HYDROGEN'S ROLE IN AVIATION'S ENERGY TRANSITION

Hydrogen has the potential to support aviation's long-term energy transition, both as an option for direct propulsion and as a feedstock for sustainable aviation fuel (SAF) production. Hydrogen can significantly reduce aviation emissions while also supporting the scale-up of SAF pathways. The aviation sector's goal to achieve net zero carbon emissions by 2050 is likely to create significant demand for hydrogen.

Why hydrogen matters to achieve net zero carbon emissions

Over the last few years, development has intensified on disruptive propulsion systems using new energy sources such as electricity and hydrogen. Hydrogen in particular can contribute to aviation's decarbonisation in three ways:

- **As a low carbon fuel in either fuel cell or combustion aircraft propulsion systems**: this works in the same way as conventional internal combustion, but with hydrogen replacing traditional jet fuel.
- **As a feedstock for SAF production, especially eSAF options:** this fuel is created when hydrogen produced using renewable electricity is combined with carbon dioxide. This fuel can already be added to fossil fuels and used in conventional jet engines.
- **In hydrogen fuel cells**: this technology converts energy stored in molecules into electrical energy.

Hydrogen is one of several technologies being explored to support aviation's long-term decarbonisation, but its contribution prior to 2050 is expected to be more moderate than earlier forecasts suggested.

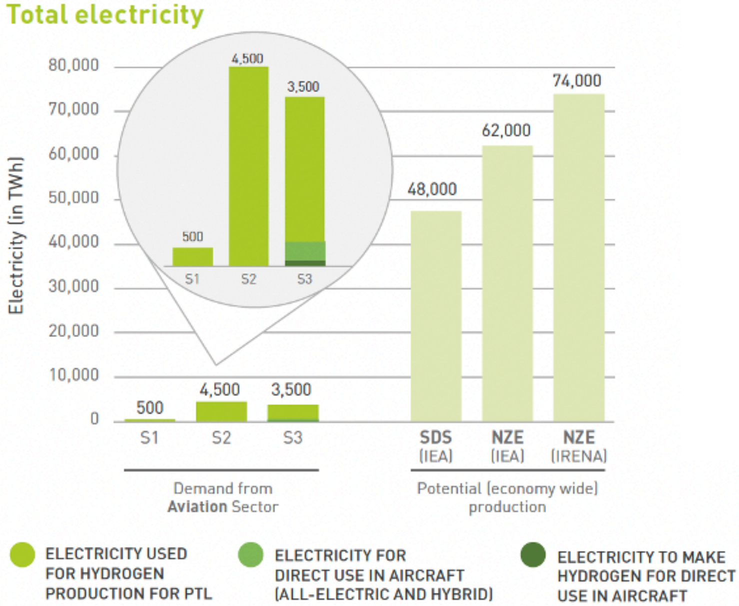
SAF is to remain the primary decarbonisation lever through 2050, with hydrogen expected to complement a broader portfolio of solutions including aircraft efficiency improvements, operational measures and other emerging propulsion technologies.

Hydrogen combustion has the potential to reduce the climate impact of flying by 50 to 75%, and fuel-cell propulsion by 75 to 90%[1]. It also offers important operational advantages. With around three times the energy content per unit mass compared to conventional jet fuel, hydrogen-powered aircraft would require significantly less fuel weight for the same flight. This could enable lighter aircraft designs, including reduced structural weight, smaller wings and more compact engines.

