Status Quo Analysis of German Airports Regarding Fuel Infrastructure and Hydrogen Development Opportunities

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1 Introduction

To achieve the ambitious goal of net-zero CO_2 emissions in the aviation sector in 2050, significant changes to the current aircraft fleet, as well as the fuel supply infrastructure, are necessary. As shown in Figure 1, even when assuming significant efficiency improvements, greenhouse gas (GHG) emissions are expected to increase due to growing demand. Sustainable Aviation Fuels (SAF) already play an essential role in the aviation industry, with a current global share of 0.2 % [1]. By introducing a European quota of 6% by 2030, SAF will make a significant contribution to GHG reduction, with the advantage of only minor changes to the aircraft fleet and fuel supply infrastructure. In the future decarbonization, SAF, mainly hydrogen-based power-to-liquid (PtL), will play an important role, especially on medium- to long-range flights [2]. Besides the use of SAF, currently the only options for aviation are battery-electric and hydrogen (H_2)-powered aircraft. The Mission Possible Partnership estimates an alternative propulsion penetration of 21-38% in 2050 [3].

Battery-electric aviation for short flights could contribute to decarbonisation only to a limited extend due to the aircraft range of 400-600 km [3]. H_2-powered aircraft either powered by a fuel cell or a turbine could contribute significantly in the short and medium range segment. Besides the development of aircraft technologies, the liquid hydrogen supply infrastructure represents one of the main challenges for H_2-powered aviation.

Today's Jet fuel consumption in the German market is approximately 10-11 million cubic meters (m^3) per year. As a result of growth, technological improvements and optimisations in the Open Skies Agreements[1], the consumption volumes for aviation fuel in German aviation are not expected to change in a logistically relevant way until 2050. DLR's extrapolations (Figure 2) show that the increase in hydrogen demand by 2045 will lead to significant quantities being produced for a single airport, which could develop into one of

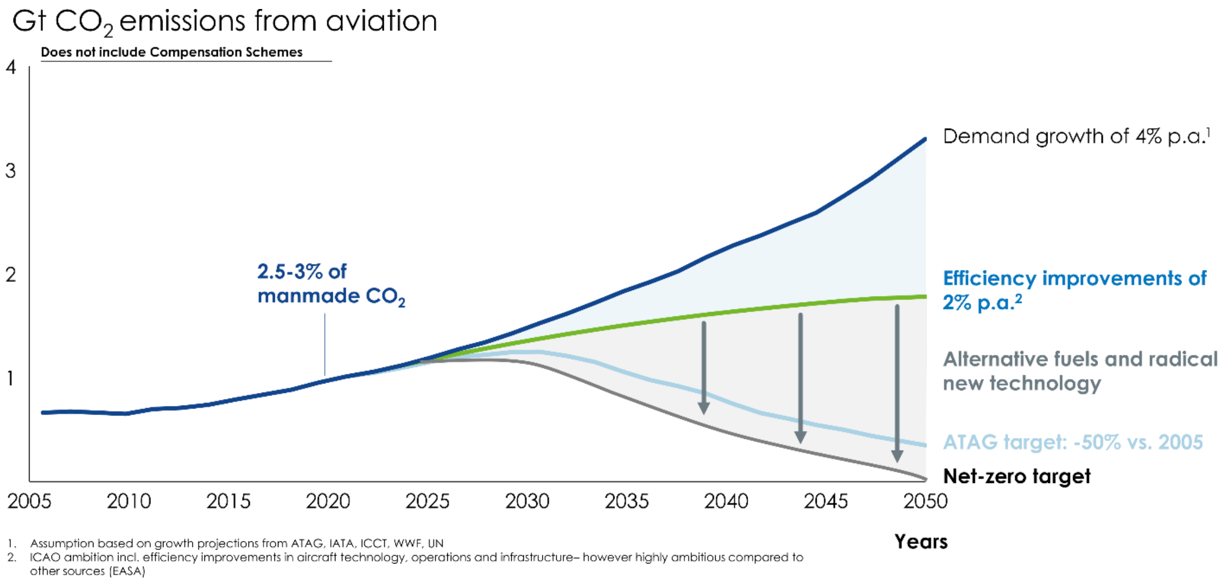


Figure 1: Projections of CO2 emissions from aviation [2]

[1] Open Skies Agreements in the aviation sector are international agreements for reciprocal liberalization.

the region's main demand drivers [4]. These numbers are an optimistic projection and are highly dependent on future aircraft development but show the high impact that H_2-powered aviation could have on future airport infrastructure.

