Launching Hydrogen-Powered Aviation

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HYDROGEN IN AVIATION

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FOREWORD

By Johan Lundgren, CEO of easyJet and Chair of Hydrogen in Aviation (HIA).

HIA is made up of leading companies, all deeply committed to decarbonising aviation. Around 7% of the UK's total emissions come from aviation, but it is not an activity we can simply switch off. Aviation brings huge economic and social benefits, and we need to make sure these are retained, and that flying does not revert to being something only the rich can afford.

Hydrogen-powered flight offers huge potential to deliver this ambition. To begin with, when produced using carbon-free energy, hydrogen flights will have no carbon emissions. It also has the potential to deliver a cost-effective replacement for short haul aviation, as industry looks to ensure hydrogen is as cost-effective if not cheaper than kerosene.

The use of hydrogen in aviation is already underway. There are already two manufacturers in the UK of hydrogen-powered aircraft, Airbus and ZeroAvia, and some of these aircraft are flying today. Excitingly, Airbus have committed to developing a commercial scale hydrogen-powered aircraft, entering service in 2035.

But this isn't just about flying carbon-free, it is about the potential for the UK to be a global leader, and for hydrogen-powered aviation to support the roll out of hydrogen transport across the UK.

Our sector is one of the greatest success stories of the UK economy, contributing more than £22bn directly to GDP, plus £34bn from exporting aerospace components, and directly employing over 230,000 people across the four nations of the UK. UK Aerospace is a crown jewel for UK innovation, intellectual property, trade, and exports.

The UK has made significant contributions to the development of hydrogen-powered aviation technology, in particular through the Government's Aerospace Technology Institute programme. Now we need to do something that the UK has not always had a good track record for – turning our innovative and exciting R&D into a long-term productive industrial sector that can take advantage of these gains. The UK was at the forefront of the early technological advances in aviation, and we have the opportunity to achieve this again.

This is one of the rallying cries that brought Airbus, Bristol Airport, easyJet, GKN Aerospace, Ørsted, and Rolls-Royce together to form Hydrogen in Aviation (HIA) in September 2023. As a group, HIA represents the vital components of the aviation ecosystem: airlines, manufacturers, airports, infrastructure, and energy producers. We are focussed on ensuring that hydrogen-powered flights become a normal everyday thing in the UK, and that the UK becomes a global leader in hydrogen-powered aviation. Doing so will ensure the UK continues to be an aviation world leader and globally competitive.

We have all the right ingredients for this. The UK is home to some of the leading developers of hydrogen-powered aviation technology, including Rolls-Royce, GKN Aerospace, Airbus, and ZeroAvia. We have a leading aviation regulator, which is well placed to move quickly and support the sector. And we have leading airports and airlines that can facilitate the introduction of the new technology. The UK also has the natural and geographic resources, as well as a skilled workforce, to become a global leader in the production and use of clean hydrogen.

But this is not going to simply happen on its own. We need a clear plan and a strong government vision to make it happen. This is why we have produced this report; to set out how the Government can put in place an industrial plan to ensure the UK is a global leader in the delivery of hydrogen-powered aviation, and what is needed to achieve this.

We commit to doing our share of this work - each of us has made a pledge as part of this, and we want to work with the Government, regulators, and other stakeholders to make sure this happens.

This report sets out milestones around four core journeys we must take in parallel to keep investment flowing into UK hydrogen-powered aviation R&D, modernise regulatory frameworks, and deliver the physical and non-physical infrastructure (i.e. skills) required to get a commercial, hydrogen-fuelled plane off the ground.

We are grateful for conversations that have taken place between the HIA and key stakeholders.

The publication of this report concludes the first period of activity of the HIA, and we will now turn our focus from research and identification, to advocacy, progress, and delivery.

The goal of the HIA is for the UK to lead the world in the field of hydrogen-powered aviation.

I am proud that all HIA members have, at the end of this report, committed to individual pledges to take forward this work. This evidences our commitment to the journeys ahead, and to taking the required action today to seize the once-in-a-lifetime opportunity that is before us.

Guillaume Faury, Airbus CEO

By Guillaume Faury, CEO of Airbus

Air travel plays a vital social, geopolitical, and economic role. It provides the bridges to keep us all connected, to deliver valuable goods, and support millions of jobs. As the need for aviation has never been greater, so is the need to tackle its decarbonisation, thrusting our sector into a new age. How can we succeed in this challenge?

Hydrogen is a cornerstone of the transition from fossil kerosene. It has been safely used in the aerospace and automotive industry for decades, and for aviation, hydrogen is estimated to have the potential to drastically reduce carbon emissions. It enables multiple options for aircraft propulsion, including direct combustion, fuel-cell electricity or a combination of both, and also provides a low-carbon energy source for synthetic fuels.

Harnessing the potential of hydrogen requires important aircraft engineering work. While its energy-per-unit mass is three times higher than traditional kerosene-based jet fuel, its volumetric density is much lower. This leads to significant design challenges, but those whose solution is at reach with current technological capabilities. By the end of this decade, Airbus will have launched its commercial hydrogen-powered aircraft programme.

However, for such an aircraft programme to be successful the maturity of its surrounding hydrogen ecosystem will be at least as important as the aircraft development. Hydrogen production, distribution infrastructure, and the regulatory environment play a crucial role. None of us can tackle all of this alone. Success hinges on coming together with determination.

Within HIA, we are already engaged in technological partnerships dedicated to pioneering solutions for sustainable aviation. Finding agreement on policy recommendations has been the much-needed next step.

As the only industry-led group focused on hydrogen in aviation, HIA has the breadth of representation and expertise to outline, for the first time, how the UK can become a leader of the future hydrogen-powered aviation economy.

EXECUTIVE SUMMARY

Hydrogen in Aviation (HIA) was established in the summer of 2023. The members are Airbus, Bristol Airport, easyJet, GKN Aerospace, Ørsted, Rolls-Royce, and ZeroAvia. Johan Lundgren, CEO of easyJet, currently serves as Chair.

HIA brings together leading organisations operating across the value chain, covering airlines, airports, manufacturers, infrastructure, and energy production. Our members share the belief that hydrogen-powered flight has the potential to deliver Net Zero aviation in a way that preserves the huge social and economic benefits of flying and continues to further enrich people's lives.

Our core mission is to ensure the UK maximises its opportunity to be a global leader in hydrogen-powered aviation. Hydrogen presents a significant opportunity to help realise Net Zero flight, as a feedstock for sustainable aviation fuel (SAF) or as a direct fuel; we will need both uses to achieve this. This report focuses on hydrogen as a direct fuel and doesn't seek to replicate already valuable work from cross-sectoral groups like the Hydrogen Innovation Initiative, to sector specific activities such as the Jet Zero Council's Zero Emission Flight Delivery Group. This transition will not be without challenges, particularly as hydrogen production will require a significant amount of energy. The HIA has been created to contribute to this rich landscape and help ensure political and government focus remains on hydrogen over the coming years and decades.

To bring together this report, the HIA established three working groups, focusing on investment, infrastructure, and policy and regulation. Each group carried out a series of meetings, undertook research to identify milestones, engaged with relevant stakeholders, and produced a series of recommendations. This report is a culmination of the work carried out by these groups, as well as the Steering Group that manages the activities of the HIA.

A full list of the recommendations is set out on p42, and the pledges that the HIA members have made are on p40. Next, we will look to work with all the various stakeholders to deliver the industrial strategy that we need for the UK to become the global leader we all think it can be.

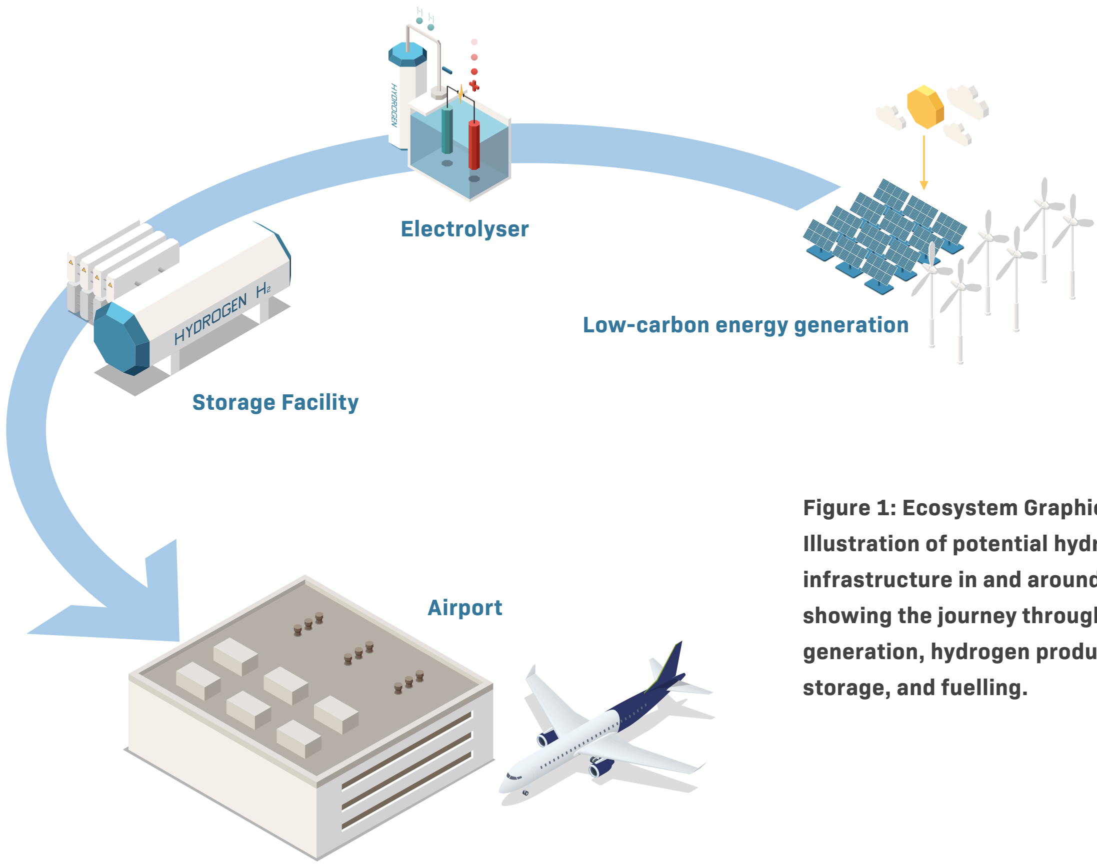


Figure 1: Ecosystem Graphic: Illustration of potential hydrogen infrastructure in and around an airport, showing the journey through energy generation, hydrogen production, storage, and fuelling.

The timeline below highlights some of the key recommendations made in the report, and when they need to be enacted to enable hydrogen-powered aviation.

Short-term (2024-2026)

- Additional CAA funding and capacity to enable hydrogen-ready regulations and standards to be developed
- Supply of liquid hydrogen needed to support R&D and testing
- Reforms to government funding mechanisms for hydrogen production (HAR)
- Aviation hydrogen demand estimates to be identified and shared with government and other stakeholders
- Implement changes to reduce electricity network and grid connection costs to accelerate green hydrogen projects
- Airport engagement with stakeholders to begin planning for future hydrogen supply and the necessary storage, distribution, and refuelling infrastructure
- Airports to develop hydrogen-ready plans
- Hydrogen-pioneer airports established
- Government to create a National Hydrogen Academy by 2025
- Additional funding rounds of the Future Flight Challenge or a similar undertaking, that focuses specifically on developing hydrogen skills
- Industry to develop future workforce plans and to work with academia to build out new curriculums
- Accelerate private sector investment in hydrogen infrastructure development at airports
- Scale technologies through increasing the level of public funding though R&D beyond technology level 6

Medium-term (2027-2030)

- Maturity of regulations and standards
- Hydrogen transition fund for airlines and airports
- Long-term ATI funding settlement of at least ten years
- Government targets for renewables, CCUS, nuclear and hydrogen beyond 2030
- Hydrogen industry '2035-2050' taskforce formed to provide line of sight on potential hydrogen production pipeline
- Research to understand 'tipping point' for hydrogen supply to airports
- Incentives and support for airlines to enable re-fleeting and improve price competitiveness of hydrogen-powered aircraft
- Initial 'starter' network of hydrogen-ready airports to be developed

Long-term (2031-2050)

- Full network of hydrogen-ready airports to be in place
- Enable supply of renewable electricity available for hydrogen production and liquefaction

Across everything

- Stability and longevity in government policy to generate certainty, enabling the UK to secure long-term investment and attract global talent

Key recommendations

1. **Hydrogen-ready technology research and development:** Enable the transition from research to development, and ultimately industrialisation, of world leading hydrogen propulsion and aircraft technologies in the UK.
2. **Hydrogen-ready CAA:** A regulator that is well-funded and resourced, with the capacity to lead on certification, standard-setting, and new regulation.
3. **Hydrogen-ready airports:** A well-developed network of hydrogen-ready airports both in the UK and overseas.
4. **Transition fund and incentives:** The support and incentives needed to get the sector over the hurdle of transition costs and investment in new infrastructure.
5. **Delivering aviation's hydrogen requirements:** Ensuring that we can secure sufficient hydrogen for all sectors that need to decarbonise, including aviation.
6. **Hydrogen-ready skillsforce:** Building the hydrogen skills needed to support the transition to this new technology.

