Hydrogen power — boldly going to the heart of climate-neutral aviation

By Glenn Llewellyn (Airbus), Val Miftakhov (ZeroAvia)

Introduction

Hydrogen fuel offers significant potential for eliminating aircraft greenhouse gas emissions. Early concepts for smaller commercial aircraft are already flight testing gaseous hydrogen as a fuel, while larger airframes (50 plus seats) are likely to leverage liquid hydrogen due to its improved energy density.

With hydrogen as a fuel, either in combustion engines or used in a fuel cell, there are no in-flight carbon dioxide (CO_2) emissions whatsoever. Hydrogen can be made through electrolysis powered by renewable energy, ensuring there are no direct CO_2 emissions in fuel production. Hydrogen can thus be the pathway towards "net zero" in aviation.

In this two-part article, Airbus' Glenn Llewellyn (VP, Zero Emission Aircraft) and ZeroAvia's Val Miftakhov (CEO), both leaders in the development of hydrogen aircraft technology, explain their respective companies' solutions, and the benefits and challenges of the approach they are taking to develop hydrogen aircraft propulsion in depth.

Airbus-ZEROe — from concept designs to the real thing

Liquid hydrogen's high energy density makes it suitable to fuel large aircraft as a replacement for kerosene. To this end Airbus is evaluating several hydrogen approaches for future aircraft designs, which include 'direct hydrogen combustion' and 'hydrogen fuel cells'. The latter, which produce zero emissions, convert energy stored in hydrogen atoms into electrical power via an electro-chemical reaction. Hydrogen is also a key ingredient for a third category: power-to-liquid synthetic fuel which is even compatible with existing aircraft – whereby 'green' hydrogen is combined with carbon dioxide to form a synthetic fuel with net-zero carbon emissions.

For the direct combustion approach, hydrogen is injected and ignited in a modified turbofan's combustor to generate thrust – a process which is identical to that in traditional jet engines. With hydrogen replacing kerosene, the direct combustion products are water vapour (H_2O) + energy, plus some trace gases. The upside is that CO_2 and the majority of soot emissions are eliminated. The challenge is to significantly reduce NOx and persistent contrails. To this end, Airbus is working with its technology partners to eliminate this potential climate impact of hydrogen combustion.

Airbus and its partners are already working on four hydrogen-powered concept aircraft – known as ZEROe – which were unveiled to the world in 2020 (Figure 1). These designs correspond to mission ranges of 1,000 nm or 2,000 nm and capacities of between 100 and 200 passengers, thus representing a large portion of the market including transcontinental flights.

Three of the concept aircraft would use hydrogen combustion engines in combination with a megawatt scale hybrid-electric component. The latter comes from fuel cells rather than batteries due to the overall performance benefit especially given that there is already hydrogen on board the aircraft. The fourth ZEROe concept is a fully fuel-cell powered aircraft, for which the propulsion system as well as all non-propulsive energy needs are powered by fuel cells.

FIGURE 1: Introducing Airbus ZEROe

A down selection on ZEROe's technology choices and aircraft configurations is expected to start as early as 2025, which means that the first hydrogen-powered airliner could be certified and ready for service entry by 2035.

While liquid hydrogen has a specific energy-per-unit mass which is three times higher than traditional Jet-A1 kerosene, its volumetric energy density is actually lower, therefore the visual appearance of future aircraft will likely need to adapt accordingly – with more internal volume devoted to storing the liquid hydrogen. This is reflected in the respective ZEROe concept configurations whereby, in the turboprop and twinjet designs for example, extra fuselage length is devoted to storing liquid hydrogen in cylindrical tanks. Meanwhile, the largest concept aircraft takes advantage of its exceptionally large internal volume afforded by the "blended-wing" itself for accommodating the hydrogen.