As of today, no German airport has practical experience on the apron in supplying, storing and refuelling hydrogen. One of the market leaders in hydrogen logistics, Air Liquide, has so far only demonstrated liquid hydrogen refueling at Maribor Airport in Slovenia [5].

In order to consider a possible future liquid hydrogen supply infrastructure, it is essential to understand the structure of the airports and their current fuel supply. Therefore, this study aims to give an overview of the current fuel supply at German airports and highlight the challenges associated with transforming the fossil jet fuel supply to green hydrogen. The study is based on assumptions such as a sufficient supply of green hydrogen in Germany. Further prerequisites are research and development progress for the efficient storage of hydrogen in aircraft, as well as the establishment of a safety-compliant hydrogen infrastructure at the airports.

To achieve this, first the German airports organisation and fuel supply infrastructure is discussed in Chapter 2 followed on how airports can influence this infrastructure in Chapter 3. In Section 4, a detailed description of some of the most important airports in Germany is provided followed by a discussion of the effect for the supply of hydrogen based on today's perspective in Chapter 5. The study finishes with a conclusion and outlook.

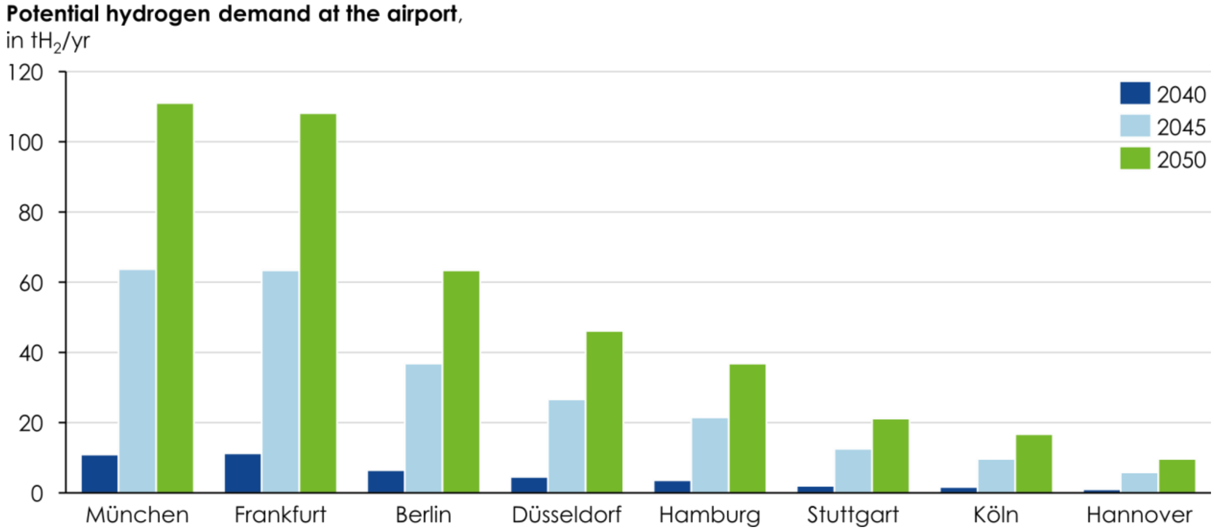


Figure 2: Future hydrogen demand at German airports [4]

2 Overview of German airport organisation and fuel infrastructure

This chapter gives an overview of the organisation of German airports and fuel infrastructure.

2.1 Airport Ownership

In Germany, airports are run as privately organised companies. In many cases, the public sector (federal, state, municipal) has a shareholding in the airports' operating companies.

