Bauhaus Luftfahrt
The Aviation Think Tank

Hydrogen for climate-friendly aviation – even on long-haul flights

The long-term goal: climate-neutral aviation

With the European Green Deal, the European Commission aims to achieve net-zero greenhouse gas emissions in the European Union by 2050, which will require a widespread transition to renewable energies in all sectors ↗. In the aviation sector, the Air Transport Action Group (ATAG) and the High Level Group on Aviation Research, in cooperation with the Advisory Council for Aviation Research and Innovation in Europe (ACARE), have already defined emission targets at fleet and aircraft level ↗. The International Air Transport Association (IATA) has set the ambitious goal of reducing net CO_2 emissions from global aviation to zero by 2050 ↗. This target represents an immense technological, economic, and political challenge. In addition, the transition to climate-neutral flying also requires the avoidance and offsetting of the non-CO_2 climate impact of air travel.

Cross-sectoral potential of green hydrogen

While efficiency gains and operational improvements are probably the most effective means of reducing CO_2 emissions in the early phase of the transformation, the challenge in the final phase will be to eliminate CO_2 emissions entirely. The use of renewable fuels with significantly lower climate impact plays a special role here. Both the Federal Government of Germany, as part of its National Hydrogen Strategy, and the European Union in its "Hydrogen strategy for a climate-neutral Europe" highlight the potential of cross-sectoral use of green hydrogen to achieve the goals of the Paris Climate Agreement ↗ ↗. In addition to the use of renewable hydrogen for the production of synthetic kerosene, the direct use of hydrogen is a promising option as a fuel for aviation. This is a future driver for new, radical hydrogen-based propulsion concepts.

Concepts for hydrogen aircraft in the most important market segments

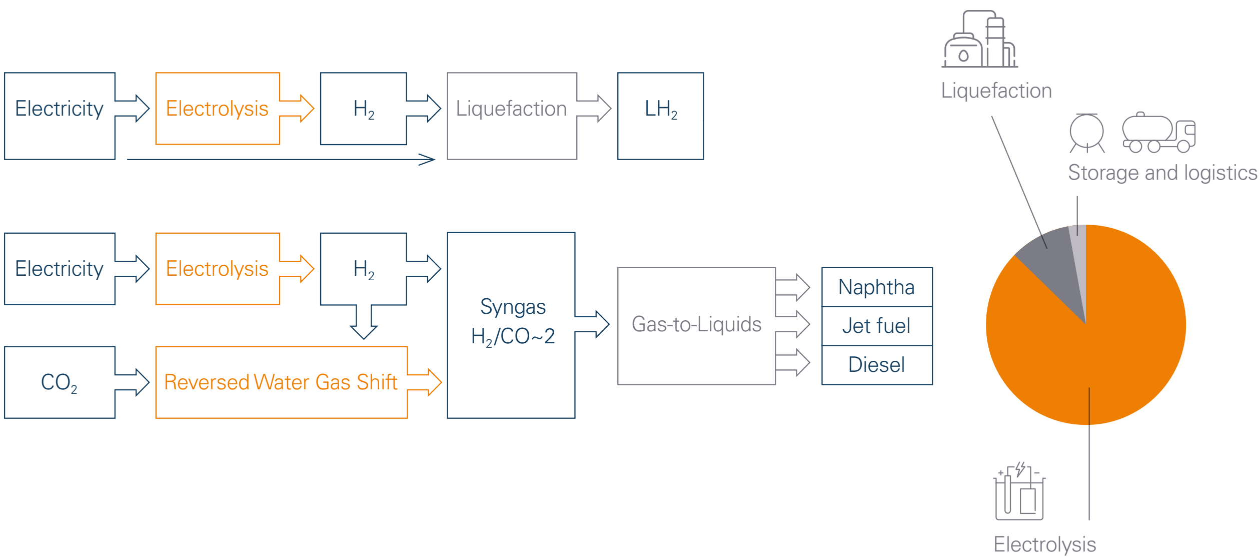
In the medium term, hydrogen could become cheaper than sustainable kerosene.

Just a few years ago, advanced biofuels that produce kerosene from widely available raw materials such as straw or wood were considered the most plausible option for an energy transition in aviation. Now, however, the production of hydrogen through electrolysis is also considered one of the most cost-effective and sustainable methods for obtaining renewable energy sources, either in the form of liquid cryogenic hydrogen or chemically bound in kerosene-like fuels.

Solar and wind as primary energy source

This paradigm shift is based primarily on the significant cost reductions in solar and wind energy and their future availability as primary energy sources in resilient value chains. Compared to power-to-liquid production (i.e., synthetic kerosene), the production of liquefied hydrogen (LH_2) can be made significantly more efficient and cost-effective, as no CO_2 is required, process steps are eliminated, and hardly any by-products are produced. These advantages can outweigh the higher costs and losses along a representative LH_2 supply chain.

The energy-intensive liquefaction process for the production of LH_2 should take place directly at the water electrolysis site, as renewable electricity must be available there at low cost anyway. Logistics by sea is carried out using LH_2 tank trucks, while trailers or railway tank cars are used for transport by land. This would allow LH_2 to be supplied at relatively low-cost across major airports.



Left: Comparison of hydrogen and synthetic fuels;
Right: Proportion of energy required for hydrogen production through electrolysis, liquefaction, and transport

Hydrogen is also attractive for long-haul transport

Bauhaus Luftfahrt sees promising potential in long-haul flights, as this market segment offers disproportionaly high emission savings and fuel cost dominate operating costs. In addition, there are no viable substitutes from other climate efficient transport modes, and initial operation can begin with a limited number of airport conversionss or fleet renewals.