Airbus is also adapting and evolving existing hydrogen storage technology for use inside aircraft. Several new research and development facilities across Europe have

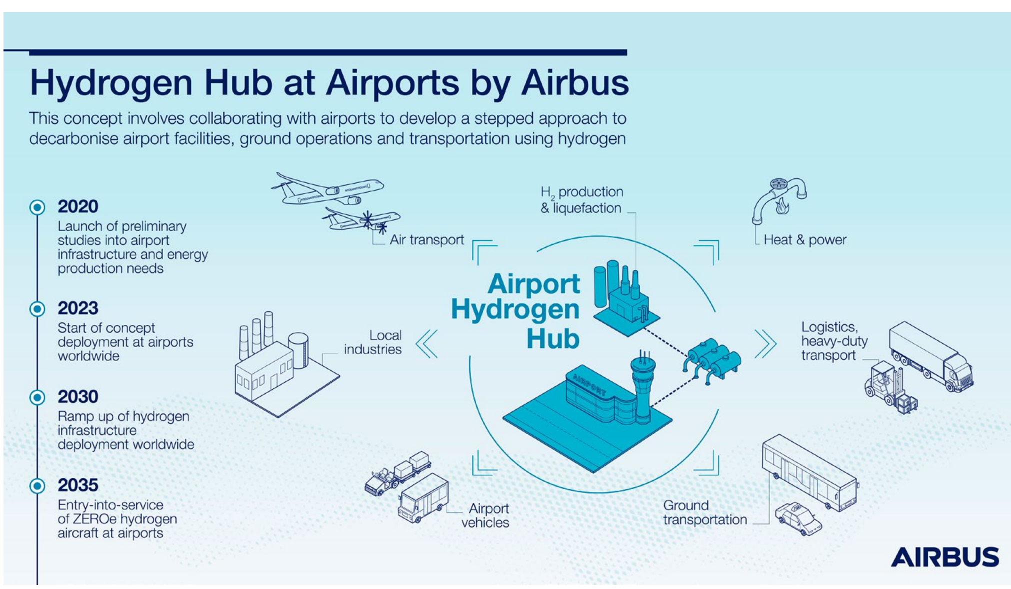

FIGURE 2: Hydrogen hub at airports by Airbus.

recently begun work on liquid hydrogen storage tanks for its ZEROe concept aircraft. These 'cryogenic' tanks will be insulated to keep the hydrogen in liquid form at around -253 degrees Celsius.

In February this year, Airbus signed a partnership agreement with CFM International to collaborate on a ZEROe hydrogen propulsion demonstration. In terms of hardware this comprises an A380 testbed onto which is mounted a hydrogen-fuelled test engine provided by CFM. The programme's objective is to initially perform tests on the ground. Subsequently there will be in-flight trials starting in 2026 with a direct combustion turbofan engine fuelled by hydrogen. Airbus' A380 flying testbed, dubbed "FlightLab", will be equipped with four cylindrical tanks housed inside the rear fuselage which will contain the liquid hydrogen fuel.

In parallel with the development activities regarding engines, cryogenic fuel tanks and aircraft platforms, Airbus is also working alongside its airline and airport and energy supplier partners on "Hydrogen Hub At Airports" – an initiative which is investigating ground infrastructure requirements for hydrogen. Specifically, Airbus is collaborating with airports to plan a stepped approach to deployment, including using hydrogen to decarbonise all airport-associated ground vehicles. To date, agreements have been signed with partners in Paris, Seoul and Singapore, with more to follow.

ZeroAvia - hydrogen-electric powertrains for aviation

ZeroAvia has decided to develop exclusively hydrogen-electric engine technology in its bid to deliver zero-emission flight, initially focusing on retrofitting existing airframes. From the outset, the company has been targeting delivering electrification to the aviation market to remove all emissions (both CO_2 and non-CO_2), but realised very early in a first principles analysis that battery-electric power was not viable due to the significant weight limitations.