"As early as 1999, European airport operators were obliged to allow a certain number of third parties or self-handlers at their home locations. The opening up of competition on the apron has the effect of removing the monopoly position of airports, which inevitably leads to increased pressure on the turnover and earnings of the European airport industry as a whole" [6]. In 2016, 47% of all German airports were in mixed ownership with public and private owners, and the others in public ownership [7]. The fuel supply is mainly left to the oil companies in terms of logistics.

2.2 Organizational Structure

To a major extent, airports in Germany do not own fuel infrastructure, nor do they play an active role in the fuel business. The supply contracts are concluded directly between airlines and suppliers. Due to the limited open access to the refuelling infrastructure, new market participants, including future producers and suppliers of SAF and probably hydrogen, often face challenges in entering the market.

Even if the sales business for jet fuel takes place between oil companies and airlines, the airport operator is obliged (in accordance with the Operators' Ordinance) to maintain a sufficient quantity of jet fuel for smooth flight operations or to delegate this task to a third party.

The airport can declare the refuelling infrastructure to be part of the central infrastructure (CI), resulting in a throughput or usage obligation for all contracting parties who purchase jet fuel at the airport.

The tank terminals are predominantly built by oil companies and the operation and into plane business is carried out by a service provider. However, as the refueling facilities rarely belong to the airport, airport operators have few options in this business. An agency model has become established at smaller and medium-sized airports. An oil company sets up the entire fuel business for the airport, including product delivery, construction of the fuel depot and provision of the tanker trucks. However, as jet fuel sales are the responsibility of the oil companies, the airport is also dependent on them.

Since the mid-1990s, the so-called BOOT (built own operate transfer) concept has also become established in industrial sectors such as tank farm construction. The operator models were initially developed for public projects, where they are also referred to as public-private partnerships (PPP). The facilities are transferred to state ownership after the operating phase in these projects.

However, the most common model is a joint venture of oil companies that take care of the refueling business. In particular, the tank storage facilities operated by Aviation Fuel Services

GmbH (AFS) often have a joint venture ownership structure consisting mainly of oil companies as suppliers. This means that a large part of the value chain, from production to delivery and ultimately to ownership of the tank farm at the airport, is in one hand.

So far, tenders have only been issued at a few German airports. However, the operation of the fuel tank farm and the refueling service, the into-plane service, are part of the ground handling services according to BADV (Ordinance on Ground Handling Services) §6 [8].

2.3 Logistical structure

German airports are mainly refuelled by two into-plane companies, Skytanking, a private company with the American parent company PrimeFlight and AFS, a joint venture between Lufthansa and Swissport. Refuelling is carried out in accordance with JIG (Joint Inspection Group) guidelines.

These two companies also operate most fuel tank farms in Germany. For reasons of cost efficiency, it makes sense for operators of the into-plane service also to take over the operation of the tank farm. Except for a few German airports, the oil companies or joint ventures own the fuel depot, resulting in a more restrictive supply.

In addition, there are also smaller refueling companies, which are mainly limited to serving niches in the general or business aviation sector.

2.4 Delivery and supply options

The delivery of jet fuel can be provided by rail (tank wagons), with a corresponding railway unloading station, by road with tankers (trucks), by ship (barge) or by pipeline. The larger the quantities, the more economically viable it is to invest in pipeline or rail delivery systems. The airport's fuel infrastructure starts from the airport security fence.

75% of Europe's Jet fuel demand is imported; an important distribution centre is the Amsterdam-Rotterdam-Antwerp (ARA) ingestion area, which can transport large quantities of Jet fuel to airports through pipeline systems.

The Central European Pipeline System (CEPS) shown in Figure 3 is the largest of the eight major pipeline and storage systems of NATO (North Atlantic Treaty Organization) [9]. Revenues from military and non-military use cover the costs of the CEPS, as well as contributions from participating States.