Hydrogen storage options on board

Several options are available for storing energy in the form of hydrogen on board aircraft. For large passenger aircraft, several studies have shown that liquid storage in cryogenic pressure tanks is by far the most promising technology. The development of the necessary systems for the refueling and distribution of hydrogen in the aircraft during flight is a mandatory step toward such a system. Because liquid hydrogen cannot be stored in the wings – due to its volume, storage pressure, and necessary insulation – new solutions are needed, for example by integrating tanks into the fuselage. The relatively larger fuselage diameter of a long-haul aircraft allows for a structurally more favorable tank design than in narrower fuselages. The disadvantages of the additional fuselage drag can be counteracted by integrating a boundary layer suction drive at the rear.

New possibilities for wing design

Furthermore, new possibilities are opening up with regard to wing design: the space in the wing that was previously reserved for fuel can now be used for optimized structural load paths that are adapted to the loads of wings with high-aspect ratios. In addition, improved flight control architectures and their actuators can be implemented. Both aspects complement each other, as high-aspect ratio wings can be advantageously designed as highly flexible, actively controlled wings.

Even though green hydrogen as an energy carrier promises an immediate improvement in the climate balance, it is still important to increase the efficiency of the aircraft as much as possible in order to keep the total amount of hydrogen required and thus also the negative implications for the aircraft as low as possible. In view of the changed aircraft characteristics, as well as the resulting cost models, it is also necessary to reevaluate previously unused technological options.

Aircraft concept with boundary layer ingesting propulsor at the aft-fuselage

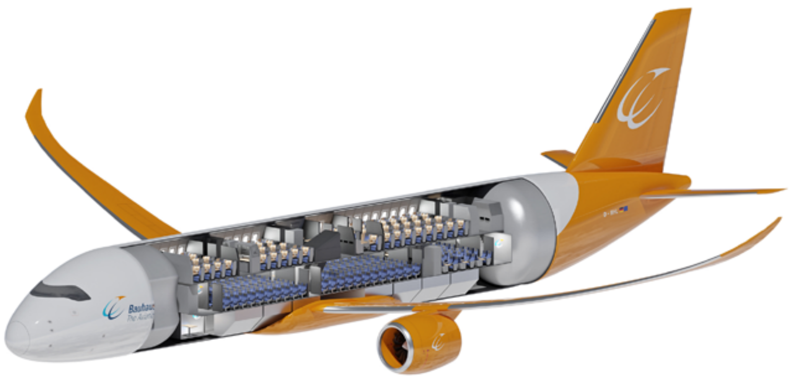
Gas turbine remains the primary propulsion option

The primary propulsion option for commercial aircraft – including those powered by LH_2 – remains the gas turbine. However, the presence of hydrogen in the aircraft also enables the use of direct electrochemical conversion devices, namely fuel cells, to provide electrical energy. While a combination of fuel cells and electric motors as the primary propulsion option can only be considered for aircraft up to the size of regional aircraft for the time being, fuel cells could, for example, replace the classic APU (auxiliary power unit) with the on-board hydrogen storage system and supply the electrical subsystems with electricity during flight. This would reduce secondary power consumption by the engines, allowing them to be designed for lower power output.

In addition, combined systems consisting of fuel cells and turbomachines with synergy potential are conceivable. For example, the water produced as a by-product in the fuel cell could be treated and used to increase the performance and efficiency of the gas turbine. Furthermore, a fuel cell would be an attractive energy source for the boundary layer suction drive at the rear.

The challenge:
Parallel operation of kerosene and hydrogen infrastructure with high safety requirements

In addition to its use as a fuel for future fleets, hydrogen can also be used in the aviation sector for ground operations, such as vehicles for baggage and passenger transport or for supplying electricity and heat to airports. A transformation of these various areas would also take place over different time horizons. The general use and gradual introduction of hydrogen will place various demands on airports and airlines. On the one hand, the parallel provision of liquid hydrogen and kerosene will be necessary for airport operations in the foreseeable future. In addition, it must be considered whether LH_2 will be supplied for refueling by tank trucks or by permanently installed pipelines at the gate. The former solution would potentially require less intervention in the current airport infrastructure, but does not offer the same scaling potential as pipeline solutions. On the other hand, the introduction of hydrogen requires modified safety requirements due to the properties of hydrogen. With regard to changed regulations and standards for handling hydrogen, the aviation sector can draw on other sectors and corresponding parameters where its use is more widespread.



Concept for the synergistic integration of hydrogen in a future long-haul aircraft

System transformation in aviation: a joint effort by all stakeholders

Research is currently underway to determine what a transformation of aviation to hydrogen as an essential fuel might look like. There is also considerable uncertainty about the market segments in which hydrogen should be introduced and what realistic time frames might be. Almost all aviation segments are conceivable, from urban air mobility and business aviation to long-haul flights.

For a successful introduction strategy, aircraft manufacturers, airlines, and airports must be involved at an early stage, along with supplier industries, research, politics, and society. In addition, synergies with other potential hydrogen-consuming sectors must be promoted. In particular, a certain degree of investment security must be guaranteed right from the start of the transformation so that the necessary, at some point in time possibly large investments in infrastructure investments and R&D activities can be financed in a timely and sufficient manner. A successful system transition can only succeed if the right impetus is provided at an early stage, almost all stakeholders benefit, global standards and uniform systems are established, and the transformation is supported by policymakers in the long term.

The parallel provision of liquid hydrogen and kerosene will create new requirements for airports and airlines.

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