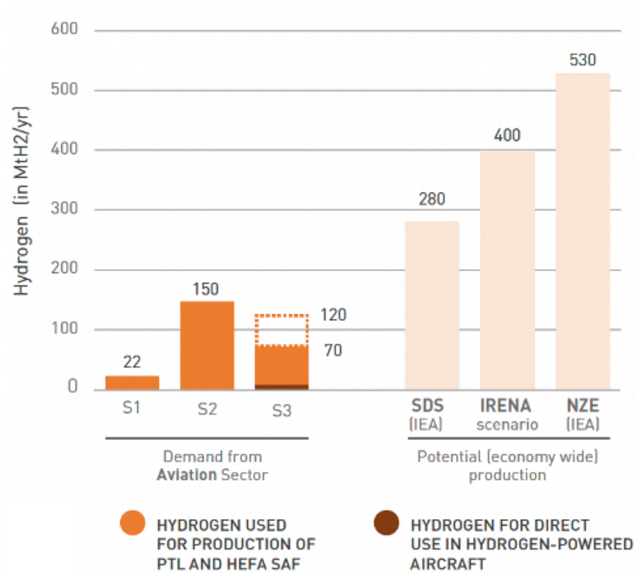
Increasing demand

Demand for hydrogen as a feedstock for SAF production is expected to rise significantly in the coming decades. Aviation's hydrogen needs could represent a substantial share of economy-wide hydrogen production, estimated at around 8–12% of total supply[2;3]. For eSAF to be economically viable for aviation, both renewable energy and hydrogen must be abundant in supply and low in cost. Aviation's requirements for renewable energy and hydrogen must be factored into wider national energy strategies, alongside its requirements for renewable liquid fuels.

Total electricity



Total hydrogen



[1] McKinsey & Company for the Clean Sky 2 Joint Undertaking and Fuel Cells and Hydrogen 2 Joint Undertaking, Hydrogen-powered aviation, 2020: https://ataglink.org/3ShbNyk
[2] Waypoint 2050, Ed. 3, 2026: https://ataglink.org/4wZckTO
[3] IATA, Hydrogen for Aviation V2.0, 2025

The aviation sector will also need access to low-carbon electricity both to produce eSAF and potentially for primary use in aircraft propulsion. Analysis suggests that aviation could account for between 1% and 9% of currently planned low-carbon electricity production, and between 4% and 52% of projected green hydrogen demand in 2050, depending on the scale-up of eSAF. Meeting this demand will require the parallel expansion of renewable electricity and green hydrogen production capacity. Investment in eSAF facilities is expected to stimulate additional supply rather than compete with other sectors for existing resources.

How to ensure hydrogen is a sustainable solution[4]

Pure hydrogen is a fuel that contains no carbon and produces no CO_2 emissions, soot, or unburned carbon particles when used. In principle, it can be produced wherever water and electricity are available. However, not all hydrogen is equal. Today, the large majority of global production is so-called grey hydrogen, made from natural gas and generating carbon dioxide emissions during the production process.

Access to large volumes of green hydrogen - which is generated by splitting a water molecule into hydrogen and oxygen, using electrical energy from renewable sources - would enable aviation to deliver significant climate benefits.

Hydrogen production pathways

Green hydrogen	Produced by splitting a water molecule into hydrogen and oxygen with electrical energy from renewable sources.
Pink hydrogen	Produced by using nuclear power
Yellow hydrogen	Made from electrolysis but using energy from the grid
Blue hydrogen	The CO_2 emitted during the production of **grey hydrogen** is captured and stored, reducing hydrogen's carbon footprint by up to 90%.
Grey hydrogen	Produced from fossil fuels – usually natural gas – without capturing the resulting CO_2 emissions.

When will we fly with hydrogen-powered aircraft?

Several programmes for commuter- and regional aircraft types are progressing towards future entry into service from the mid-2030s onward. However, the industry's *Waypoint 2050* anaylsis indicates that the anticipated contribution of hydrogen-powered aircraft now seems more modest than earlier forecasts, especially pre-2050.

This reflects both the slow ramp-up in the required hydrogen ecosystem and the fact that the initial products will mainly serve shorter range flights, which account for a limited proportion of fuel consumption. Hydrogen propulsion is best suited for commuter, regional, short-haul, and medium-haul aircraft.

Indicative timelines for hydrogen fuel cells in different aircraft types[5]

COMMUTER AIRCRAFT (9-50 Seats)	**From around 2030**
REGIONAL AIRCRAFT (50-100 Seats)	**Possibly by 2035**
SHORT-HAUL AIRCRAFT (100-150 Seats)	**From 2040-2050**
MEDIUM-HAUL AIRCRAFT (150-200 Seats)	**From 2040-2050**
LONG-HAUL AIRCRAFT (250 Seats)	**After 2050**

[4] IATA, Hydrogen for Aviation V2.0, 2025
[5] Waypoint 2050, Ed. 3, 2026: https://ataglink.org/4wZckTO

Preparing for hydrogen-powered aviation

Hydrogen-powered aviation will require substantial research and development, investment, and supportive regulation to enable safe, commercially viable aircraft and the necessary infrastructure. Robust infrastructure readiness is essential for hydrogen-powered operations. A 2025 concept of operations outlines how hydrogen and battery-powered aircraft can be integrated into airports, in support of aviation's 2050 net zero goal[6]. It examines potential changes in ground handling, refuelling, charging, safety, and emergency response, and helps to prepare for the development of future regulations.