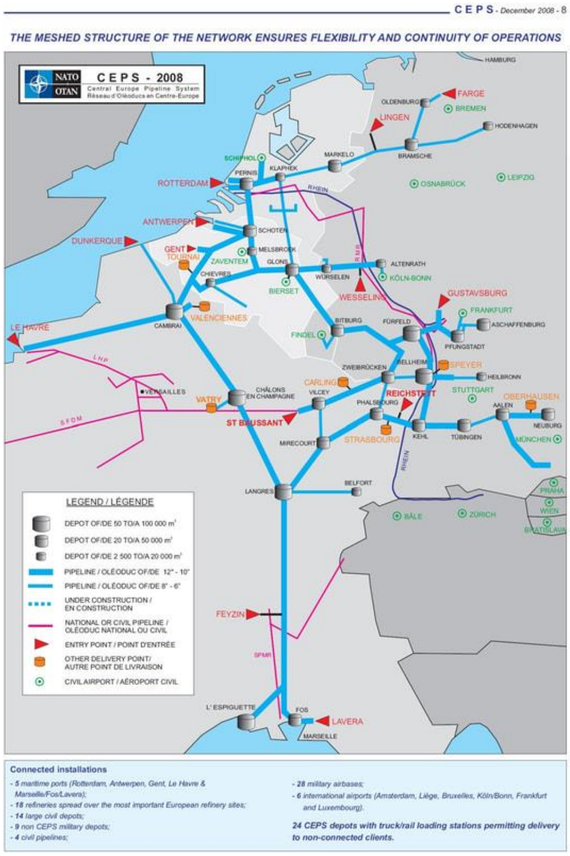


Figure 3: CEPS - Central European Pipeline System 2008 [9]

3 Airports influence on the fuel infrastructure

In this section, the airports influence on the fuel infrastructure is discussed with a focus on fuel pricing and contracting.

3.1 Fuel pricing

The fuel price includes the market price, CO_2 price, taxes and fees, as well as the "airport cost", the so-called differential for each airport as shown in Figure 4.

The market price of jet fuel is not publicly accessible; an overview of the last two years based on internal estimates is shown in Figure 5. The connection for jet fuel markets in the European market is, in principle, assigned to the regional refinery processing or ingestion areas, e.g. Amsterdam-Rotterdam-Antwerp (ARA) region, North Sea and Mediterranean region. The quotations for the common European markets Rotterdam (FOB ROT), North West Europe (NWE) and Mediterranean (MED) can be purchased through the largest supplier Platts or OPIS and ARGUS.

The differential at the airports refers to logistics costs, including the margin of the oil suppliers, which are inherent for each airport. The logistics costs include transport from the refinery, shipping costs, costs for interim storage, onward transport by truck to the airport, or transport from the port by pipeline without any intermediate handling surcharges. At the airport itself, there are also costs for throughput through the tank farm, as well as the costs for refueling operations. If a hydrant system exists, a usage or throughput fee will be charged, as well as the fee for into-plane refueling with a hydrant vehicle instead of an airfield truck (bowser). In recent years, some oil companies have been showing tank storage fees separately in their invoices ("separate line items") to make logistics costs at airports more transparent. The price components for fees vary depending on the airport, country and other structural conditions.

In Germany, a stockpiling fee of 2.85 EUR/m3 is charged, which each airline must pay equally. The task of the Petroleum Stockpiling Association (EBV) is to maintain stocks of crude oil and petroleum products (petrol, diesel fuel, heating oil and aviation turbine fuel [Jet fuel]) which correspond to at least 90 days of net imports of crude oil and petroleum products.

Since 2012, aviation has been participating in the European Emissions Trading System (ETS) and currently pays for a part (average ca. 80% when introduced) of its CO2 emissions. From 2026, the historical allocation of allowances will no longer apply. Since its