Hydrogen-electric powertrains – utilising hydrogen fuel cell systems to produce electricity from hydrogen fuel in order to power electric motors – offer significant advantages over other alternative propulsion types. According to the US Department of Energy, a fuel cell coupled with an electric motor is two to three times more energy efficient than an internal combustion engine running on gasoline. In a fuel cell propulsion system the only emission is water vapour, and mitigations to contrail impacts are also possible given the relatively low temperature and slower exhaust of the water. For ZeroAvia this is crucial, as there are no carbon emissions in the system, but also none of the other non-carbon emissions that are present in current turbine engines like NOx, SOx, particulates and soot, now known to contribute significantly to aviation's full climate impact.

There are challenges in bringing hydrogen fuel cell powered propulsion systems to market, such as the volume required for hydrogen fuel storage, but these are not insurmountable and there is no theoretical limitation in physics as to why hydrogen-electric propulsion cannot power the largest airplanes or the longest flights in service today.[1]

ZeroAvia has already demonstrated its hydrogen-electric powertrain technology in a six-seat Piper Malibu using a 250kW system, with gaseous hydrogen as the fuel. The company is also well advanced in the development of a 600kW system (ZA600), capable of supporting 10-20 seat aircraft with an initial range of 300 nautical miles. The company plans to certify this technology in time for entry into service by 2024 and has signed an initial deal with Hindustan Aeronautics Ltd, enabling the

FIGURE 3: ZeroAvia

1 See CleanSky report https://www.fch.europa.eu/sites/default/files/FCH%20Docs/20200720_Hydrogen%20Powered%20Aviation%20report_FINAL%20web.pdf

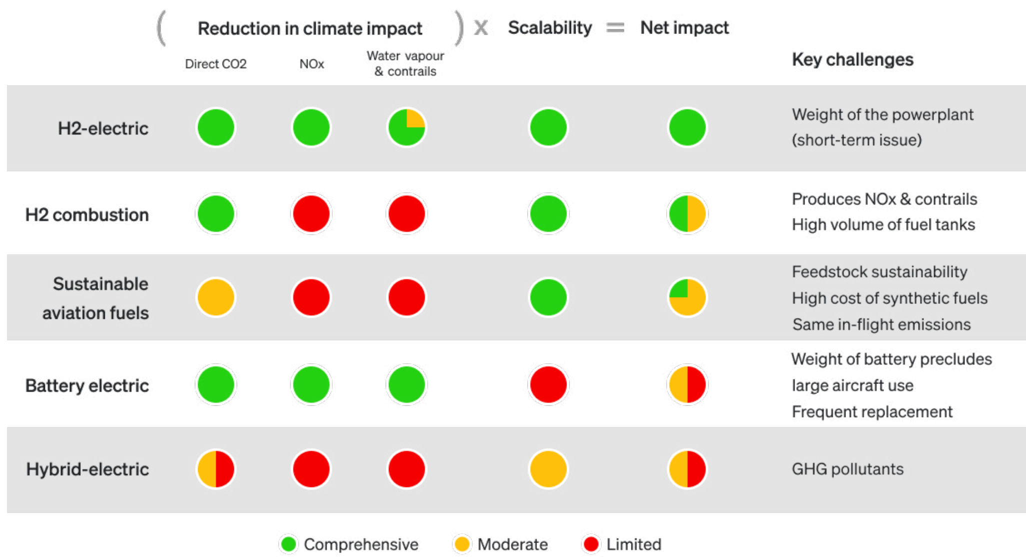

FIGURE 4: Why hydrogen-electric?

Indian manufacturer to offer retrofits to existing Dornier & Hindustan-228 Aircraft and line fit new manufactured Dornier & Hindustan-228 aircraft with hydrogen-electric powertrains.

ZeroAvia is concurrently working on research, design, certification and production of a modular 2-5 megawatt (MW) hydrogen fuel cell powertrain between now and 2026. This powertrain would be capable of powering 40-80 seat aircraft over distances up to 1,000 nautical miles – equivalent to Washington DC to Dallas, or London to Reykjavik. Sub 1,500 nautical mile flights cover more than 50 per cent of all aviation greenhouse gas emissions and 80 per cent of all trips – showing that as the technology advances it can have a meaningful impact this decade. The technology also promises lower operational costs meaning more viable regional routes, better connectivity (boosting local economies) and lower costs for passengers. This is a big reason why major airlines such as Alaska Airlines, United Airlines and British Airways are backing the companies' technology.