Hydrogen Test Rig at Loughborough University

CHAPTER 1:

ENABLING HYDROGEN-POWERED AIRCRAFT

Hydrogen-powered flight has significant potential to support the delivery of Net Zero aviation, in particular for short-haul flights. The companies that deliver this will secure a leading place in the aviation economy, along with economic benefits for their home countries. In recent years, the development of low-carbon emission technology has accelerated exponentially.

A core part of the UK's aerospace ecosystem is the government-backed Aerospace Technology Institute (ATI), which provides direct government support to research and technology activities. The ATI's FlyZero project concluded that "green liquid hydrogen is the most viable low-carbon emission fuel with the potential to scale to larger aircraft..."[1]. Critically, Airbus has announced they are developing the world's first hydrogen commercial aircraft to enter service in 2035, which will lead to hydrogen-powered aircraft operating flights at UK airports.

The UK's leading aerospace sector provides a clear economic advantage over other countries, from technology development through to delivering large aircraft parts. Keeping this in the UK is essential to deliver a return on that strategic advantage. Without these anchors, the UK would struggle to compete and the aerospace sector could erode, along with the economic benefits associated with it.

New aircraft concepts need to be designed, as hydrogen fuel cannot be used in existing aircraft. Across the UK, many organisations are working on different aspects of the hydrogen-powered aviation ecosystem:

- Rolls-Royce is testing hydrogen combustion systems and cryogenic fuel pumps to deliver liquid hydrogen into the engine.
- GKN Aerospace is developing hydrogen fuel cell and fuel systems technologies capable of servicing the commercial regional and sub-regional markets.
- ZeroAvia is already trialling aircraft/propulsion systems and aims to have a certified engine by the end of 2025, which startup operator Ecojet plans to use in its commercial operations.
- Go-Ahead has launched a fleet of hydrogen buses around Gatwick airport, with a further 34 on order.
- Tees Valley Transport Hydrogen Hub features demonstration activity at Teesside International Airport for commercial and support vehicles.
- Cranfield University owns and operates its own airport and research aircraft, and is taking a leading role in hydrogen R&D activities.
- Airbus UK, whose Fuel System Centre of Competence based in their Filton site is key to providing the expertise and skills needed to realise their ambition to introduce the world's first hydrogen commercial aircraft.

R&D in propulsion and fuel system technologies is the cornerstone, from which everything else follows. If the UK loses the ability to develop these technologies, there is no market signal to invest in the rest of the value chain, including infrastructure. Technology investment risk in aerospace is much larger than other sectors due to the long lead times and long-term estimates of market conditions, which increase the number of potential failure points and decrease the attractiveness for private investment in aerospace.

[1] Aerospace Technology Institute. (2022) The Case for the UK to Accelerate Zero-Carbon Emission Air Travel. Available at: https://www.ati.org.uk/wp-content/uploads/2022/03/FZO-CST-PPL-0041-Case-for-the-UK-to-Accelerate-Zero-Carbon-Emission-Air-Travel.pdf

Rolls-Royce and easyJet collaborate on the first test run of a modern aero engine on hydrogen

Aerospace is a high value sector with high barriers to entry. Companies take on long-term risk underpinned by long-term technology development in anticipation of keeping pace with the market. Around the world, including the UK, governments invest public money in the sector, which is often a co-investment alongside industry. The model is in part premised on the inability of banks to reward the level of risk and the ability of government to recoup investment over a longer period. The US goes further in its support for the aerospace sector, by investing heavily in supply chain resilience and new technology to secure a market advantage.

They have selected aerospace as a priority sector to grow and invest in, to stay ahead of the competition.

The ATI has proven to be an effective model to secure demonstrator-ready technologies. However, industrialising these technologies is much harder to do, particularly on match-funded, 50% geared projects. Developing the technology to enable hydrogen-powered flight will require investment beyond what private companies can deliver alone, so increasing the percentage of government investment, either through the ATI or other means, is essential.

GKN Aerospace is developing sustainable aerospace technologies ranging from complex aerostructures to hydrogen fuel-cells

Case Study: Rolls-Royce and easyJet's hydrogen combustion engine technology

easyJet and Rolls-Royce are pioneering the development of hydrogen combustion engine technology, capable of powering an easyJet-sized aircraft in the future. The programme will develop a whole engine fuel system targeting the completion of a functioning liquid hydrogen gas turbine engine within the year. There are three technology challenges in the journey to enabling hydrogen for use in aviation: fuel combustion, fuel delivery, and fuel systems integration with an engine. All elements must be confirmed to operate safely.

In September 2023 Rolls-Royce set a world first when tests on a full annular combustor of a Pearl 700 engine at the German Aerospace Centre DLR in Cologne, with the engine running on 100% hydrogen and proving the fuel can be combusted at conditions that represent maximum take-off thrust. This part of the programme included upgrading four cells at the UK National Centre for Combustion and Aerothermal Technology (NCCAT) at Loughborough University, which led to improvements on fuel nozzle design that helped make this possible.

The latest set of tests, to prove aerospace cryogenic liquid hydrogen pump systems, have begun at Rolls-Royce's facility at Solihull, UK. These will address a key engineering challenge of taking low-pressure liquid hydrogen, chilled below -250°C, and pressurising it so that it can then be pumped into an engine to be combusted.

Case Study: Airbus ZEROe – working towards the world's first hydrogen-powered commercial aircraft

Airbus' ambition is to bring to market the world's first hydrogen-powered commercial aircraft by 2035. The ZEROe project explores hydrogen-combustion and fuel-cell propulsion technologies, with a dedicated Development Centre and Fuel System team in the UK. The ZEROe project is exploring a variety of configurations and technologies, as well as preparing the ecosystem that will produce and supply the hydrogen. As Airbus moves towards its ambition of bringing to market a hydrogen-powered commercial aircraft, many of the technological and testing milestones revolve around establishing the means of propulsion.

Airbus is working on four aircraft concepts powered by hydrogen, with complementary technologies. Further information on their work on the wider airport ecosystem can be found in the case study on p30.

Case Study: GKN Aerospace

GKN Aerospace is working in partnership with the ATI, industrial, and academic partners to deliver two important hydrogen technology programmes. The H2GEAR programme delivers a ground-based hydrogen fuel cell electric power train demonstrator, built and operated in the UK. A primary goal of this project is to demonstrate the feasibility of their unique hydrogen fuel cell system to power 90+ seat aircraft appropriate for the commercial market.

HYFIVE is a technology programme led by Marshall Aerospace, in partnership with GKN Aerospace, to design and develop a ground based liquid hydrogen fuel system demonstrator capable of supporting hydrogen-electric and hydrogen combustion. By developing technologies to serve both forms of propulsion the opportunities to enter the zero-emissions market will be greatly increased. GKN Aerospace is also working with international partners to explore the opportunities for a test flight demonstrator in the coming years.

Case Study: ZeroAvia

ZeroAvia is targeting the development of hydrogen fuel cell (hydrogen-electric) engines. From its R&D hub in the Cotswolds, it has made enormous strides under the ATI HyFlyer programmes, including world-first flights of two prototypes. Most recently ZeroAvia has conducted ten test flights of a testbed Dornier 228 with the left-side powered by its ZA600 prototype engine, designed for up to 20 seat planes. The company is now advancing certification work with the Civil Aviation Authority (CAA) for this first engine with an entry-in-service target of the end of 2025, while also developing the technology for an engine for 40-80 seat planes, with commercial entry planned by 2027.

These examples are just a snapshot of the work already going on across the UK. Thanks to the strength of the UK's aviation industries, we are currently ahead of international competitors. However, the gap is closing, and it is vitally important that we act now to ensure the UK industrialises this R&D and secures a long-term leading position.

Gaps and recommendations

Whole of government targeted interventions

Companies in the UK are already making considerable progress towards hydrogen-powered flight, but we cannot be under any illusion that this is an easy and quick challenge to solve. The R&D required upstream to develop the propulsion systems and airframes will take many years and require targeted public and private investments. The scale of R&D required around power propulsion alone to achieve hydrogen-powered flight is extensive and includes, but isn't exclusive to: combustion properties, compressors, and cooling, fuel cell development, cryogenic and heat management affinities, noise performance, fuel impacts, mitigating the impact of non-CO2 emissions such as NOx, and on-aircraft hydrogen storage and distribution concepts. Around this there are infrastructure requirements and skills needs that must be accessed.

The interventions required from the Government span multiple departments, so it is imperative that a whole of government approach is adopted, centred on delivering focused objectives so those interventions are targeted and achievable. Industry and government must collaborate right through from research to market, underpinned by dedicated strategic support and a vision for UK aerospace, including future flight technology development such as hydrogen-powered flight. The UK should learn from other countries to establish its strategy for protecting aerospace as a strategic national asset. Doing so would provide a clear vision for government, industry, and investors, and a route to delivery through the whole of government working towards the same objectives. Doing so would position the UK to benefit from first and early mover advantage, remain at the forefront of technology development, strengthen supply chains, deliver required infrastructure, and increase sector resilience to the benefit of the UK economy.

The Hydrogen Capability Network (HCN) has mapped out the interventions required for the UK to deliver and scale hydrogen for aviation purposes. The HCN model is focused on maximising the ambition to secure liquid hydrogen technology in the UK – an ambition shared by Hydrogen in Aviation – and their early to medium-stage interventions include access to materials, testing infrastructure, liquid hydrogen supply, and a skills base to help deliver these.

Recommendation: *It is imperative that the Government continues to support and utilise the work of the HCN in policy development, including engaging industry on future public investment.*

Recommendation: *In support of work already being undertaken by the HCN, Government to progress the development of two medium scale liquid hydrogen Test Hubs and mature the UK's test capability network, particularly to support cryogenic testing at the scale required to move from research to flight.*

Funding the transition from research to market

Scaling these technologies to market will be considerably challenging but could deliver strong economic returns. It is critical that public funds can be invested in moving from research to market-focused commercialisation, moving through the technology readiness level (TRL) process beyond TRL6 – the 'demonstrator phase' – to TRL9 once the technology is ready to market. Doing so would help bridge the transition from research to commercially viable technology. In a hangover from EU state aid rules, the UK's public investment rules in R&D are limited to funding up to TRL6, which can be a key inhibitor for commercialising research and technology. Changing the rules to allow for increased public-private collaboration and investment beyond TRL6 will reduce the risk on companies scaling technology and would better protect companies within the aerospace sector. It would also allow UK companies to better perform compared with those in countries like Germany and the US, which have governments more willing to share the risk between state and industry, making their technology and product markets more attractive. One way to help finance this increase in public commitment without restricting current aerospace finding could be through reinvesting funds through the UK Emissions Trading Scheme directly back into aerospace technology development.

Recommendation: *Amend the UK R&D funding rules and associated delivery mechanisms to allow public investment in aerospace technologies beyond TRL6.*

Recommendation: *Reinvest funds raised through the UK Emissions Trading Scheme (ETS) into aerospace technology development, recognising this as new funding not a replacement for existing committed funds such as those administered through the ATI.*

Creating the right investment environment

The aerospace sector has high barriers to entry with long investment cycles, where return on investments can be realised more than a decade later. This does not make for an attractive proposition or represent lower-level risk for investors, which makes access to capital both difficult and expensive. As noted in a joint report between the ATI and PwC, "...aerospace represents an attractive sector for investors who are comfortable with capital intensity and long product development cycles"[2]. Operating and investment costs remain high for aerospace firms, so to strengthen the competitiveness and resilience of the UK's aerospace sector the investment environment must be de-risked to provide stronger demand signals, improve investor confidence in delivery, and improve access to long-term patient capital. It is important to note here that the absence of effective financing schemes and affordable capital drives companies to look elsewhere or fail. In both cases, this could mean private equity or sovereign wealth fund takeover which doesn't provide any guarantee of UK capability or state-friendly ownership.