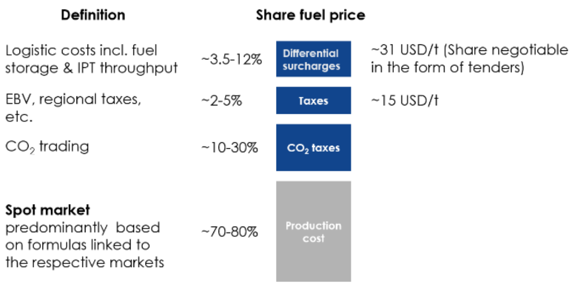


Figure 4: Structure of the fuel price share- Pro Aviation data

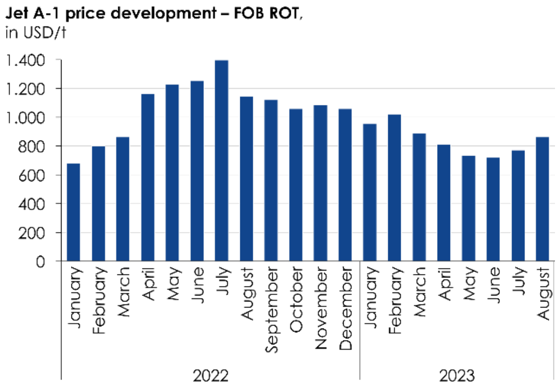


Figure 5: Jet A1 price development – own data

introduction, the price per CO_2 ton has roughly quadrupled.

3.2 Contracting

Fuel contracts are concluded directly between the suppliers and the airlines. The airport only has a direct contract with the airline in the Jet fuel business if it is involved in Jet fuel sales. The suppliers, in turn, hold throughput contracts with the tank farm operators and the into-plane service providers.

Airlines usually release an annual tender for their Jet fuel supply at all airports. Criteria such as supplier creditworthiness play a significant role compared to the tendered quantity. As a result, it is not necessarily the airline with the most significant quantity that gets the best price. The price element to be negotiated is only the differential, representing approximately 5-30% of the total price. The highly volatile jet fuel market price accounts for most fuel costs and is not part of the negotiation process in the tender, but it can be hedged via separate hedging or paper transactions.

Most of the supply contracts are concluded over a period of twelve months and include a 100% (also 20% or 50%) supply of the purchase volume at the airport tendered. The tendered quantity may differ from the actual quantity. The supplier usually bears the risk of the supply difference.

Even though many German airports give the impression of a diverse supplier side, the airport is often only supplied by one supply source with delivery preference through a physically nearby refinery. Other suppliers offer products based on a swap transaction. Some German airports are supplied exclusively by one supplier. The price, or the differential offered, is always based on the second-best delivery option for jet fuel. Ultimately, the airline has only one way to get out of the tight price corset by setting up its own jet fuel supply.

Airports have little impact on influencing or actively contributing to the structure of the jet fuel supply.

4 Overview of the main airports in Germany

This section gives an overview of the organisation and current fuel infrastructure of the main airports in Germany based on 10 selected airports. The selection of airports was made in order to provide as broad an overview as possible and was based on available information.

4.1 Frankfurt Airport

The Frankfurt Airport (FRA) is operated by the Fraport AG. It is the main national hub for long-haul flights and accounts for approximately 50% of Germany's fuel business.

As a property owner, Fraport provides an area to the hydrant operating company (HBG) on which HBG operates the tank farm and the underground hydrant system. In addition, HBG constructed its port delivery service in Kelsterbach. Until 1995, concessions were levied, which were transformed into leases by the Hamburg Agreement.

The entire HBG infrastructure has been declared as central infrastructure by Fraport. Thus, every Jet fuel consumer is obligated to use the facilities. Therefore, the throughput fees in the airport charges can be accessed on Fraport's webpage [10].

HBG's hydrant system is fed by two port access points: delivery by barge via Kelsterbach and Raunheim. The ships, or the barges, are unloaded in the port and fed directly into HBG's pipeline system. There is no separation of costs between the tank farm and the hydrant system. HBG is a joint venture (JV) comprising the delivery companies and the hub carrier.

In addition, Frankfurt Airport is supplied with Jet fuel by two pipelines, the Rhein-Main-Rohrleitungstransportgesellschaft mbH (RMR) pipeline, which has no open access and the NATO pipeline (CEPS), which has been open to the public since the privatisation of the military network. The NATO Pipeline System is a banking system, i.e. the ordered quantity is not delivered point-to-point. However, regardless of the entry point, the following available product (batch) is taken from the pipeline. Since 2012, Frankfurt Airport has obtained another Jet fuel pipeline connection. The 22-kilometre-long pipeline runs from the tank farm in Gustavsburg directly to the HBG tank farm. The operator is the Mainline Verwaltungs-GmbH, which belongs to the Dettmer Group in Bremen.

