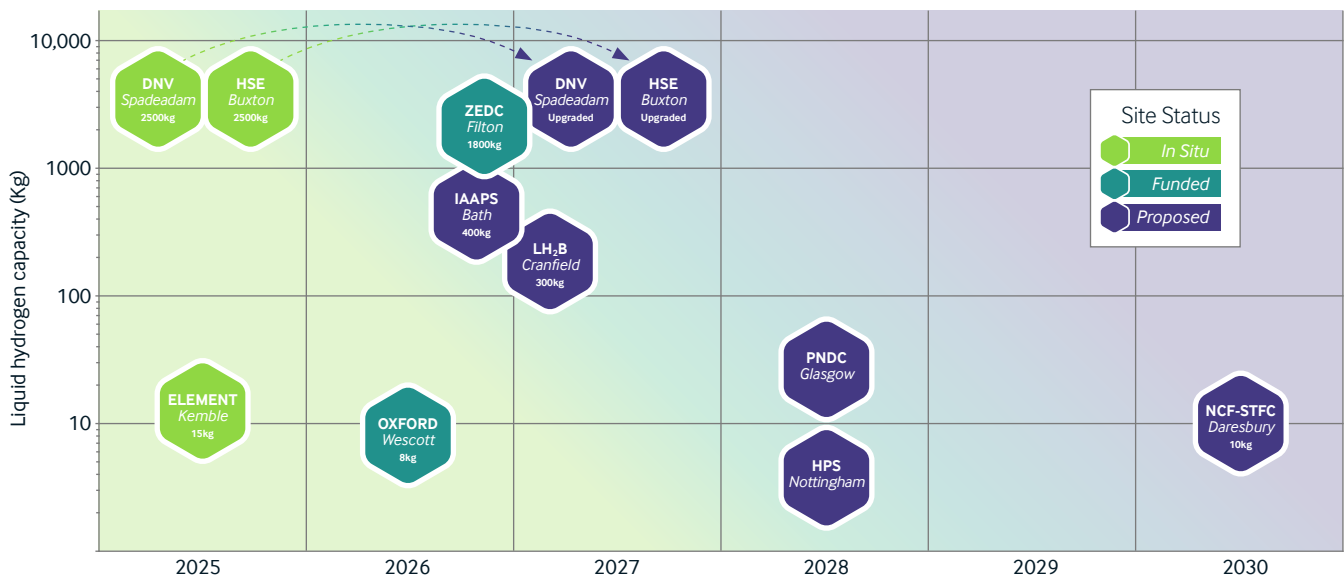


Figure 8 - Timeline of proposed UK LH₂ facilities and scale

LH₂ Supply

LH₂ in the UK is still difficult and costly to obtain. The cost of LH₂ can reach £5000/kg when considering small quantities, whereas the minimum order quantity for a tanker of LH₂ is typically 2500kg. Both factors place a large barrier to access LH₂ in the UK.

Potential solutions to this include the investment of a long-term storage trailer, built with Liquid Nitrogen (LN₂) insulation to store LH₂ for up to 200 days. Alternate solutions include onsite small-scale liquefaction, and the exploration of smaller LH₂ tankers which could be used to deliver smaller quantities from the UK's larger hubs to smaller facilities.



CRYOGENIC HYDROGEN SKILLS

The HCN's conclusions regarding skills remain largely unchanged since the publication of the HCN's Skills Recommendations^[16] in April 2024. Currently, the talent pool for LH₂ related skills is small globally. UK companies are struggling to find suitably qualified and experienced personnel (SQEP), and without near-term actions, the UK's long-term zero-carbon aerospace competitiveness is at risk.

Despite this, other countries are beginning to build their capability with LH₂ by providing opportunities for 'learning by doing'. Through a combination of funding research, developing test facilities and supporting supply chain projects, other countries' sectors have developed their understanding of how to store, handle and transport LH₂ safely.

Conversely, the UK currently has shortages in academic LH₂ projects, testing experience and test design and set-up. As such there is a need to build a community to accelerate the growth of the talent pool in the UK, whilst also supporting technology development. The recommendations mentioned in the sections above will all play a role in building this community, particularly as research projects and LH₂ facilities begin to expand.