[2]Aerospace Technology Institute and PwC. (2022) Funding Growth in Aerospace. Available at: https://www.pwc.co.uk/aerospace-defence/assets/funding-growth-in-aerospace.pdf

ZeroAvia aircraft

Recommendation: *There are several ways the current lending environment could be improved for aerospace firms:*

- *Long-term government policy stability, focused around targeted objectives to achieve hydrogen-powered flight that includes a cross-government strategy to stimulate the market and unlock investment.*
- *Commit to guaranteeing future aerospace R&D funding for at least ten years. The ATI's current multi-year funding commitment to 2031 is welcome, but continues to provide an uncertain outlook for aerospace companies looking to invest in technology development for a speculative future market.*
- *Include aerospace within the UK Green Taxonomy. This would reward positive progress towards ESG goals that support lower investment rate of return (IRR) hurdles and allow for greater confidence in longer-return investments, including for hydrogen-powered aviation technologies.*
- *The asks contained in this report may require amendments to the Subsidy Control Act for these proposals to be implemented, so we recommend reviewing and amending prohibitive provisions in the Act to enable greater partnership between the Government and UK aerospace. The UK Government doesn't have a direct stake in its aerospace sector, instead it uses public investment to leverage private investment. Reducing investment barriers and strengthening the commercialisation of R&D may require amendments to the Subsidy Control Act for this to be truly realised.*

Supply of liquid hydrogen for research, development, and testing

Demand for liquid hydrogen for testing will accelerate at pace alongside technology development but the UK currently has no domestic supply of liquid hydrogen. The UK is not alone in seeking increasing volumes of liquid hydrogen, and sourcing it from countries such as the Netherlands will become increasingly difficult, as nations with production facilities look to retain their own supplies. If the UK has an insufficient supply of liquid hydrogen and testing facilities, the R&D required to achieve hydrogen-powered flight will become unviable, and the UK falls behind in the global race to realise the benefits of early mover advantage. Already the lack of available hydrogen in the UK has led to Rolls-Royce choosing to test its demonstrator engine outside of the UK. It should be noted that even in a gaseous system, it is likely liquid hydrogen may be the preferred choice for storage because of the volume of gaseous hydrogen required for medium/large scale testing. Securing liquid hydrogen requires the right demand signals and a coordinated approach that ensures supply is secure at an affordable cost; ideally not subject to volatile price fluctuations. We welcome the focus placed on this challenge by the HCN and its research into how the UK could coordinate to optimise UK liquid hydrogen supply around location, cost, and delivery so that there is a degree of security of volume for testing. It should be noted that beyond aviation, a sufficient domestic supply of liquid hydrogen in the UK should also support efforts to develop the wider hydrogen economy.

Recommendation: *The Government should ensure that there is a sufficient domestic supply of liquid hydrogen to support R&D and testing in the UK by enabling:*

- *The coordination of accurate liquid hydrogen demand forecasts for aviation testing, in support of the Department for Energy Security and Net Zero's tracking and analysis of total UK liquid hydrogen demand.*
- *Industry should engage with government through the Hydrogen Capability Network to explore options for an agile plan to ensure the short-term and long-term supply of liquid hydrogen, including on the potential for international purchasing, tankering, and onshore liquedfaction.*

Product certification and standardisation

Regulators across the world, including the European Union Aviation Safety Agency (EASA) and the UK Civil Aviation Authority (CAA) have started the process of developing hydrogen specific technical regulations and standards that will sit around the new technological developments. In the UK, there is a wider ecosystem of organisations working on various aspects of this, overseen by the CAA. Leadership by UK regulators is vital to identify certification regulations and industry standards for the design of aircraft, engine, and all relevant technologies.

The significant shift in aircraft concept and design as we move to hydrogen fuel will lead to a greatly increased number of technological challenges and innovations, and therefore less certainty about the regulatory framework around them. Industry will need to work with authorities much earlier in the process to identify and agree certification requirements. Safety is the number one priority for the aviation sector and hydrogen technologies must prove an equivalent level of safety to current regulations, which needs to be reflected in hydrogen-related standards.

Although we are still to develop a full understanding of the technical and regulatory challenges, this must not deter urgent efforts to deliver hydrogen-powered flight. However, previous means of engagement may not be sufficient going forward. Industry and the CAA should review engagement best practice with specific attention to hydrogen, which may reveal more effective models of engagement.

Recommendation: *The CAA should be appropriately resourced to address the challenges outlined in this report, working in co-ordination with other relevant bodies and the academic community to develop the required standards, procedures, and regulations. This should include (but not be limited to):*

- *Standards and means for compliance for the fire safety aspects of hydrogen-powered aircraft, emergency planning, and crashworthiness.*
- *Standards and procedures for the airside use of gaseous and liquid hydrogen.*
- *Operating procedures and regulatory regime for airside hydrogen fuelling.*
- *A process that ensures a universal understanding of how the current certification specifications for large aircraft relate to additional requirements that may not be covered by existing regulations.*

UK leading on international regulatory alignment

Due to the nature of the aviation industry, the harmonisation of regulations internationally will be fundamental to achieving the transition to hydrogen-powered aircraft. Industry needs to have confidence that they will not be required to design technologies and products to meet a range of different standards. Standardisation will allow more access to global opportunities and ensure UK companies can be more competitive.

There is the potential for misalignment between regulators internationally. These situations result in inefficiencies and, especially in the case of a disruptive change like hydrogen, uncertainty. It is crucial that the CAA works closely with other regulators like the EASA, the Federal Aviation Administration (FAA), and the International Civil Aviation Organisation (ICAO), as well as understanding work that is being done on regulations in the wider aviation landscape (e.g. other than the aircraft itself).

The CAA is a highly respected industry regulator and is well placed to drive the development of global standards, and any special conditions to accommodate new technologies.

It is in a position that would allow it to be more agile than many regulators and has the advantage of the presence of so many hydrogen aviation innovators in the UK.

Recommendation: *The CAA should take on a critical role, representing the UK in working with EASA and FAA, in driving regulatory alignment on certification, the operation of hydrogen-powered aircraft, and related infrastructure.*

Skills

The aerospace industry benefits from its size and desirability, making it easier to attract the best talent domestically and from around the world. For hydrogen, the skills market is international and becoming increasingly competitive. In aerospace, the size of the industry means there is a large and increasing need for these new skills.

Approaches to address the growing hydrogen skills shortage have seen varied success. The UK's skills system is reactive, requiring a market to be in place before industry and government are able to respond. A more predictive system would identify the skills required early, enabling better planning. This will be fundamental if we are to maintain our early lead in hydrogen. The Hydrogen Capability Network and the Hydrogen Skills Alliance (HSA), a collaboration between industry, academia, research organisations, industrial clusters, government and skills bodies, should both be supported in their work to predict and address the future hydrogen skills need across the value chain.

The UK needs a timely, proactive national strategy to identify the long-term skills required and build the curriculums today. As highlighted in FlyZero research, without a clear plan, industry will experience significant delays, particularly as the nascent UK hydrogen industry is at a fragmented stage. For the aviation industry, growing the skills base is particularly needed to develop gas turbine and electrical technology capability, fuel cells, systems, and structures.

Recommendations:

- *The Government should establish a National Hydrogen Academy, to be operational by 2025, contributing to a just low-carbon transition The academy should include hydrogen handling skills for airport ground operations, with training programmes linked to the two hydrogen pioneer airports.*
- *Aviation is a global sector with talent and capability placed around the world. Securing the UK's position as an aviation global leader will require access to this global talent pool so in delivering on the 'Jet Zero' commitments, the Government should ensure continued access to talent from abroad in addressing a growing skills need within and around aviation.*

CHAPTER 2:

MAKING HYDROGEN FOR AVIATION

Ørsted's Walney Extension Offshore Wind Farm

The Government has committed to investing in low-carbon hydrogen production, with the headline ambition to deliver 10GW by 2030 - made up of 6GW of electrolytic hydrogen, and 4GW of CCUS-enabled hydrogen. By comparison, Germany has also set target of 10GW of hydrogen production by 2030, and France has a target of 6.5 GW of production capacity by 2030, scaling up to 10GW by 2035.

The HIA respects the Government's 'colour agnostic' approach, where the focus is on ensuring that hydrogen is produced with the lowest possible carbon impact, rather than using any specific production method. This maximises potential hydrogen production to achieve Net Zero. As this chapter illustrates, the volumes of hydrogen that will be required in aviation (including for use in SAF production) will require the production of hydrogen via renewables, access to CCUS, and associated processes for hydrogen production, and nuclear sources.

FACT: *Electrolytic hydrogen, often referred to as 'green' or 'pink' hydrogen, is made using electricity from renewable (green) and nuclear (pink) sources. CCUS-enabled hydrogen, often known as 'blue' hydrogen, is made using natural gas, a process which is made low-carbon through carbon capture, usage, and storage.*

In December 2023, the Government announced 11 projects that would receive funding support via the Hydrogen Production Business Model (HPBM), in the first Hydrogen Allocation Round (HAR1) (see Page 18 for further information). As the Government stated at the time, this represented "the largest number of commercial scale green hydrogen production projects announced at once anywhere in Europe". These projects total a combined hydrogen production capacity of 125MW. Projects without public funding are also being progressed. Hydrogen UK's Project Database includes 146 projects with a total capacity of 24.8GW, based on publicly announced hydrogen projects in the UK (including those in the HAR process)[3]. A map of these hydrogen production projects in the UK can be at Figure 3. The Government's latest Hydrogen Net Zero Investment Roadmap (Feb 2024) indicates 27GW of potential low-carbon hydrogen production projects identified in the UK pipeline through to 2037.

However, in a worldwide context, the International Energy Agency's Global Hydrogen Review 2023 found there is a significant delivery gap between plans for hydrogen projects on paper, and Final Investment Decisions (FID). It concludes that "of the potential volumes projected for 2030, only 4% globally have reached FID". When taking into account the demand for hydrogen-powered aviation and the significant amounts of hydrogen that will be needed to make SAF (see DESNZ demand estimates below), these findings help to evidence the necessity for the UK Government to maintain an attractive investment and policy environment that accelerates the production of hydrogen in the UK.

Figure 3: UK Hydrogen Production Projects

Source: Hydrogen Energy Association

[3] Hydrogen UK. (2023) Electrolytic Hydrogen Production. Available at:https://hydrogen-uk.org/publication/electrolytic-hydrogen-production/

This shows the scale of the challenge to ensure the delivery of projects on the ground to provide a secure and reliable supply of hydrogen when compared to the estimated demand of c. 350k tonnes annually by 2050 (according to the central estimate from Jacobs, see below and page 19). Assuming the higher heating value (HHV) of hydrogen, Jacobs estimates that the required rate of energy generated by the hydrogen production system will be c.90 MW from 2035, ramping up to 1.6 GW by 2050. This rate of production would deliver a total of 0.8 TWh in 2035, and 14 TWh in 2050.[4]

Figure 4: Hydrogen Demand Range Aviation Total
Figure 4 shows how the Department for Energy Security and Net Zero (DESNZ) estimates the demand for hydrogen in aviation will remain relatively low until 2035, before potentially becoming the most hydrogen-demanding transport sector by 2050.

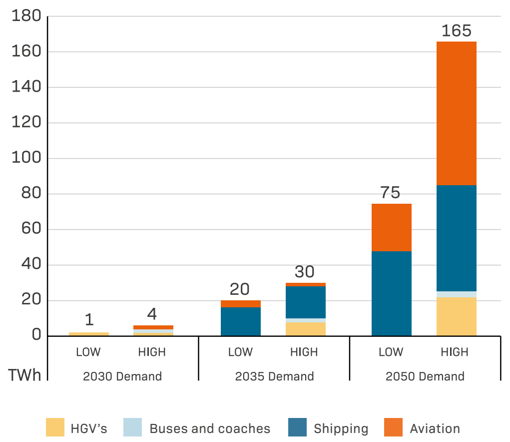
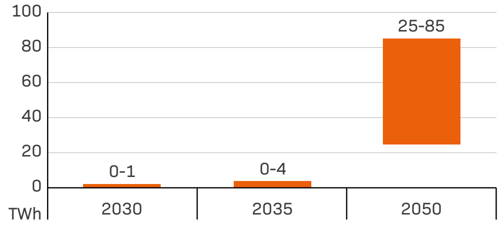


Figure 5: Hydrogen Demand in Transport
Figure 5 shows how these demand levels can vary and will increase significantly from 2035 as hydrogen-powered flight technology becomes ready for mass deployment.



