TECHNOLOGY READINESS LEVEL (TRL) - 2023

TECHNOLOGY DETAILS

Technology: **Hydrogen PEM FCEV**
Sub-technology: **Aircraft**

Value chain: Road
Sub-sector or technology: Vehicle/aircraft/vessel and components
Sector: Transport
Demand/Supply/Infrastructure: Demand

TRL $_{2023}$: 4

Several projects are ongoing for larger aircraft. Since the biggest advancement was realized for the four-seater DLR and Universal Hydrogen, which can be relevant for the taxi application, the overall TRL for the technology can be defined as 4: Small prototype - Early prototype. For larger aircraft, this TRL is surely pretty high.

TECHNOLOGY DESCRIPTION

Hydrogen is a renewable energy source that can be used to completely eliminate all CO2 emissions during flight and during the whole energy lifespan. Its use in fuel cells enables emission-free (including NOx and particle) propulsion. Moreover, fuel cell propulsion could reduce climate impact in flight by 75-90%, compared to 30-60% for synfuels, according to “Hydrogen-powered aviation” study. However, before its full potential can be realized, a number of technical challenges must be overcome.

The low volumetric energy density of hydrogen, about a quarter that of jet kerosene, together with the need to keep cryogenic hydrogen at low temperature, calls for new aircraft design. Fuel tanks may be located in the fuselage rather than in wings to meet flying range requirements, which would reduce the space available for passengers. Existing programmes prioritize cryogenic hydrogen over pressurized hydrogen at ambient temperature, allowing for longer ranges. However, Liquid hydrogen systems are expected to be practical for large commercial air transport applications, but the "in-tank" temperature must be kept at -253 degrees Celsius, making liquefying and storing liquid hydrogen difficult. Significant research and development challenges are brought about by the effects on tanks, fuel/distribution systems, replenishment, and overall system design, dependability, and safety. The availability of hydrogen, its distribution, the requisite recharging/refuelling infrastructure, and renewable generation are essential to the overall success of this approach.

There are two aircraft designs that use hydrogen as an energy carrier; hydrogen can either be used to operate a fuel cell on an electric aircraft or used as combustion fuel to power a jet engine. Neither produces direct CO2 emissions during the operation of the aircraft (although the upstream emissions depend on the technologies used to produce and transport the hydrogen). Combustion of hydrogen produces water vapour, which can contribute to global warming.

In electric aircraft designs with fuel cell technology, batteries are typically used to regulate power output or as back-up fuel source, but not as primary energy storage. The reduced battery capacity requirements, together with the high energy density of hydrogen per unit mass, alleviate a major constraint of electric flying (related to the low energy density of current batteries that prohibit electric flights beyond short-haul flights).

Hydrogen aircraft are at an early development stage and commercial application in small regional jets is only expected in the long term. An early application of hydrogen in aircraft will be in auxiliary power units (APU) for non-propulsion applications such as lighting, HVAC, or cabin pressurization.

KEY COUNTRIES

Germany, France, USA, Spain, New Zealand, China, The Netherlands, United Kingdom

PROTOTYPE OR DEMONSTRATION PLANS, DEDICATED INVESTMENTS, LEADING INITIATIVES

* Airbus announced three concept hybrid aircraft. The aircraft, which Airbus aims to bring to the commercial market by 2030, are to be powered by liquid hydrogen using modified gas turbine engines, as well as by hydrogen fuel cells to generate electrical power to complement the gas turbine. https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html

* Boeing demonstrators (engine or auxiliary power unit): http://www.boeing.com/news/frontiers/archive/2008/may/ts_sf04.pdf

Boeing fuel cell electric aircraft: http://www.wired.com/2008/04/in-an-aviation/

DLR fuel cell electric aircraft: http://www.dlr.de/content/de/artikel/news/2016/20160929_emissionsfreier-antrieb-fuer-die-luftfahrt-erstflug-des-viersitzigen-passagierflugzeugs-hy4_19469.html

H2Sky Project in Germany has the goal of carrying out the development and the pre-industrialisation of 100-200 kW fuel cell stack for use in the main propulsion system of an airplane. The overall grant is around €26.5 million, with around €18 million self-financed from the consortium, totalling an overall project volume of over €44 million. (Highest level of funding ever received by an individual project under the National Innovation Programme for Hydrogen and Fuel Cell Technology, Germany)

https://www.now-gmbh.de/en/news/pressreleases/h2sky-project-to-develop-aviation-optimised-fuel-cell-stacks-receives-euro-26-5-million-in-funding/

*Universal Hydrogen takes to the air with the largest hydrogen fuel cell ever to fly

https://hydrogen.aero

Important Clean Hydrogen JU projects:

- HEAVEN: Integration of a modular high-power fuel cell system for propulsion of an aircraft, in combination with an innovative cryogenic (liquid) hydrogen storage system.

- HYCARUS: Development of a flight-ready fuel-cell based auxiliary power unit system, including a high-pressure hydrogen tank, adequate for pressurised passenger aircraft.

- FLHySAFE: Development of an emergency power unit for flight controls, linked hydraulics and flight-critical instrumentation in case of emergency.

DEPLOYMENT TARGETS

75% of the global civil aviation fleet will be replaced by 2050 thanks to the technical and industrial preparedness that will enable the deployment of new aircraft with this performance no later than in 2035.

When used in conjunction with sustainable 'drop-in' fuels, the designed aircraft will allow net CO2 savings of up to 90%, or zero CO2 emissions in flight when employing hydrogen as an energy source.

As a European joint corporation, Airbus' ZEROe strategy aims for a production-ready passenger airplane operated on a hydrogen and fuel cell basis by the year 2035 (possibly 2030). This is to be used over medium distances, for example, for destinations within Europe.

(https://www.now-gmbh.de/en/news/pressreleases/h2sky-project-to-develop-aviation-optimised-fuel-cell-stacks-receives-euro-26-5-million-in-funding/)

According to the Clean Aviation Joint Undertaking's mission, the European Green Deal and carbon neutrality by 2050 will be supported by the Clean Aviation JU's development of innovative new aircraft technology. In comparison to 2020 state-of-the-art, these technologies will result in net greenhouse gas (GHG) reductions of at least 30%.

COST REDUCTION TARGETS

- Fuel cell module durability, from 15,000 up to 30,000 hours in 2030
- Fuel cell system cost, down to 3,000 €/kW in 2030
- Fuel Cell Gravimetric Power density, up to 2 kW/kg in 2030
- FC system efficiency up to 50% in 2030
- Tank gravimetric efficiency (liquid hydrogen): up to 35% of weight in 2030, considering tanks with more than 1 ton of hydrogen stored

RELEVANT PARAMETERS

Energy density	0,75 kW/kg (FC System)
Fuel cell efficiency (%)	43,5
Cost (€)	> 15.000 EUR/kW
Platinum loading	0,4 g/kW
Durability	15.000 h (FC Module)

Based on expert input:

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