Best practices from other sectors with novel technologies has shown that a coordinated approach is the best route to ensure that skills are developed proactively in the UK. Case studies from the Nuclear, battery, electric vehicle and artificial intelligence sectors has shown that the following steps should be taken:

- **Signposting of open-access training courses and job opportunities** - The HCN's Network Map^[17] has started to share relevant courses with the LH₂ community.
- **Training Support** - provision of bursaries for people to attend relevant training and conferences.
- **PhD and Postdoc Enrichment** - building a cohort of postgraduate students to deliver training, build a community and share industry challenges.
- **Conferences** - The HCN's cryogenic research conference in January 2025 highlighted the value of knowledge sharing, community building, and career promotion
- **Learning-by-Doing** - Collaboration with test facilities, industry and universities to ensure that experimental best practices and lessons learned are shared with the wider community.

Existing hydrogen skills efforts such as the **Hydrogen Skills Alliance**^[18] or the **Aerospace Growth Partnership's Skills Working Group**^[19] are important but are focussed on longer-term planning or the broader skillset for the aerospace sector. However, a coordinated approach is required for LH₂ in aerospace to accelerate talent pool growth, bridging knowledge across all sectors working in this space.

HCN CONCLUSIONS AND SUMMARISED RECOMMENDATIONS

Over a 24 month period, the HCN has worked collaboratively to capture and consolidate requirements and convene groups from across the hydrogen value chain. Active attendance to the HCN's workshops and conference as well as detailed input to surveys has enabled the HCN to establish the conclusions discussed in this report.

In the last two years, the zero-carbon aerospace sector has moved forward. Sub-regional, gaseous hydrogen aircraft are being flight tested, but the challenges of developing larger, LH₂-fuelled aircraft have become more pronounced, delaying the timelines of these programmes.

With larger scale zero emission flight moving into the 2040s, there is an opportunity for the UK sector to position itself to win workshare and become a leader on future platforms. To achieve this, a coordinated approach is required on fundamental research, development of infrastructure and the acceleration of testing with LH₂.

A summary of the HCN's recommendations have been consolidated below and on the following pages.

LH₂ FUNDAMENTAL RESEARCH



- ▶ Fundamental research is required in cryogenic materials, thermofluids and health and safety to anchor industrial R&D in the UK.
- ▶ The UK needs to develop fundamental science, data and understanding, through a standardised approach in order to move towards commercially viable and certifiable LH₂ aircraft in the future.
- ▶ Integrating and coordinating research across TRLs will enable the rapid transfer of knowledge from academia to industry.
- ▶ Experimental testing is required to generate aerospace relevant datasets.

LH₂ AIRCRAFT TECHNOLOGIES AND SUPPLY CHAIN



- ▶ The cryogenic hydrogen storage and fuel system has been identified as a critical area for development, requiring significant technological advancements. The research gaps discussed above need to be addressed to ensure manufacturing of LH₂ fuel systems remains in the UK and opportunities for storage tanks are exploited.
- ▶ Components such as sensors, pumps, valves and pipes that are reliable and certifiable in a cryogenic environment are needed for the fuel system, they will also support the testing and development of other LH₂ technologies.
- ▶ Supporting the UK's supply chain and providing access to research and data at an early stage will build capability and allow manufacturers to develop products for this market. Securing early experimentation and testing will lead to the generation of more IP in the UK in later years.

LH₂ TEST INFRASTRUCTURE AND LH₂ SUPPLY



- ▶ Investment in UK-based test facilities is needed to accelerate understanding of LH₂ and enable the production of experimental data. These facilities will fill the global gaps in understanding of fundamentals and support technology development.
- ▶ Experimental facilities are a means to unlocking other areas discussed in this report. Centralised facilities enable research at all levels, creates experimental data, develops health & safety best practices and improves the UK's skills base for handling, storing and testing with LH₂.
- ▶ Supply of LH₂ is needed in the UK. Providing access to LH₂ at all scales enables increased research, testing and skills development.

CRYOGENIC HYDROGEN SKILLS



- ▶ There is a need to build a community to accelerate the growth of the talent pool in the UK, whilst also supporting technology development.
- ▶ Through the provision of signposting, training support, conferences and community building, the UK will be able to grow the skills base at an adequate pace to support the development of LH₂ technologies.