Source: DESNZ, Hydrogen Transport and Storage Networks Pathway

Note: these figures include assumptions about hydrogen to be used as a feedstock for Sustainable Aviation Fuels, whereas the Jacobs figures cited above and later in the report look at hydrogen-powered flight only.

The production of low-carbon hydrogen faces a unique challenge on its journey to commercialisation, as both supply and demand need to be developed in parallel. To attempt to overcome this 'chicken and egg' situation, the Government has prioritised policy and funding for scaling up the production and supply of hydrogen.

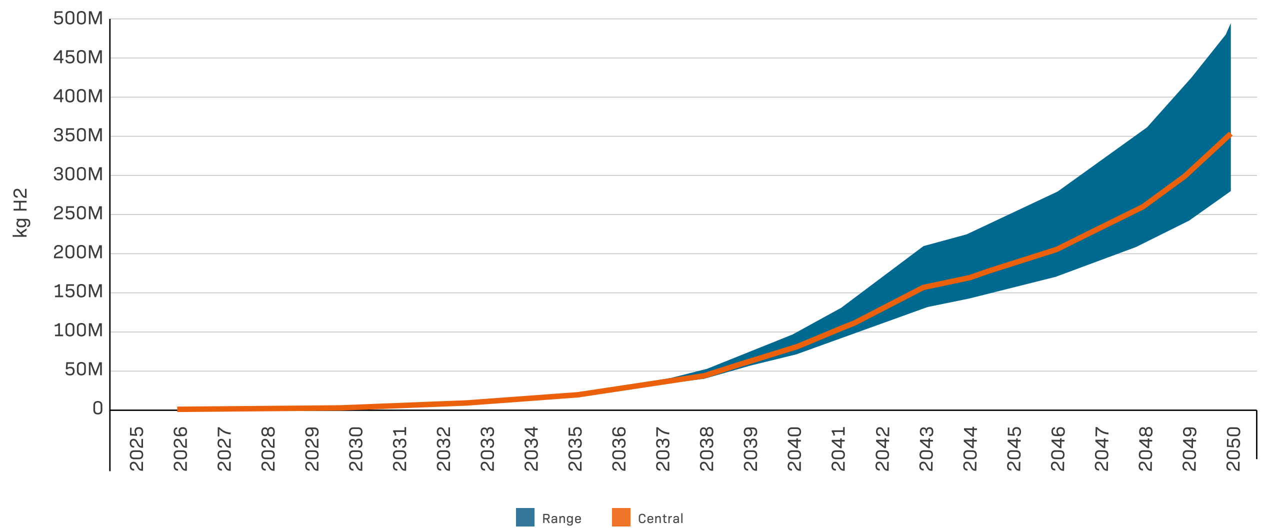
How the UK Government is helping to finance early electrolytic hydrogen production projects

- Public financial support for electrolytic hydrogen is being provided through the HPBM, delivered through the Hydrogen Allocation Round (HAR) process.
- DESNZ has confirmed there will be annual HARs up to 2029, with allocation levels for HAR2, HAR3 and HAR4 being 875MW, 750MW and 750MW respectively.
- The HPBM is currently financed via the Exchequer, but the Energy Act 2023 has given enabling powers for the introduction of a 'hydrogen levy' that would see funding of the levy move to gas shippers. The Government is expected to consult on the levy in 2024, with a view to introducing it from 2026.

Independent analysis from Jacobs[4] adds further detail to government-produced data, calculating estimated demand scenarios for hydrogen-powered aircraft alone (i.e. without the hydrogen needed for SAF). Their analysis considers low, central, and high usage scenarios, based on insight from easyJet, Airbus, Rolls-Royce, and ZeroAvia forecasting entry into service dates for a range of aircraft sizes.

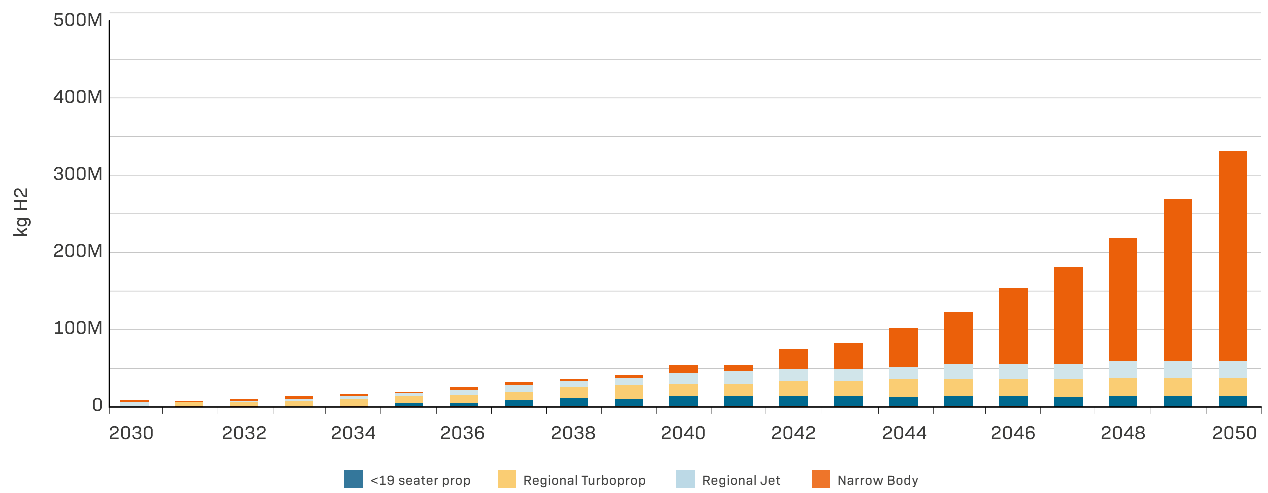
In the central scenario, Jacobs predicts that the demand for hydrogen will be c. 20k tonnes annually for aviation by 2035, ramping up to demand of over c. 350k tonnes annually by 2050. To meet this demand, they predict that the required rate of energy generated by the hydrogen production system will be c. 90MW from 2035, ramping up to 1.6 GW by 2050. If produced through electrolysis, Ørsted estimates that multi-GWs of offshore wind equivalent capacity would be required to meet this c. 350k tonne requirement.

Figure 6: UK Aviation Hydrogen Demand Projection
Figure 6 compares the 3 scenarios.



Source: Jacobs UK Aviation Hydrogen Forecast

Figure 7: UK Aviation Hydrogen Demand by Aircraft Type
Figure 7 represents the baseline scenario, and shows demand from narrowbody planes (typically flown by airlines such as easyJet) compared against demand from other sizes of aircraft.



Source: Jacobs UK Aviation Hydrogen Forecast

The volume of hydrogen required to enable hydrogen-powered aviation at scale increases significantly from 2035. It is therefore important that the Government advances policies and schemes that will accelerate deployment of low-carbon hydrogen production technologies, as well as the required enabling infrastructure.

[4]All figures from Jacobs are provided as an estimate for the purposes of this report and are not to be used in other contexts.

Ørsted's Wind Farm

Gaps and recommendations

Securing domestic hydrogen supply

Hydrogen-powered aviation will require an estimated c. 350k tonnes of hydrogen by 2050, ramping up from around c.20k tonnes in 2035. At the earlier stages of innovation, testing, and R&D (up until 2030), hydrogen demand is expected to be 11-22 tonnes per quarter.

To enable this early testing and R&D it will be important to have access to a secure, reliable domestic supply of hydrogen. However, eligibility criteria for the design of the hydrogen allocation rounds could restrict this. The Hydrogen Allocation Round (HAR) process currently does not allow risk-taking intermediaries (entities which purchase hydrogen for resale). This means that the likely end-users for HAR schemes will be located close to a hydrogen production site. In the case of aviation test sites, this will not always be possible, making it more difficult to access sufficient hydrogen, and adding significant cost and complexity.

Recommendation: *To help enable organisations to invest in R&D for hydrogen-powered aviation and early trials, the Government should bring greater flexibility into the HAR system, allowing different business models to exist. This can be achieved by removing the current restriction that prevents a risk-taking intermediary being a qualifying offtaker from a HAR-funded hydrogen production project.*

Unlocking private sector capital

Unlocking private sector capital will be key to ensuring the production of the large-scale, reliable, and affordable volumes of low-carbon hydrogen required to enable innovation and drive down supply chain costs.

While private investment will be the main driver of growth in UK hydrogen production, public funding and strategic government policy will play an important role to help get the market going. The HIA is concerned that there remains uncertainty around the future structure for how the Hydrogen Production Business Model (HPBM) will be funded via the hydrogen levy.

Recommendation: *To nurture investor confidence for long-term decision making required to ensure the necessary scaling-up of hydrogen production, the Government must maintain an environment of both high political ambition and strong policy progress. This means providing clarity and stability on timings, policy, and targets towards 2035 across low-carbon technologies, and giving clear indications that these frameworks will be in place in the longer-term. This can be achieved by:*

- *Maintaining the pace and execution of annual allocation rounds, including the Hydrogen Allocation Rounds and across different renewable technologies.*
- *Make firmer decisions on the potential future of a 'hydrogen backbone' pipe network (see p26).*

Long-term planning

Meeting expected aviation demand requires a significant scaling up of low-carbon hydrogen production from 2035. The Government should also consider the wider requirements of the aviation sector, for instance the need for critical raw materials, particularly for producing hydrogen fuel cells. Considering the long lead times involved in financing and building infrastructure, planning needs to begin now. This process will be aided by providing investors a longer line of sight over hydrogen demands.

Recommendation: *The HIA invites trade bodies that represent the hydrogen, carbon capture, and nuclear sectors to form a '2035-2050' taskforce. The purpose of this taskforce will be to assess potential hydrogen production levels across the three sectors and provide this analysis to the Government, to support long-term Whitehall policy making.*

Recommendation: *The Government should deliver short-term certainty, and long-term guidance and transparency over funding mechanisms and volumes of financial support for hydrogen production, further clarifying plans beyond 2035, and up to 2050. The Government should:*

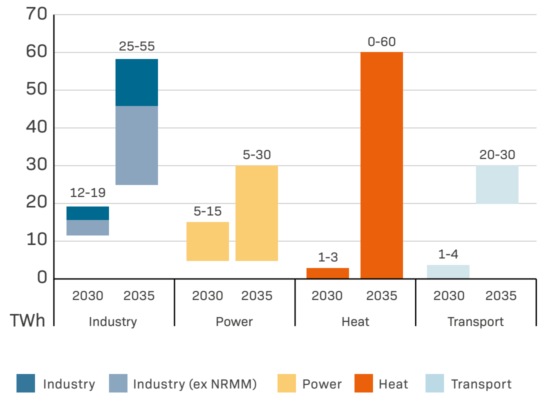
- *Ensure that the consultation on the hydrogen levy is not delayed, and the process to enact the necessary secondary legislation is prioritised.*
- *Provide greater detail on DESNZ's offer to have direct discussions with hydrogen producers looking at schemes over 1GW, to scale-up hydrogen production to meet anticipated demand.*
- *Provide longer-term clarity to industry on the availability of hydrogen by signalling its intentions on energy and hydrogen production targets beyond 2040.*

2MW Electrolysis Plant

National hydrogen demand calculations

By choosing to prioritise policy and funding on scaling up the production and supply of hydrogen, the Government has created gaps in signals to the market in terms of where and how it expects hydrogen usage to scale. Early estimates from DESNZ, illustrated in Figure 8, show how hydrogen demand in transport will compete alongside industry, power, heat, and Non-Road Mobile Machinery (NRMM).