For both hydrogen combustion and hydrogen fuel cell powered flight, refuelling infrastructure is a major challenge. ZeroAvia has been working to demonstrate the use case for airport refuelling, having developed its Hydrogen Airport Refuelling Ecosystem (HARE) in collaboration with the European Marine Energy Centre (EMEC). Using an onsite electrolyser at its R&D bases to produce compressed hydrogen gas which is then passed into its mobile refuelling truck, the company has been demonstrating the infrastructure for gaseous hydrogen

FIGURE 5: Green hydrogen powers electric propulsion using the fuel cells

refuelling in its flight testing programme over the last two years. The company has also been working on concept studies to support larger aircraft programmes with liquid hydrogen refuelling infrastructure.

Over the next three years ZeroAvia expects to achieve certification of its 600kW hydrogen-electric powertrain system, and begin working with airline and airport partners on zero-emission commercial routes carrying 10-20 passengers. The company has already struck a deal with Royal Schiphol Group and Rotterdam The Hague Airport Group to develop a route between the Dutch airport and a London airport, for example.

Simultaneously, the company will further develop its ZA2000 product to the point of certification within the next three years, supporting 40-80 seat turboprop aircraft such as the Dash-8 Q400 which it will be working to demonstrate over the period as part of a partnership with Alaska Airlines. ZeroAvia is targeting market entry for this powertrain to support larger aircraft in 2026.

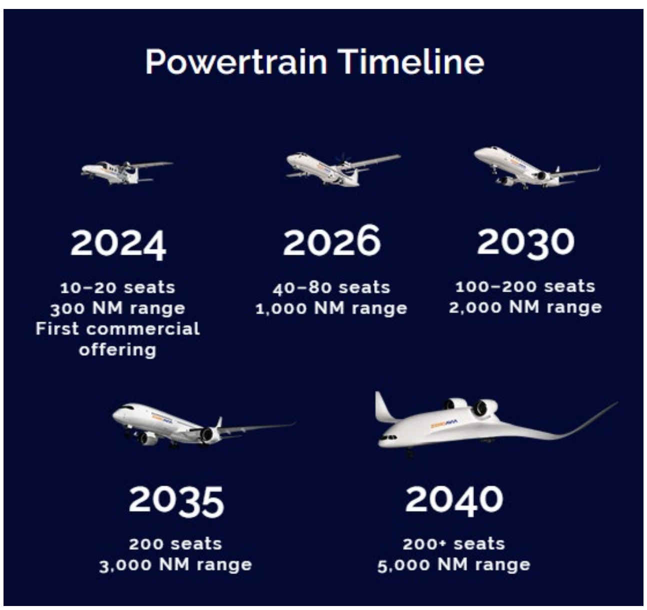

FIGURE 6: Powertrain Timeline

Further to its propulsion R&D, ZeroAvia will conduct additional research, development and demonstration of its HARE programme, developing a stronger body of knowledge on the provision of liquid hydrogen fuel in an airport context, and building on its hydrogen generation and refuelling infrastructure at its Hollister, California and Kemble, UK airport locations supporting the company's flight testing programmes. The installation of gaseous hydrogen production at airport sites to support routes and ancillary use cases will further demonstrate to a wide audience the economic and environmental opportunities of hydrogen within aviation.

Collectively driving industry's transition to hydrogen

Airbus and ZeroAvia are two out of a rapidly expanding group of proactive aviation players, who, collectively, are driving the major industry shift – from simply viewing hydrogen as a potential opportunity to showing how the fuel has an integral part to play in reducing the environmental impact of operations both on the ground and in the air. Moreover, by working together with industry partners and authorities the resulting momentum is already bearing fruit: Demonstrations of hydrogen combustion, zero-emission fuels cells and hybrid hydrogen-electric combined configurations are accelerating. These will be closely followed with the first certifications for technology enabling net-zero-emission and beyond commercial flight.