COMMON THEMES ACROSS ALL AREAS



Coordination across the sector

Coordination is required across all the topics mentioned above to reduce duplication, maintain coherence and focus on the strategic priorities, ensure collaboration and appropriate open dissemination of data, knowledge, standards and guidelines to advance the sector at pace. The HCN has demonstrated the importance of coordination in bringing organisations together and prioritising key research areas. This end-to-end sector leadership is the first time this approach has been employed for LH₂ in the UK, and a sustainable approach is needed for the future. The HCN took a unique approach to forming the CHYMES consortia which brought together academia and research organisations to respond to the requirements set out by industry. Although the project wasn't funded during the HCN programme, the approach would have enabled a series of IP-neutral experiments carried out at pace and in a standardised manner reducing overall cost and ensuring open dissemination.



Challenge-based approach

For a novel and disruptive technology, a different approach to funding is required for the areas where coordination failures exist and a market led approach will not drive the pace required. Specifically, for LH₂ adoption in aviation a challenge-based approach should be employed that strategically manages across the TRL boundaries for a broad set of stakeholders. As the new aircraft technology needs to be integrated with new airport technology, and the challenges for understanding the safe handling, operation and certification of LH₂ is based on similar research for both aerospace and airports, a challenge approach should look to work across the aerospace and aviation sectors. In the way the **Future Flight Challenge** approached the advanced air mobility challenge and small technology demonstrations are proving valuable, such as the hydrogen powered live aircraft turnaround at **Exeter Airport**^[20] under the CAA's **Hydrogen Challenge Programme** and **Project Acorn**^[21] supported by the Hydrogen Innovation Initiative.

The HCN's unique approach of coordinating academia, industry, government, LH₂ suppliers and facilities has been important in highlighting the requirements, opportunities and challenges for LH₂ in the UK. The HCN has drawn inspiration from other challenge-based initiatives such as the **Faraday Battery Challenge** for batteries, the **Future Flight Programme** for advanced air mobility, and **Driving the Electric Revolution** for the electrification of ground transport. This challenge-based approach has allowed initiatives to holistically support fundamental research, skills, spinouts, infrastructure, as well as funding mid-TRL technologies. The HCN recommends this approach to supporting LH₂ in aerospace in the future.



Long-term strategy and funding

The current UK landscape has limited LH₂ test facilities, and it is expensive and difficult to obtain LH₂ to test with. Facilities are unable to build an investment case without guaranteed end users. End users are unable to guarantee demand without having completed initial testing in an LH₂ environment. This situation means organisations are increasingly looking to undertake tests overseas. It is also a situation which would greatly benefit from long-term strategy and funding. This would ensure research is supported at all technology levels, including the building of suitable facilities to ensure testing is carried out safely, with an adequate supply of LH₂. This long term, proactive approach would anchor future research and testing in the UK through building world-class facilities now.



Collaboration across the sector

Bridging the gap between OEMs, supply chain and academia will ensure that fundamental research is supported all the way to commercialisation by industry and will ensure the UK's skills base grows at an adequate pace to support the development of LH₂ technologies. Collaboration with other sectors is vital as the production, storage, transportation and end-use of hydrogen relies on many other organisations who traditionally have not interacted with aerospace in the past.

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APPENDIX

ORGANISATIONS MENTIONED IN THIS REPORT

- [Aerospace Growth Partnership](#)
- [Airbus ZEROe](#)
- [Civil Aviation Authority](#)
- [Climate Change Committee](#)
- [Department for Business and Trade](#)
- [EasyJet](#)
- [Exeter Airport](#)
- [German Aerospace Centre \(DLR\)](#)
- [GKN Aerospace](#)
- [H2FLY](#)
- [Health and Safety Executive](#)
- [Hydrogen Innovation Initiative](#)
- [Hydrogen Skills Alliance](#)
- [Joby Aviation](#)
- [NASA](#)
- [Natural Environmental Research Council](#)
- [Oxford Research & Development Ltd.](#)
- [Plug Power](#)
- [Pratt & Whitney](#)
- [Rolls-Royce](#)
- [University of Nottingham](#)
- [University of Sheffield](#)
- [University of Ulm](#)
- [Washington State University](#)
- [ZeroAvia](#)

✔ HCN's Cryogenic Hydrogen Research Conference – January 2025.



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