Figure 8: Hydrogen Demand by Sector



Source: DESNZ, Hydrogen Transport and Storage Networks Pathway

Recommendation: *It is essential that the demand requirements of the aviation sector form part of the national calculations for future hydrogen demand and are considered as part of wider policy and incentives to grow production capacity.*

- *Government ambitions to increase the deployment of renewables can support this, but momentum must be maintained through commitment to procuring sizeable new renewables to scale production.*
- *Scaling up renewable power supply would also be supported by aligning policy targets. Offshore wind development targets, annual allocation rounds, and leasing rounds need to work in tandem with annual hydrogen allocation rounds as well as long-term hydrogen infrastructure development.*
- *The HIA, following collaboration with relevant trade bodies, should provide stakeholders such as the Government and National Gas [see p26] with detailed and accurate estimated demand figures as soon as possible to ensure that aviation demand feeds into nationwide plans. The findings in this report should go some way towards achieving this.*

Reducing electricity network costs for electrolytic hydrogen producers

The current cost of hydrogen production is high, with the largest cost-driver for electrolytic hydrogen being electricity. Electrolytic production facilities consume large amounts of power and face high grid connection and transmission charges by being directly connected to the National Grid. This can be mitigated via co-location e.g. locating hydrogen production facilities close to renewable energy sources (such as connection points for large offshore wind generation assets). This would reduce the impact on the grid and make production more cost-effective. Changes to eligibility for Contracts for Difference (the UK Government scheme to incentivise the building of renewables) and the Hydrogen Production Business Model (HPBM) would also support this.

Recommendation: *The Government should establish a fairer cost allocation that reduces the electricity network costs for low-carbon hydrogen producers. By reducing these costs and encouraging more commercially viable electrolytic hydrogen projects to come online, it would also be possible to capture electricity that would otherwise be at risk of curtailment. During these periods where electricity production exceeds demand, hydrogen can be produced at a low cost.*

This could be achieved by:

- *Giving low-carbon hydrogen producers full exemptions from the relevant network charges.*
- *Allowing a route for co-located, integrated electrolysers with CfD assets to utilise private wires without impacting eligibility for CfD and HPBM payments, which would also reduce the cost of hydrogen production.*

CHAPTER 3:

GETTING HYDROGEN TO THE AIRPORT

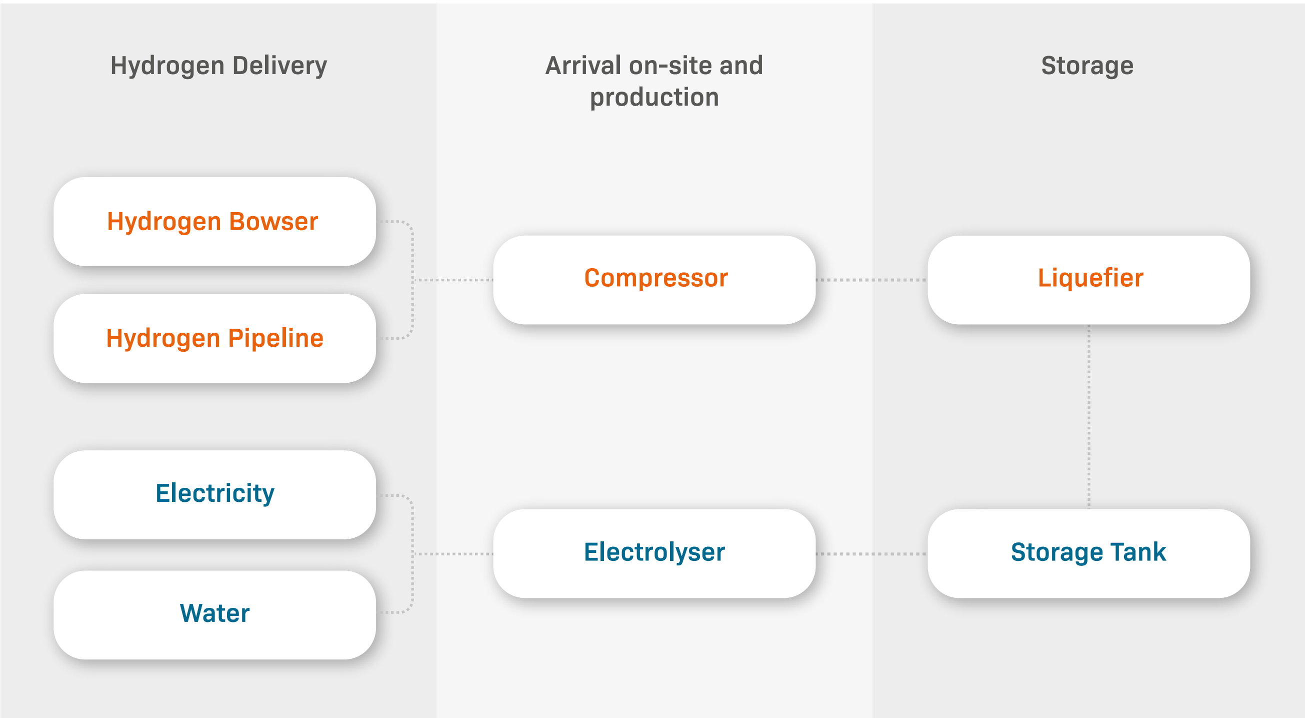
In the early stages, hydrogen is likely to be transported to airports via road in liquid or gaseous form. As demand scales up, gaseous hydrogen will likely be supplied directly to airports to secure enough supply to meet expected demand. This can be liquified at either the production site or at the airport premises. Once liquefied, the options for transport and distribution are more limited, as liquid hydrogen can only be transported short distances via pipeline. It is widely expected that gaseous hydrogen would be liquefied and stored on-site at the airport. This is an energy intensive process (although less energy intensive that using electrolysis to produce hydrogen in the first instance) and will need to be factored into future infrastructure projects. In the long-term, airports could look to produce hydrogen on-site. Wherever it is located, hydrogen infrastructure will require access to power, water, and space.

Depending on their local situations and hydrogen requirements, it will not be feasible for all airports to produce enough hydrogen to meet demand on-site. Ultimately, how hydrogen will be supplied to airports will depend on factors including the cost, regional supply options, and the wider development of hydrogen transport and storage infrastructure across the UK, for both liquid and gaseous hydrogen. Initially, hydrogen pipelines will be focused on clusters, connecting hydrogen production with end-users, possibly including airports. While some nascent projects are exploring hydrogen provision on-site or near to the airport, as demand scales up it is likely that pipeline connections will be easiest in or near carbon capture, utilisation, and storage (CCUS) and hydrogen industrial clusters.

The Department for Transport (DfT) and DESNZ have a strategic role in driving the development of hydrogen transport and storage infrastructure across the UK. DESNZ is developing business models to provide the support needed to bring forward this infrastructure, based on projections for how the hydrogen economy might develop in the UK and the scale, location, and type of demand.

There are plans for a national hydrogen 'backbone' by the 2030s, repurposing sections of the national gas transmission network to transport hydrogen. Led by National Gas, 'Project Union' would connect hydrogen production centres to major industrial clusters, with an option to expand in the future.

Figure 9: Indicative high-level illustration of hydrogen infrastructure outside airport boundary



Source: Jacobs (original amended for use in this report)

Example of hydrogen fuelling system

Case Study: Project Union

National Gas's Project Union explores the potential to repurpose sections of the gas National Transmission System where possible, in addition to new build pipelines where required, to develop a hydrogen backbone network. The project will connect hydrogen production centres to industrial, heat, transport, and power consumers. It will repurpose existing gas infrastructure and connect to a proposed European Hydrogen Backbone. The plan is for the network to span the UK, connecting major industrial clusters and hydrogen production centres. While National Gas doesn't support the aviation sector today, they are currently working with existing customers and other stakeholders to determine where and when the hydrogen pipeline will be required. It is important that the aviation sector begins engagement with National Gas as soon as possible to ensure that future plans and thinking around potential hydrogen demand can be fed into the planning process.

Gaps and recommendations

Understanding the 'tipping point' for a piped supply of hydrogen

More research needs to be conducted to understand the 'tipping point' for hydrogen supply to individual airports. As demand for hydrogen increases, the number of road deliveries needed is likely to become impractical, and costly. This will differ from airport to airport depending on factors like the local road network. Further research is required at a national level to understand when this 'tipping point' might be reached, to inform planning for future infrastructure needs such as connections to Project Union.

Recommendation: *The Government and industry should jointly fund a project to better understand when the 'tipping point' occurs for individual airports. This could be under an existing, currently funded mechanism such as the Connected Places Catapult the UK's innovation accelerator for transport.*

Piped hydrogen supply to airports

There will be very long lead times for hydrogen pipeline connections, either via a local cluster or a future national backbone. Plans and decisions need to be made now to ensure that the necessary infrastructure can be put in place. Much of the focus on hydrogen supply has been on other industries, and accurate aviation demand figures are currently not being fed into wider policy and projects, including plans for a national hydrogen backbone.

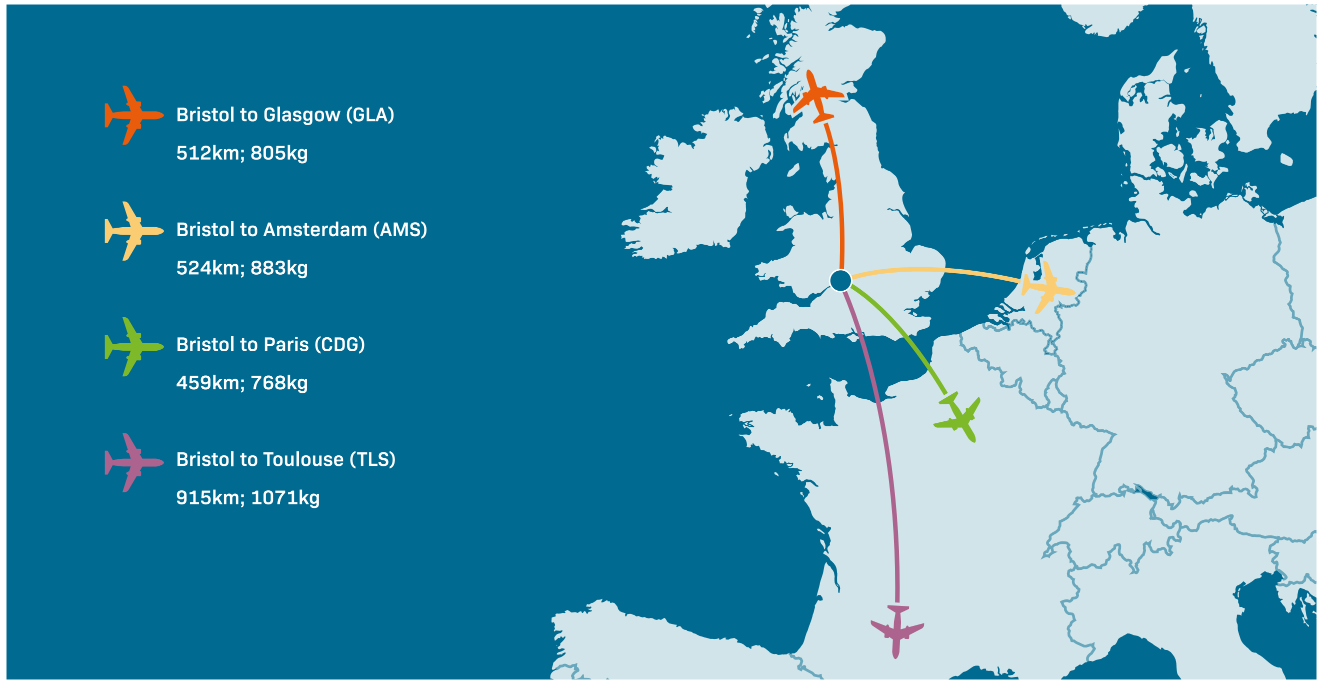
Recommendation: *The aviation industry, particularly airports, should prioritise engaging with government, local hydrogen clusters, National Gas, and regional gas distribution networks to begin planning for future hydrogen supply.*

- *DESNZ should continue to deliver its commitments on hydrogen transport and storage.*
- *Airports should form contacts with their regional hydrogen consortium to explore opportunities for future hydrogen supply.*
- *The aviation industry should provide National Gas with accurate estimated demand figures as soon as possible, to ensure that aviation demand will feed into the plans for Project Union.*
- *National Gas should use aviation demand figures to help shape plans for the development of Project Union.*

Planning for airport infrastructure

For airports receiving a piped supply of gaseous hydrogen, this will need to be liquefied and stored on-site. Once liquified, hydrogen needs to be stored at very low temperatures (-253C), and this process requires access to sufficient electrical power and land. Liquid, cryogenic hydrogen (cooled to extremely low temperatures) takes up less space than gaseous hydrogen but delivers the same energy at a reduced volume and weight – a critical consideration for aircraft. It is important that the Government acknowledges the importance of hydrogen liquefaction and can encourage the development of liquefaction capabilities in good time.