Storage and distribution systems

For hydrogen to be used in direct aviation propulsion, it must be stored in a liquid form at temperatures below -253°C. This will require the development of highly insulated storage tanks and next-generation fuel handling and distribution systems at airports receiving hydrogen-powered aircraft.

Aircraft design

Hydrogen is not a "drop-in" fuel. The larger volume of hydrogen requires additional storage capacity on board, meaning existing aircraft will need retrofitting and entirely new aircraft designs will be needed.

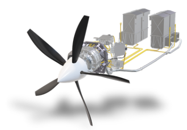
Special equipment and procedures

On the ground, much of the existing fuel infrastructure would need to be adapted, including trucks, trains, pipelines, and storage facilities. Handling liquid hydrogen also requires special equipment and procedures to manage risks such as extreme cold exposure, leakages, spills, and fire hazards.

Ongoing hydrogen projects

There is ongoing research and development into aircraft designs and hydrogen-powered energy systems. The development of these solutions is largely within the expertise of the sector, although collaboration with academic and institutional research programmes is key. Industry examples include:

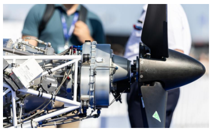
JetZero: The JetZero (Z4) is a revolutionary all-wing design. The JetZero aircraft is designed to be compatible with hydrogen propulsion or advanced hybrid-electric systems in the future and therefore has a zero-emissions potential. JetZero is aiming for potential entry into service in the early 2030s.



Zeroavia ZA600: The ZA600 is a 600kW hydrogen-electric powertrain designed for fixed-wing aircraft. It combines advanced fuel cell and electric engine technologies to deliver zero-emissions propulsion with the potential for improved operating efficiency. Gaseous hydrogen is stored onboard in lightweight tanks and supplied to fuel cells, which generate electricity to power electric engines and produce thrust through propulsors.

Rolls-Royce Pearl: The Rolls-Royce Pearl 700 is being used to develop future hydrogen-compatible aviation technologies. Building on advanced turbofan architecture, research is focusing on adapting combustion systems and fuel delivery technologies to enable the use of hydrogen as an aviation fuel.

Pratt & Whitney HyADES: The Pratt & Whitney Hydrogen Advanced Design Engine Study (HyADES) is exploring how hydrogen combustion technologies could be integrated into next-generation aircraft engines. The programme is focusing on adapting gas turbine architecture to enable it to be used with hydrogen fuel and is also examining the implications for aircraft integration, fuel storage, and airport infrastructure.



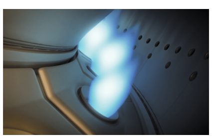
SAFRAN: Turbotech and Safran successfully carried out the first ground tests of a hydrogen-fueled engine as part of the BeautHyFuel project. This project serves a dual purpose: preparing the certification of a SAF-powered turbine for light aviation and demonstrating its adaptability to be powered using hydrogen as fuel.

Ongoing hydrogen projects

Airbus ZEROe: The ZEROe project is exploring the feasibility of hydrogen fuel cell technology. The ZEROe aircraft will feature an electric propeller propulsion system powered by hydrogen fuel cells, which transform the hydrogen into electricity through a chemical reaction. The only byproduct of this reaction will be water, meaning the process will be almost carbon neutral as long as the hydrogen is made using renewable energy.

ATR Evo: The ATR Evo is ATR's proposed next-generation regional airliner featuring a hybrid-electric propulsion system. While currently relying on traditional fuel and SAF, its architecture is future-proofed to eventually accommodate zero-emission hydrogen fuel cell technology when the required infrastructure and technology are sufficiently matured.

