Renewable Hydrogen for Aviation

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Introduction

Aviation is responsible for 2% of carbon dioxide (CO_2) emissions[1] and is at the heart of environmental challenges. Whilst existing technologies will keep improving, the development of radical new technologies is required in order to reach the industry's goal of Net-Zero Carbon Emissions by 2050[2]. Hydrogen with a potential to drastically reduce aviation's carbon footprint needs to be assessed in the years to come. Present across the entire hydrogen value chain and with an expertise spanning more than 50 years in the aerospace industry, Air Liquide is using its technical and industrial expertise in hydrogen to help decarbonise aviation from the ground to the air.

This article details the potential of hydrogen as well as the challenges to tackle along the value chain.

Hydrogen production

With the climate challenges we are facing today, the supply of fossil-based hydrogen needs to be gradually replaced with renewable and low-carbon hydrogen in order to have a positive impact on the carbon footprint. Hydrogen is the most abundant element in the universe, but reacts easily with other elements to form, among others, carbon chains and water. Since it is very seldom available in a pure form, it needs to be extracted, using mainly two major pathways: steam methane reforming and water electrolysis.

Currently, steam methane reforming is the most common pathway to produce hydrogen, but its carbon footprint must be drastically reduced. For this, it's possible to replace methane by biomethane (from biomass), and the CO_2 produced can then be considered as biogenic. To reduce the carbon impact of steam methane reforming, it is also possible to capture carbon dioxide produced during the process and store or valorise it (an example being carbonated drinks). Carbon capture is the only short-term realistic solution to decarbonise quickly and at a large scale. It is also possible to reduce even further the impact of a steam methane reformer by combining the use of biomethane and carbon capture.

Hydrogen can also be produced using water electrolysis. This pathway is now mature and the most virtuous, provided that the energy source is renewable or low-carbon. We are currently witnessing an increase in the number of large-scale projects on all continents, as well as a rapid evolution of electrolysis technologies, whether for alkaline, Proton Exchange Membranes (PEM) or emerging technologies such as Anion Exchange Membranes (AEM) or even high-temperature electrolysis. The most promising technology to produce large quantities at a controlled cost is currently PEM, as shown by numerous projects worldwide. This is the feat that has been achieved by Air Liquide in Canada, with the world's largest PEM electrolyser (20 megawatts), inaugurated in January 2021[3]. Scaling up is key. Walking the talk, Air Liquide has since launched several new projects at an even larger scale: 30 MW in Germany, 200 MW in France through Air Liquide Normand'Hy to create the first low-carbon

1 https://www.icao.int/environmental-protection/Pages/scientific-understanding.aspx
2 RESOLUTION The 77th IATA Annual General Meeting
3 https://www.airliquide.com/stories/industry/inauguration-worlds-largest-pem-electrolyzer-produce-decarbonized-hydrogen

FIGURE 1: Producing, conditioning and distributing renewable and low-carbon hydrogen for airport ecosystems

hydrogen network in the world, capable of supplying all industrial customers in Normandy, as well as hydrogen refuelling stations for mobility (Figure 1).

The airport ecosystem

Low-carbon hydrogen is produced in gaseous form. Due to intensive usage, airports need large quantities which can be better suited by liquid hydrogen due to its high energy mass density[4]. It then has to be transported to the usage location by a pipeline network and dedicated fleets of trailers. Once it is transferred to storage containers, it can be used for many purposes, including ground logistics: baggage tractors, forklifts, pods, super tugs, shuttle buses, etc. On top of internal uses, the deployment of hydrogen-based mobility solutions can benefit external uses such as bus, taxi and all other ground mobilities. **The complementarity of uses in the ecosystems is a major lever for making low-carbon hydrogen accessible and creating early sources of demand. This is important because it will prepare the infrastructure and airport ecosystem for the arrival of hydrogen aircraft.**

With a well established presence in many strategic basins in North America, Asia and Europe, Air Liquide is ideally positioned to develop synergies between mobility applications.

In 2021, Air Liquide entered into partnerships with key players in the aeronautical sector in order to facilitate the development of airport infrastructure and be prepared for the arrival hydrogen-powered commercial aircraft by 2035:

- Air Liquide has partnered with Seoul International Airport (Incheon) to build two high-capacity hydrogen stations for airport vehicle fleets with filling times of under five minutes. The environmental impact of these vehicles fleets is considerably reduced by using hydrogen to power them.
- In June, one of the Air Liquide Group's projects was the winner of the AMI "H2 Hub Airport" organised by Groupe Aéroport de Paris, Air France-KLM, Airbus, Île-de-France Region to adapt existing liquid hydrogen trailers for aviation applications.
- In June and September, Air Liquide signed two Memorandum of Understanding with 1)Airbus and Groupe Aéroport de Paris and 2)Airbus, Groupe Vinci, Lyon Airport.