Figure 10: Estimated liquid hydrogen requirements for one-way flight



Airports need to start assessing the need for hydrogen infrastructure, and the land-use planning implications to enable it. The date at which airports will switch from bowser (road) supply to a pipeline will differ but is expected to be around 2040-2045 for high users. There is a risk that the necessary infrastructure may not be in place to meet a sharp increase in hydrogen demand.

Recommendation: *In 2024, the Government should update its guidance on the development of airport masterplans so that it includes a requirement to consider future hydrogen infrastructure needs, and recommend that every airport should have a broader 'hydrogen-ready' plan. New airports should also have a hydrogen infrastructure development plan at the start of the planning permission application process. At a minimum, as part of their 'hydrogen-ready' plans, airports should commit to:*

- *Updating their master plans to identify short-term and long-term indicative land requirements for future hydrogen storage (whether gaseous or liquid), transportation, and liquefaction, as well as electricity production on airport land.*
- *Working with the AOA to knowledge-share around the construction of on-site liquid hydrogen storage, to minimise costs.*
- *Beginning the planning process for the construction of on-site liquid hydrogen storage in 2030.*
- *Reviewing their surface access plans (in 2030-35) to take account of hydrogen requirements for ground transport and/or opportunities to work in partnership with third parties to use hydrogen vehicles to decarbonise existing public transport routes.*

Case Study: Project NAPKIN

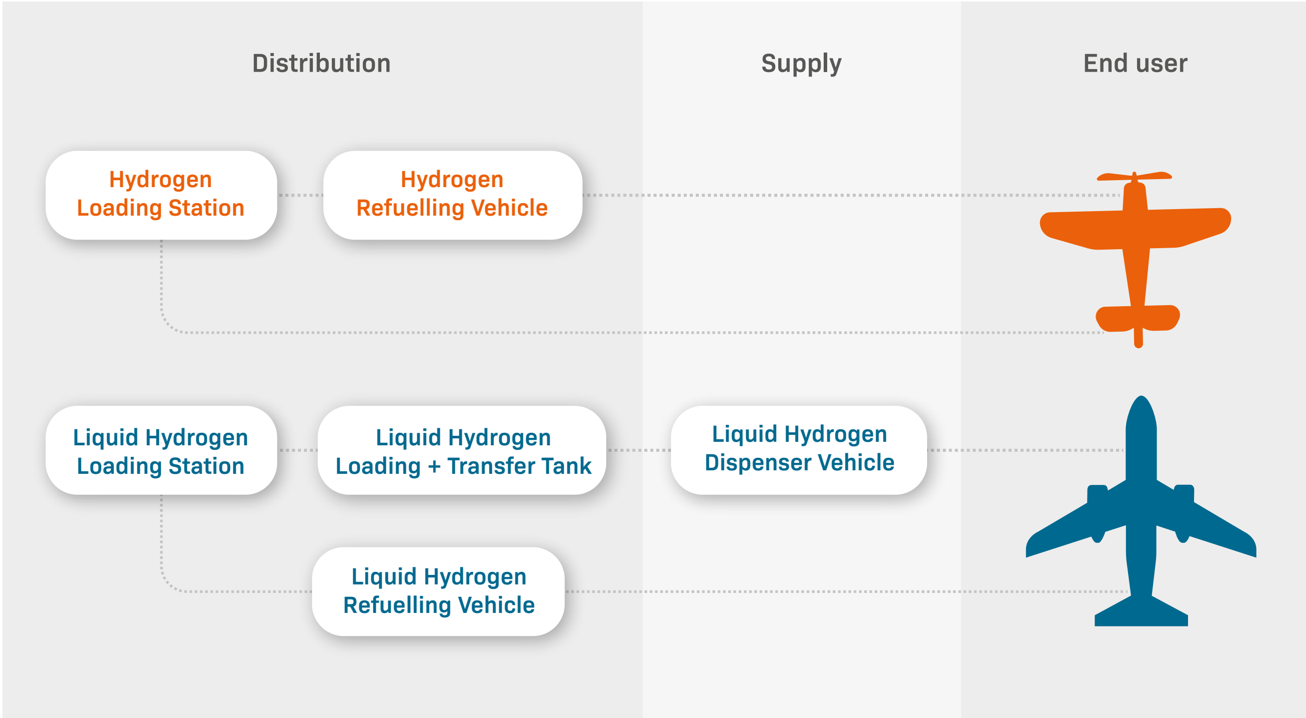
Project NAPKIN brought together Rolls-Royce, GKN Aerospace, Heathrow Airport, London City Airport, and Highlands and Islands Airports to produce a blueprint for the introduction of commuter and regional zero-emission (hydrogen) aircraft. The project tested the practical and economic viability of zero-emission concepts and how their introduction necessitated a scale up of infrastructure at airports. Several of the project partners are now carrying forward further research on narrowbody aircraft in the wider European market, looking to better understand fuel demand, rate of aircraft uptake, and infrastructure requirements. Government should consider the recommendations set out by Project NAPKIN, which complement the findings of this report.

CHAPTER 4:

GETTING THE PLANE IN THE AIR

Using hydrogen at airports will require a significant change in day-to-day operations. The complexity of handling hydrogen poses its own challenges, and new process and standards for airports will be required. As it has different properties to kerosene, there will be changes to the processes and regulations around storage (whether liquid or gaseous), handling, and use. There are additional challenges to consider for liquid hydrogen when compared to gaseous. For a period of time, airports will be simultaneously handling kerosene, SAF, and hydrogen, with separate equipment and crews required as they make the transition. The risks associated with this will also have to be carefully considered and mitigated. The refuelling of aircraft is likely to take place using hydrogen refuelling vehicles, in a similar process to that carried out at airports today (although other options such as static refuelling stations may be viable in the long-term). These vehicles are at an early stage of development and require further testing and demonstration, a process that is likely to take 3-5 years.

Figure 11: Indicative high-level illustration of hydrogen infrastructure inside airport boundary



Source: DESNZ, Hydrogen Transport and Storage Networks Pathway

Case Study: Project Acorn

Project Acorn is a multi-partner trial led by easyJet and Bristol Airport that aims to demonstrate hydrogen's safe use in a live airside environment, and specifically to refuel and power ground support equipment during the turnaround of an aircraft. Learnings from Project Acorn will be used to develop safety guidance to inform the regulatory framework for using hydrogen in an airside environment.

There is also the potential for airports to use hydrogen in other ways on-site, such as by heating or powering airport facilities, using hydrogen to fuel ground operations and transportation (e.g. in airport vehicles), or even supporting wider local communities and industries. The 'hydrogen hub' approach has been adopted and funded by the US and the EU and looks to leverage on-site production and storage at airports to serve other energy needs.

Case Study: Glasgow Airport H2 Hub

A consortium led by Glasgow Airport and Net Zero consulting co-developer Ikigai Group was set up in May last year with funding from the Scottish Government's Hydrogen Innovation Scheme, which aims to support the development of renewable hydrogen technologies. The Glasgow Airport Hydrogen Innovation Hub consortium (which includes ZeroAvia) was tasked with delivering a feasibility study to determine the most efficient, bankable, green hydrogen production, storage and refuelling solutions, and to assess the operational feasibility of a multi-modal hydrogen hub at the airport. The interim results of the study suggest that the development phase to generate, store and distribute hydrogen could commence this year with the objective of the hub being ready to support zero-emission flights at Glasgow Airport by 2027.

Figure 12: Airport Hydrogen Hub

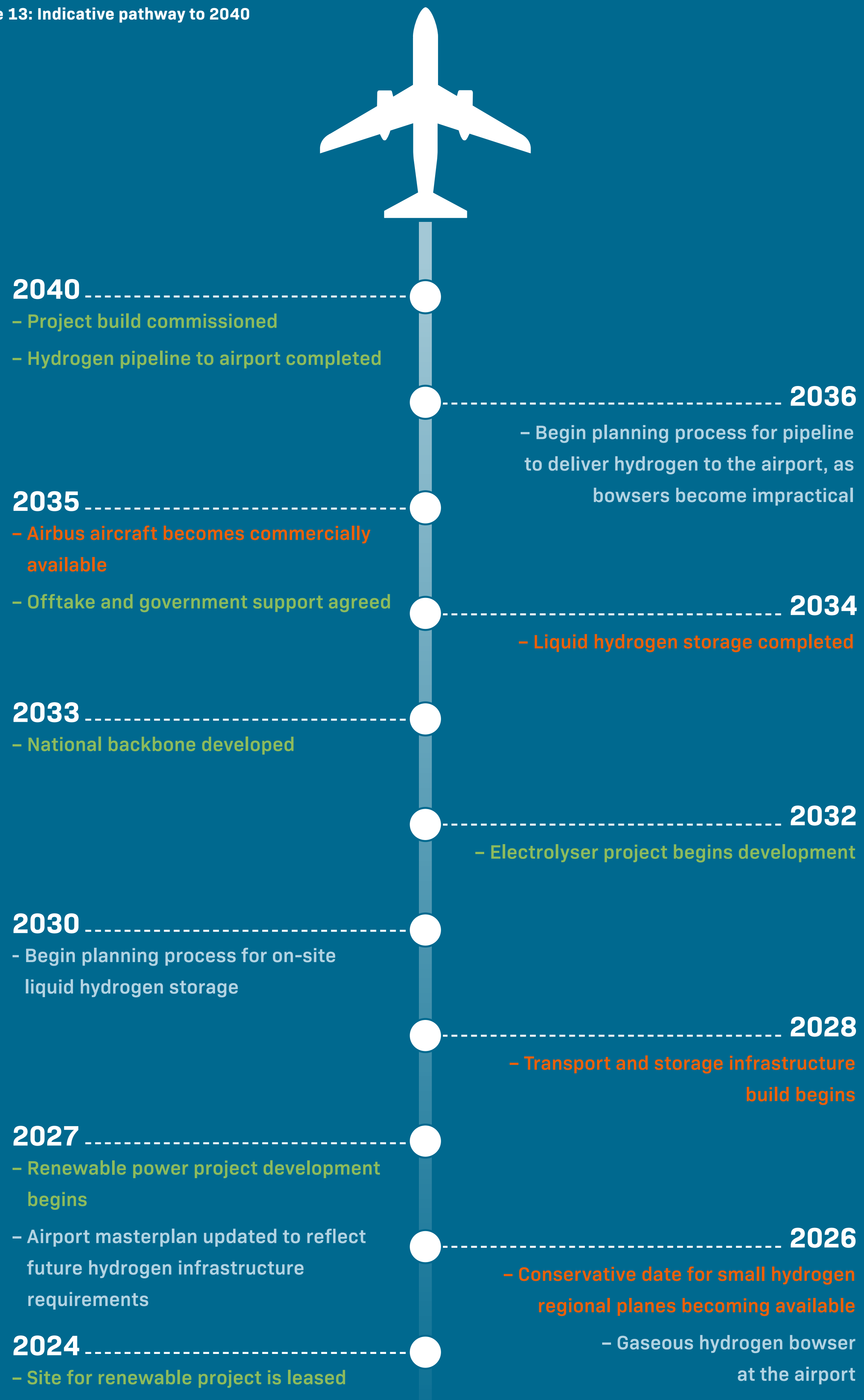
Source: Airbus

Case Study: Airbus- Airports as Hydrogen Hubs network

In 2020, Airbus launched its Hydrogen Hubs at Airports network to drive research into the infrastructure requirements and low-carbon airport operations across the value chain. The network's membership includes more than 60 members from the airports, airlines, and energy sectors in 11 countries including France, the USA, the UK, Singapore, Japan, South Korea, and New Zealand. Their approach involves working with airports to develop a stepped approach to decarbonising airports using hydrogen – including for hydrogen-powered flight, ground operations, transportation, facilities, and use outside of the airport. By enabling hydrogen usage outside of just aircraft, industry can prepare regulations and standards for the handling of hydrogen, ensure a wide supply of liquid hydrogen by 2035, and foster efficiencies and improvements in hydrogen liquefaction, storage, and distribution.