Boeing: Boeing has been exploring hydrogen technologies for more than two decades through a series of demonstration projects focused on fuel cells, liquid hydrogen propulsion, and hydrogen storage. These initiatives include the world's first piloted hydrogen fuel-cell aircraft, hydrogen-powered unmanned aerial vehicles, onboard fuel-cell systems for auxiliary power, and the development of advanced cryogenic fuel tanks.



GE Aerospace: CFM and Airbus are collaborating on a hydrogen demonstration programme with plans to flight test a hydrogen combustion engine in preparation for entry-into-service of a zero-emission aircraft by 2035.
CFM will modify the combustor, fuel system, and control system of a GE Passport™ turbofan to run on hydrogen.

Hydrogen projects at airports

Several airports are also taking action to introduce hydrogen solutions and develop the necessary infrastructure, including storage, refueling, ground handling, and energy systems to support future hydrogen-powered aircraft operations. Industry examples include:

TULIPS: The TULIPS consortium, led by Schiphol Airport, includes demonstration projects on future aircraft energy supply advancing procedures as well as operational and logistical practices for electric and hydrogen-powered aviation. The consortium is also developing airport-facilitated hydrogen flight demonstrations, to gain insights into operational processes and safety considerations across the entire hydrogen supply chain at airports.

Hydrogen hubs at airports: Airbus founded the Hydrogen Hubs at Airports project, which involves over 215 airports and aims to advance the development of a global hydrogen ecosystem.

Aéroports de Paris: Aéroports de Paris and Air Liquide have formed a joint venture called "Hydrogen Airport" to design and deploy hydrogen infrastructure. Preparations are underway at Paris-Charles de Gaulle, Paris-Orly, and Paris-Le Bourget to accommodate hydrogen-powered commercial aircraft from 2035

Edmonton airport hydrogen hub: Edmonton International Airport (YEG) has established YEG's Hydrogen Hub within its Airport City Sustainability Campus to accelerate the adoption of hydrogen in aviation and ground transportation. Leveraging the Edmonton region's significant hydrogen production capacity, the hub's aim is to test hydrogen technologies, including hydrogen-powered ground vehicles, passenger shuttle buses, fueling infrastructure, and the future use of hydrogen in SAF production, through partnerships with companies such as Toyota, Air Products, ZeroAvia, Hydra Energy, FirstElement Fuel, Mitsui, and others.

Calls to action

Continued research and development of hydrogen and new hydrocarbon fuels will be essential for unlock their potential up to 2050 and beyond. Scaling up the production of hydrogen for use in aviation will require strong multi-stakeholder collaboration across governments, industry, energy providers, financial institutions, as well as research organisations and academia.

Significant investment, supportive policy frameworks, accelerated technology development, infrastructure deployment and workforce training will all be needed to make hydrogen-powered aviation commercially viable and scalable over the long term.

Aviation sector	• Accelerate research and development of hydrogen propulsion systems and aircraft designs • Engage in multimodal energy planning together with governments • Ensure technical requirements are standardised for hydrogen aircraft ground handling, storage, and safety to reduce regulatory fragmentation • Ensure collaboration and coordination between stakeholders in planning, preparing and implementing hydrogen-powered solutions, including between airlines that are planning to invest in hydrogen-powered aircraft and airports where such aircraft would be operated
Governments and policymakers	• Adopt durable policies that incentivise and accelerate decarbonisation innovations, including hydrogen • Develop wider national energy and industrial strategies in addition to deploying SAF and include the hydrogen and low-carbon electricity requirements of aviation in national energy strategies. Ensure aviation requirements are identified in national green hydrogen and low carbon electricity infrastructure strategies • Prepare agencies for certification processes
Energy industry	• Ensure aviation's need for renewable energy, including low-carbon hydrogen, is considered in strategic energy investment and planning. • Collaborate with hydrogen and other transport sectors to leverage technologies and build synergies • Partner with airports to pilot various infrastructure projects
Research institutions	• Continue research in collaboration with industry into critical topics • Ensure research programmes for new technology reflect real-world requirements
Finance community	• Fund new aircraft acquisition • Explore sustainable finance opportunities • Fund hydrogen-ready airport infrastructure through blended finance, loan guarantees, and green public-investment programmes • Explore investments in multimodal energy hubs