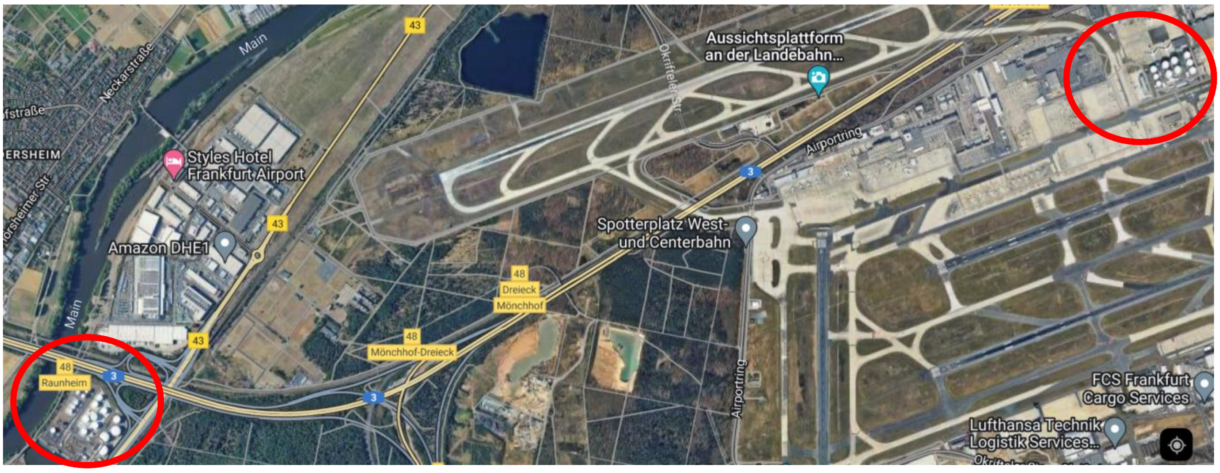


Figure 6: Two terminals FRA, HBG TL (right) declared as ZI, Google Maps 25.10.2023

In order to be able to provide liquid hydrogen in the future, it is necessary to designate areas for hydrogen liquefaction plants and liquid hydrogen storage facilities or, if necessary, to acquire new areas. Based on today`s technology, an area of approximately 9.25 km² would be required in 2050. Frankfurt Airport is expected to be connected to the German hydrogen core network from 2032.[2]

4.2 Munich Airport

As the owner of the tank infrastructure, Flughafen München GmbH (FMG) plays a unique role amongst airports.

FMG owns six tanks with a total capacity of around 44,000 m³. The tanks are filled with kerosene via tank wagon deliveries and pipeline feeds. The product mainly comes from the Bayernoil refinery (Vohburg/Neustadt) and the OMV refinery in Burghausen (direct pipeline connection 125 km to the airport tank farm). The refineries are supplied with crude oil from the port of Trieste via the Transalpine Oil Pipeline (TAL).

On average, 60% is delivered to Munich Airport by tank wagon and 40% by pipeline. The tanks are connected to the 17 km-long hydrant refueling system (HRS). Approx. 80% of refueling is handled via HRS, approx. 20% via airfield tank trucks (FTKW). The operation of the tank terminal and hydrant system, as well as the into-plane business, are put out to tender under EU procurement law, awarded externally and carried out by independent specialists (manage and operate concept). The Skytanking Munich GmbH& Co KG currently operates tank storage, HRS and holds one of two active Into-plane licenses alongside with the company AFS.

With the HyPipe Bavaria - The Hydrogen Hub project, bayernets GmbH plans to lay the foundation for a hydrogen grid in Bavaria by 2030 [11]. This is to be achieved primarily by converting 95% of the existing natural gas pipelines [12].

In addition to the many hydrogen alliances and industry projects in Bavaria, Munich Airport is part of the aviation think tank Bauhaus Luftfahrt. Here, paths and prerequisites for the implementation of hydrogen for the aviation sector were developed in cooperation with the Technical University of Munich, among others. The challenges in providing and adapting airlines' infrastructure and operational processes are also being considered. In addition to the implementation of hydrogen on short and medium-haul routes, Bauhaus Luftfahrt also sees "promising potential" on long-haul routes [13].