For airlines, the biggest change in transitioning to hydrogen-powered flight is purchasing the aircraft to enter their fleet. To enable this, airlines will need assurances that the required infrastructure is in place, not just at a handful of airports, but in a network across their destinations, both in the UK and in Europe. They will also need to be able to access the funds to purchase new aircraft. Figure 13 highlights the timelines involved for airlines to purchase new hydrogen-powered aircraft (**orange**), mapped against the development of a hydrogen production project (**green**), and expected development of hydrogen infrastructure at airports (blue).

Figure 13: Indicative pathway to 2040



Airbus ZEROe Concept Aircraft

Gaps and recommendations

Hydrogen pioneer airports

Airports and airlines are already familiar with working within the existing Health and Safety Executive (HSE) regulations and standards, with hazardous substances, and with the environmental controls that sit alongside this. Some regulations which will be required for working with hydrogen will be new to airports and airlines. Working within these new regulations will require detailed safety assessments and emergency planning with local authorities. Local authorities themselves are unlikely to have experience of hydrogen, and are likely to have insufficient resources to be able to assist airports. The safety of staff, for example ground crews, who will interact most with hydrogen fuel, will be paramount.

Other barriers or gaps in terms of the regulations and standards required include:

- Not having CAA clearance for airside refuelling is a key blocker to the progress of hydrogen in aviation.
- Standards and requirements for the hydrogen quality and purity levels required.
- Development of a new safety regime which covers fuelling, use, controls, and transportation.
- Changes to interfaces between aircraft and the external environment e.g. changes to ground equipment to enable refuelling.

Case Study: Cranfield University

Cranfield is the only university in Europe to own and operate its own airport and research aircraft. They are an important part of the UK's aerospace R&D infrastructure and are already conducting a wide range of hydrogen R&D including looking at energy production, materials and structures, and vehicle and aircraft design. Their programme includes many projects relevant to how hydrogen will be used at the airport, including work on:

- Storage vessels for compressed and liquified hydrogen.
- Hydrogen refuelling, airport facilities, and fuel certification.
- Health and safety requirements for using hydrogen, including land use planning and hazardous substance planning.

Recommendation: *There is a need for a network of hydrogen pioneer airports to serve as a testing ground for accelerating hydrogen-powered aviation - the location, funding, and governance of this programme should be finalised within the next 18 months. Other organisations, including the Jet Zero Council, are taking forward work on similar concepts, so it will be important that this is aligned. This network should be utilised by the regulator and industry as a testing ground to develop the necessary standards, procedures, processes, and regulations, including:*

- *Standards for the quality and purity required for hydrogen fuel following the established path for fuel specifications.*
- *Establishing standard operational practices and guidelines for the use of gaseous and liquid hydrogen at airports.*
- *Supporting the work already underway in the standardisation of hydrogen equipment for use at airports, following a similar regulation path to other fuels.*
- *General guidance to airports on constructing hydrogen infrastructure. This would include hazardous substance planning, land-use planning, regulations, and developing the necessary safety reports.*
- *Connected Places Catapult to take on an expanded role, supported by appropriate funding, to assist the early delivery of hydrogen infrastructure at airports.*
- *Accelerate regulations around liquid hydrogen storage on the ground.*

Airport readiness

For hydrogen-powered flight to become a reality, a network of routes with existing hydrogen infrastructure will be required. Some airports are already working towards being hydrogen-ready. The Department for Business and Trade (DBT) should consider transferring ownership of the Future Flight Challenge fund to the Department of Transport (DfT) to align and focus resources on the creation of early hydrogen flight routes. This is a £300m fund led by Innovate UK to support innovative projects positioning the UK as a global leader in advanced aviation technologies.

Case Study: Bristol Airport

Bristol Airport sits in the West of England, home to one of the world's leading aerospace and innovation clusters. The airport has led the creation of Hydrogen South West, working with the region's aerospace companies, other sectors, and R&D institutions. This consortium is working to create a regional hydrogen ecosystem, enabling new partnerships that drive the development of hydrogen infrastructure and technology. One of the UK's largest regional airports, Bristol Airport has opened itself up as a test bed for new technology. This includes hosting Project Acorn, the first airside refuelling of hydrogen equipment at a major UK airport, an early step in building the safety case and regulations for hydrogen-powered flight.

Case Study: Rotterdam The Hague Airport

Acting as a test site for innovations in hydrogen, Rotterdam The Hague Airport is working on making the first hydrogen-powered commercial European passenger flights possible. The airport is an international test site and part of the EU's TULIPS project, with funding provided to deliver, store, and refuel hydrogen. ZeroAvia have an agreement with Rotterdam, with the aim of developing a concept for hydrogen flight at airports, ahead of commercial flights beginning in 2025.

Case Study: Hamburg Airport

Hamburg Airport is Airbus' main base in Germany and is one of their ZEROe network of airports. With a planned regional hydrogen ecosystem in the area, Hamburg has also agreed with Rotterdam Airport to create a hydrogen route between the two airports and is attempting to create several routes with other airports across the Baltic Sea.

Case Study: Toulouse Airport

Toulouse Airport is the home of Airbus' HQ and site of final assembly of their aircraft. In December 2023, Toulouse Airport opened what they say is Europe's first hydrogen station at an airport, able to refuel vehicles airside and landside. In the future, liquid hydrogen refuelling for aircraft will be constructed as part of Airbus' ZEROe aircraft development.
In addition, Universal Hydrogen has set up an engineering centre at the airport and has carried out an operational demonstration of a hydrogen fuelling turnaround using its modular hydrogen capsules.
In the wider region, HYPORT is a private-regional government partnership which is responsible for developing hydrogen infrastructure.

Airbus ZEROe Concept Aircraft

Recommendation: *The aviation industry should work together internationally to create a network of hydrogen-ready airports, bringing together those leading in this area such as Bristol, Rotterdam, Hamburg, and Toulouse.*

- *In the first instance, a 'starter' network of around 5 airports in the UK should be developed in order to establish the first regional turboprop flights.*
- *The next stage would be to develop the full network of airports, scaling up production and fuel-provision for larger, narrowbody aircraft.*
- *Early adopters should prioritise linking up to their regional hydrogen consortia, which are likely to be the earliest available source of hydrogen.*
- *The Government should also financially support initial routes between at least two UK hydrogen pioneer airports (see recommendation on p32). This should aim for initial commercial flights to begin in 2026/7.*
- *This effort to create an early ecosystem for hydrogen flights should be supported by the DfT and, if relevant, the devolved administrations and local government.*
- *As a next step, industry and government should work together to identify which airports could make up the network, including the hydrogen pioneer airports.*

Incentivising the transition to a hydrogen-powered flight

Hydrogen-powered aviation is the biggest change to the sector since the introduction of the jet engine. Without the ability to refuel the aircraft at existing airports, there will be no flights. Airports will need to secure land for and construct infrastructure such as for storage and liquefaction, as well as investing in new refuelling infrastructure, and retraining their workforces. Capital investment will therefore be significant through the 2030s and into the 2040s.

Airlines will face similar hurdles. Hydrogen-powered aircraft represent a major leap forward, but the initial stages of adoption will face significant financial barriers. There is an existing mechanism to address similar challenges elsewhere in the sector – Public Service Obligations (PSOs) support air service on routes which may not be commercially viable, but are essential for social or economic reasons. Similar principles should be extended to hydrogen flights to facilitate the transition.

Recommendation: *The Government, should in the long-term establish a hydrogen transition fund for aviation, to support airlines and airport operators with initial costs. This transition fund should cover:*

- *Initial funding for the construction of the necessary airport infrastructure and procurement of new equipment and vehicles.*
- *Initial funding for a domestic hydrogen operated route network – a hydrogen version of a Public Service Obligation.*

To access the funds to purchase hydrogen-powered aircraft, airlines would need assurances that the hydrogen fuel supply and airport infrastructure is available and well-established. Recommendations in previous sections of this report are designed to work towards achieving this and would go some way to giving investors the with the confidence to provide funding with low interest rates/low financial risk.

However, there are gaps in specific support to key players in the aviation hydrogen ecosystem – specifically, airlines. Targeted policy support and incentives would have a positive contribution to the development and deployment of hydrogen-powered flight.

Recommendation: *The Government should develop policy support to improve the price competitiveness of hydrogen-powered aircraft versus kerosene-powered aircraft. A suitable incentive could include the Government seeking to reduce the cost of hydrogen by including it in the UK Emissions Trading Scheme (ETS), and introducing tax exemptions for hydrogen-powered aircraft.*

- *The UK ETS imposes a cost on carbon emissions and is intended to create a financial incentive for industries to decarbonise. The Government should treat hydrogen fuel the same way in the UK ETS as SAFs meaning that for any volume of hydrogen fuel used, airlines should receive the equivalent of ETS allowances or a zero-emission rate as deemed appropriate. This would serve as an incentive to use hydrogen under the ETS.*
- *Hydrogen-powered aircraft should be exempt from paying taxes such as Air Passenger Duty (APD) like the exemptions that exist in other sectors (for example, electric vehicles do not pay road tax).*

Airbus A380 ZEROe Demonstration Aircraft

Skills

Upskilling the workforce will be a significant challenge, and industry must put in place training plans to retrain their existing workforce and start recruiting hydrogen experts. Roles within the industry might remain the same, for example in aircraft maintenance, but the actual activity carried out will differ when working with hydrogen. Airlines will need to work with manufacturers to develop training for pilots to operate hydrogen-powered aircraft and consider repair, service, and inspection needs. The earlier these differences can be identified, the faster the skills requirements can be pinpointed, and training can take place.

The development of new curriculums requires industry to work closely with academia and government and can take several years to complete. The indicative timeline below highlights the significant lead-in time for curriculum development and the training of a new workforce:

1. **Scoping – high level knowledge and skills identification (6-12 months)**
2. **Development of an occupational standard (6-12 months)**
3. **Curriculum development with finalised occupational standard (6-12 months)**
4. **Roll out to providers**
5. **Training time – for example in an apprenticeship (1-5 years)**

It would be wrong to solely focus on the hydrogen skills that are in shortage. Skilled tradespeople are also needed to enable other technologies that deliver Net Zero. A national strategy is needed to address the domestic shortages of these skills.

Recommendations

- *Industry to develop future workforce plans and determine need, working with academia to build curriculums that address future skills needs.*
- *Government and industry to support the work of the HSA in developing a specific skills strategy for hydrogen.*
- *Additional funding rounds of the Future Flight Challenge or a similar undertaking, that focuses specifically on developing hydrogen skills, is required.*
- *The hydrogen pioneer airports would require skills-development programmes, with the airports working in conjunction with wider sector, ground handlers, CAA, and their local further education colleges to identify and share skill gaps, and programmes.*

GKN Aerospace is developing novel manufacturing processes that will form the foundations of hydrogen-powered flight

CHAPTER 5:

AN INDUSTRIAL STRATEGY FOR AVIATION

By following the recommendations in these four core journeys the UK could place itself as a world-leader, capturing the benefits of being a first mover on hydrogen-powered flight. This is a massive opportunity to grow and decarbonise the £22bn aerospace industry, secure 230,000 existing jobs, champion consumers and bring the world into the future of aviation.

The strategic advantages of the UK becoming a global leader in hydrogen-powered aviation are clear. We must leverage our position today as an international standard-bearer for aerospace safety and certification to bring this technology into commercial use. Hydrogen will be one of the single most significant tools in the decarbonisation of the aviation industry with the potential for it to become a more carbon neutral and cost-effective solution than SAF. It is critical that we keep flying affordable and accessible for consumers, who are already being asked to accept significant changes to their lives as we work towards a Net Zero future.

The wider potential of hydrogen-powered aviation, as the facilitator of a broader hydrogen ecosystem at airports, and the local economic benefits this could bring, must also be given serious consideration. Airports could bring even greater investment and decarbonisation opportunities to the UK when acting as hydrogen hubs, servicing local energy needs with the transportation, production, storage, and supply of hydrogen.