These partnerships will leverage the respective expertise of the stakeholders to support the decarbonisation of the aviation industry and to define the concrete needs: technological bricks, regulatory framework, and investments.

4 120 Mj/kg

FIGURE 2: Hydrogen usage to decarbonise airports

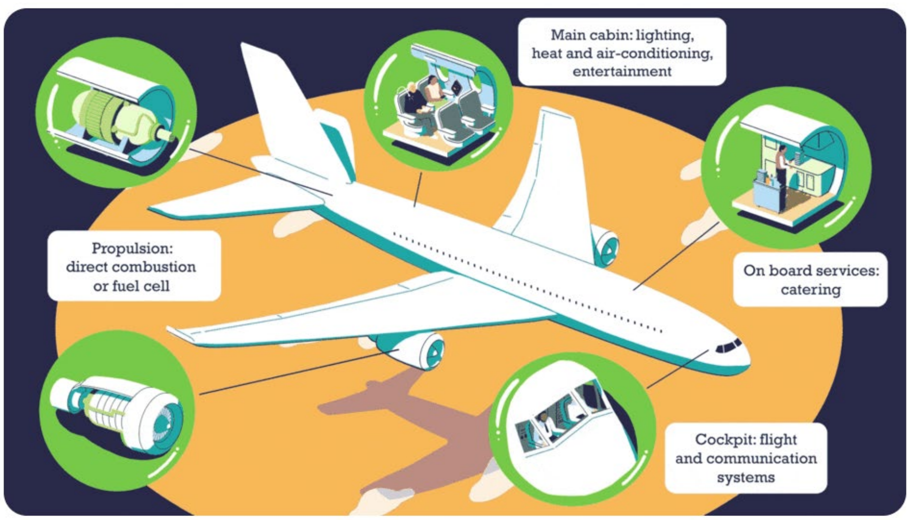

FIGURE 3: The different uses of hydrogen aboard the aircraft

Aboard the aircraft

Aboard the aircraft, hydrogen can produce electricity that will be used to power all the flight and communication systems in the cockpit as well as all on-board services. But in the future, it could be used for propulsion, either by direct combustion or by powering a fuel cell. Hydrogen significantly reduces emissions because its direct consumption in a turbine or using a fuel cell doesn't emit any CO_2 and substantially reduces nitrogen oxide (NO_x) particles. By the end of the 2000s, Air Liquide started to explore the potential of Hydrogen for aviation, with various paper studies and ground or flight demonstrators that has demonstrated that a hydrogen storage under high pressure (350 or 700 bar) is too heavy when storing more than a few kilograms of gas. The ongoing High Power Density FC System for Aerial Passenger Vehicle Fueled by Liquid Hydrogen (HEAVEN)[5] project should fly by late 2023, aboard a small 4-passengers aircraft to demonstrate for the first time the compatibility of a fuel cell system powered by a liquid hydrogen tank for aircraft propulsion. Air Liquide is responsible for the design, manufacture and testing of the tank and the ground filling station. The project aims to show that a liquid hydrogen tank suitable

5 HEAVEN project: financed by the Fuel Cell Hydrogen-Joint Undertaking of the European Commission

for flight is at least five times lighter and much smaller than a high pressure one, making it a viable solution for regional aircraft.

The development of key hydrogen technologies such as cryogenic hydrogen storage, distribution system, pump, cryogenic valves shall be supported by ambitious technological roadmaps while taking care of the safety issues: risk management, specific skills, etc.

In the short to medium term, the aviation sector is moving towards an energy mix in which synthetic fuels will be indispensable, since long-haul aircraft will not be able to fly entirely on hydrogen, mainly because of the mass/volume constraints and the necessary technological development lying ahead. Similar to hydrogen for propulsion, innovations in the field of synthetic fuels are to come and could also contribute to the decarbonisation of aeronautics. In particular, synthetic fuels will have to be produced from low-carbon hydrogen and captured CO_2 (See "Hydrogen production" Section) to have a positive environmental impact.

Key partnerships will be necessary to develop on board technologies, deploy the supply chain and organise the appropriate regulatory framework for commercial aircrafts to fly using hydrogen. Indeed urgency for energy transition and its investment potential shall cause regulations to come. But it should be noted that hydrogen for aviation will benefit from synergies with ground mobility.