While the potential here is huge, the risks associated with not acting now are just as large. Internationally, other actors such as the US and the EU are already investing heavily in hydrogen. The UK is in a global race to put in place the skills, investment, and regulation needed to secure these benefits first. It is also in a leading position to become a catalyst for cross-border collaboration on hydrogen in aviation, which will be essential to enlarge the hydrogen network at airports with other international partners, maximising CO2 reduction opportunities. This could include collaborations with other hydrogen aviation industrial alliances, such as the EU's Alliance for Zero Emission Aviation, to explore further synergies, as well as working at the global level in the ICAO to establish global standards for hydrogen.

The UK has already made significant investments in hydrogen aviation. This has not only been financial investment via the previously mentioned ATI and direct private investment, it has also come in the form of building awareness and deep technical expertise across the organisations working on these innovations.

Commercialising the UK's progress to date will require a further step change in our ambition. Bringing this technology to the aviation market, where there is so much government and regulatory involvement, will require drive and coordination. Put simply, an industrial strategy for aviation with hydrogen at its heart is of vital importance.

There are currently four government departments that hold the different parts of this puzzle – the Department for Business and Trade; the Department for Energy Security and Net Zero; the Department for Transport and His Majesty's Treasury – also, two regulators will be important factors, the CAA and HSE.

A clear lesson from the experience of other sectors that have seen transitions in support of the green economy is that we cannot simply rely on organic change. Structural changes are required to support the adoption of new technologies. To do this we need a clear lead within government, a coordinated plan, and a commitment from all the stakeholders to work together.

Taking each of these in turn. Firstly, a lead government department should be appointed the responsibility for delivering the strategy. This is the only way to bring together different parts of government and the regulators to work in unity. This lead needs to be given the resources to deliver the strategy, and the authority to take action in all policy areas.

Second, we need a clear plan. An industrial strategy for aviation needs agreed objectives and a plan to work towards an established hydrogen economy that works for the sector. This plan needs to be developed quickly by the lead department, and used as the basis to drive policy and action on hydrogen for aviation. We believe this plan should be in place by the end of 2025.

Third, the different parts of the sector should to work together and support this common goal. Government departments need to be aligned, and stakeholders in both industry and academia need to have a meaningful role in the delivery of the strategy.

HIA Pledges

The members of the HIA; Airbus, Bristol Airport, easyJet, GKN Aerospace, Ørsted, Rolls-Royce, and ZeroAvia have each committed to the pledges below, highlighting the work taking place today, in line with the milestones set out in this report. These pledges demonstrate industry's seriousness and intent to work with government to make the UK a leading centre for hydrogen-powered aviation technologies.

Airbus has the ambition to deliver our first ZEROe aircraft by 2035, powered by hydrogen, and aims to certify all of our civil aircraft to be able to run on 100% SAF by 2030.

Bristol Airport pledges to be a leading player in facilitating zero-carbon flight and will continue to build on our connections within the South West's world-leading aerospace hub and centre for research and excellence.

We will actively support the development of Airport hydrogen infrastructure with the aim of enabling commercial flights by 2035. Bristol Airport will work with partners to be a driver for change, supporting and leading where we can, actions to decarbonise flight and work with our airline partners and suppliers to decarbonise ground operations.

easyJet pledges to support the advancement of hydrogen powered flight in partnership with our UK airports and wider stakeholders. This fits with our Net Zero Roadmap to reach net zero by 2050 in which hydrogen plays a key role.

GKN Aerospace pledges to continue investing the majority of its research and development expenditure in technologies and products that will help to decarbonise the sector.

We will inspire and support customers to accelerate the pace of change through exploitation of new technologies that enable and progress hydrogen propulsion.

We as Ørsted are committed to our vision to create a world that runs entirely on green energy, with green hydrogen playing a key role to de-fossilise hard-to-electrify industries.

Rolls-Royce is committed to achieving Net Zero across its value chain, embracing the energy transition for the company and helping both customers and the sectors it operates to reach Net Zero too. We believe that the route to net zero aviation will be delivered through developing more efficient gas turbine engines, the transition to sustainable fuels and new technologies including through aircraft design, all working together.

ZeroAvia pledges to continue in its efforts to deliver the clean future of flight for the entirety of aviation by developing hydrogen-electric propulsion and fuel infrastructure.

We pledge to enable regional aircraft flying with zero-emissions this decade to catalyse adoption, and to scale our technologies to support true zero flight in narrowbody aircraft in the 2030s.

With these pledges we now turn our focus from research and identification, towards advocacy, progress, and delivery. Together with government and the wider sector, we can realise the opportunity of hydrogen in aviation, and do so at pace. Hydrogen can deliver for aviation, and for the UK.

Bristol Airport and easyJet's ultra-low emissions aircraft turnaround trial.

Summary of Recommendations

Chapter 1: Building the aircraft

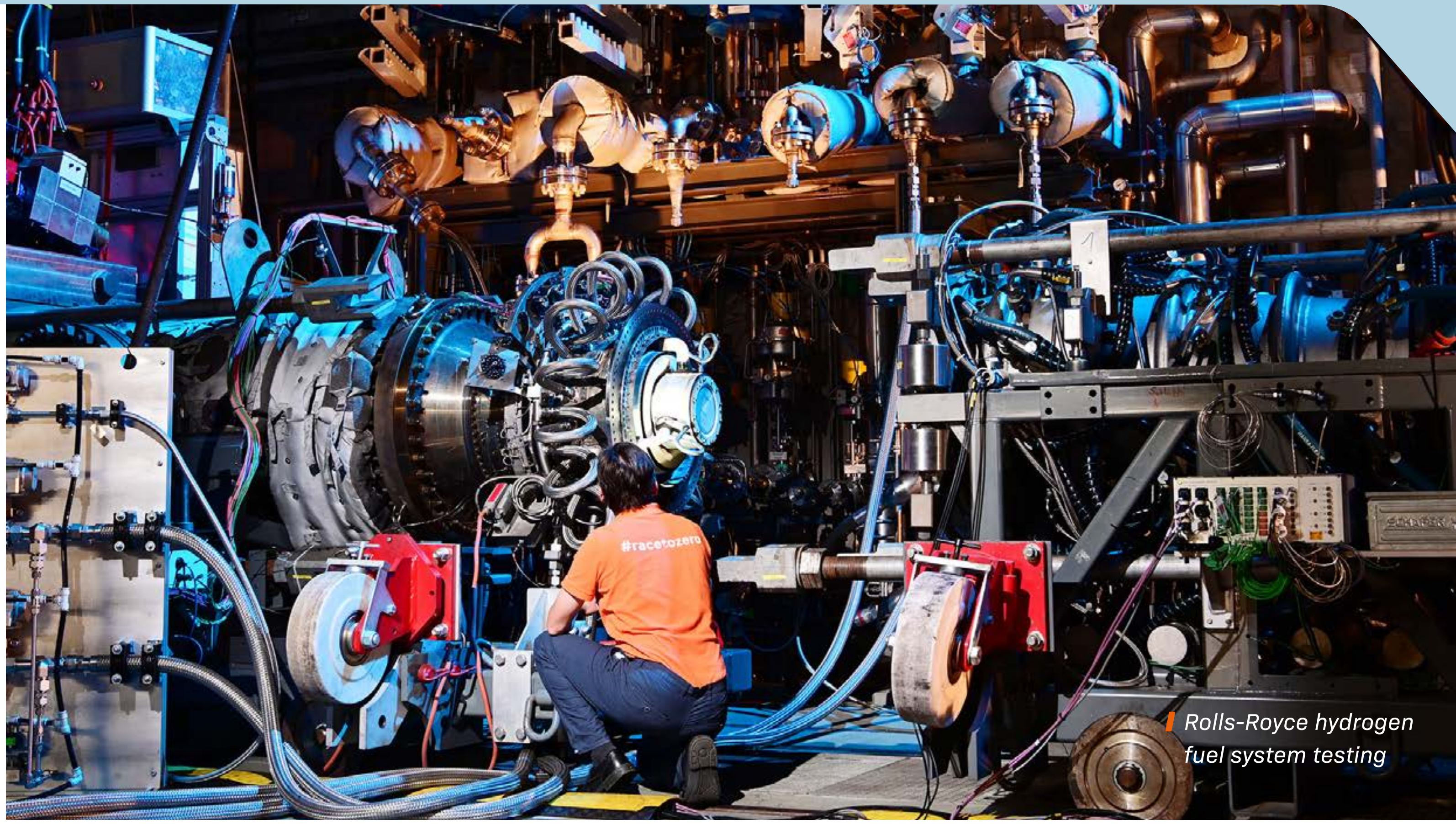
- The Government to continue to support and utilise the work of the HCN in policy development, including engaging industry on future public investment.
- The Government to support work of the HCN and progress the development of two medium scale liquid hydrogen Test Hubs and mature the UK's test capability network.
- Amend the UK R&D funding rules and associated delivery mechanisms to allow public investment in aerospace technologies beyond TRL6.
- Reinvest funds raised through the UK Emissions Trading Scheme (ETS) back into aerospace technology development, recognising this as new funding.
- Improving the current lending environment for aerospace firms through long-term policy stability, guaranteeing future aerospace R&D funding, including aerospace within the UK Green Taxonomy, and reviewing and amending prohibitive provisions in the Subsidy Control Act.
- The Government should ensure that there is a sufficient domestic supply of liquid hydrogen to support R&D and testing in the UK.
- From 2025, the CAA should be appropriately resourced to address the challenges outlined in this report, working in co-ordination with other relevant bodies and the academic community to develop the required standards, procedures, and regulations.
- The CAA should take on a critical role, representing the UK in working with EASA and FAA, in driving regulatory alignment on certification, the operation of hydrogen-powered aircraft, and related infrastructure.
- The Government should establish a National Hydrogen Academy, to be operational by 2025, contributing to a just low-carbon transition.
- The Government should ensure continued access to talent from abroad in addressing a growing skills need within and around aviation.

Chapter 2: Making hydrogen for aviation

- The Government should bring greater flexibility into the allocation rounds for the funding of hydrogen production.
- The Government to provide clarity and stability on timings, policy, and targets towards 2035 across low-carbon technologies, and indicate the intention to support these for the long-term.
- Trade bodies to form a '2035-2050' taskforce to assess potential hydrogen production levels and provide their analyses to government.
- The Government should further clarify plans for hydrogen production beyond 2035, and up to 2050.
- The demand requirements of the aviation sector should form part of the national calculations for future hydrogen demand.
- The Government must maintain momentum towards the ambition to increase the deployment of renewables through commitments to procure sizeable new renwables to scale production.
- The Government should establish a fairer cost allocation that reduces the electricity network costs for low-carbon hydrogen producers.

Chapter 3: Getting hydrogen to the airport

- The Government and industry should fund a project to better understand when the 'tipping point' occurs for hydrogen supply to individual airports.
- The aviation industry, particularly airports, should prioritise engaging with government, local hydrogen clusters, National Gas, and regional gas distribution networks to plan for future hydrogen supply.
- In 2024, the Government should update its guidance on the development of airport masterplans to consider future hydrogen infrastructure needs and recommend that every airport should have a broader 'hydrogen-ready' plan.



Rolls-Royce hydrogen fuel system testing

Chapter 4: Getting the plane in the air

- A network of hydrogen pioneer airports should be created to serve as a testing ground for accelerating hydrogen-powered aviation.
- Industry should collaborate internationally on a network of hydrogen-ready airports.
- The Government, should in the long-term establish a hydrogen transition fund for aviation, to support airlines and airport operators with initial costs.
- The Government should develop policy support to improve the price competitiveness of hydrogen-powered aircraft versus kerosene-powered aircraft.
- Industry to develop future workforce plans and determine need, working with academia to build curriculums that address future skills needs.
- Government and industry to support the work of the HSA in developing a specific skills strategy for hydrogen.
- Additional funding rounds of the Future Flight Challenge or a similar undertaking, that focuses specifically on developing hydrogen skills.
- Hydrogen pioneer airports to include skills-development programmes.

Note of thanks

With thanks to the following organisations for their advice and input during the drafting of this report.

- Civil Aviation Authority (CAA)
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- Department for Business and Trade (DBT)
- Department for Transport (DfT)
- HM Treasury (HMT)
- UK H2Mobility
- Hydrogen Capability Network (HCN)
- Hydrogen Energy Association (HEA)
- Hydrogen Innovation Initiative (HII)
- Hydrogen Skills Alliance (HSA)
- Hydrogen UK (HUK)
- Jacobs
- National Gas

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