4.3 Berlin Airport

At Berlin Brandenburg Airport (BER), the speciality of the tank structure lies in the history of the airport's operational start (previously SXF Berlin Schönefeld) and, thus, of the new tank farm. Planned to start its operation in 2013, BER finally took up operations at the end of 2020. The fuel farm and its corresponding infrastructure were well planned, developed and ready to start on 03.06.2013.

Although the new airport could not start in 2013, fuel infrastructure costs for a far more significant airport construction incurred nevertheless. Those were passed on to the users of the tank infrastructure, i.e. the airlines. In 2020/2021, throughput fees reached their peaks. Since the opening of BER throughput fees have decreased by

[2] Expert interview Frankfurt Airport

half, but still remain twice as high compared to the average throughput fee of German fueling infrastrucuture.

BER's Jet fuel is has mainly been supplied by PCK Schwedt (Petrochemical Combine Schwedt). Deliveries have been made by train. An alternative delivery by truck could be carried out via Berlin Westhafen. Additional supply options are being developed.

PCK has planned to produce green hydrogen and e-fuels. Since the shutdown of the Druzhba pipeline and the disruption of the Russian crude oil supply, the capacity utilisation of the refinery has been endangered, affecting the production of the Jet fuel supply of BER Airport.[3]

Refuelling takes place at BER Airport via a hydrant system. The THBG (tank farm/hydrant operating company) was founded for the construction of the infrastructure and keeping the ownership by a joint venture of oil companies and airline(s). AFS operates the fuel facilities of THBG which have been declared as centralised airport infrastructure by BER [14].

The example of BER illustrates that high throughput costs can incur for the supply of Jet fuel at the airport, although the quality for logistics, i.e. the way of transport as well as the source of supply, remain unchanged.

By 2050, BER will have the tenth-largest demand for hydrogen in Europe [15]. Thus, decentralised and centralised supply options will be relevant for the airport.

4.4 Dusseldorf Airport

There are two separate tank farms at Düsseldorf Airport, operated by two independent tank storage companies. The respective pools also have their own Into-Plane operations.

The Düsseldorf Fueling Service (DFS) tank farm is a joint venture in which Lufthansa also has a stake. This depot has a total capacity of 1,800 m^3. The second tank farm at Düsseldorf Airport is a joint venture of oil companies. The Düsseldorf Jet Service GbR (DJS) depot consists of 10 tanks with a total capacity of 4,600 m^3.

Düsseldorf Airport is supplied by road via trucks (30 m^3 each) from the nearby BP refinery in Gelsenkirchen and the Shell refineries in Godorf and Wesseling. The respective pool carries out the calculation and ordering of the respective quantity, especially the additional quantity, in close consultation and coordination with the airlines.

Supplying an airport tank farm by road tanker is the traditional supply method. It is particularly suitable if the respective airport has jet fuel-producing refineries or suitable tank farms nearby. From the point of view of safety at the airport and environmental pollution, however, a critical limit has already been reached, with an average of around 85 arrivals per day.

Düsseldorf Airport is very interested in the transfer of the location to climate neutrality by 2035. Among other things, the airport has entered into an innovation partnership with the EUREF-Campus to accelerate the achievement of its targets [16]. As part of the "Düssel.Rhein.Wupper Hydrogen Competence Region", the airport supports the so-called "HyPerformer Region Rhine-Ruhr" together with industrial partners, municipalities and

[3] Expert interview

research institutions, which aims to implement projects for the introduction of H2 in the field of mobility [17]. The construction and operation of an airside and landside H2 filling station is planned.

When assuming that DUS Airport has a potential demand for H_2-powered aviation of approx. 85k tons p.a. in 2050 [4], this would already be a first step towards the supply of hydrogen at the site. Due to the area restrictions of the future tank facilities, a decentralized supply, e.g., in the form of storage facilities near the airport, should also be considered.

4.5 Hamburg Airport

Hamburg Airport (HAM) is a pioneer within the aviation hydrogen landscape. HAM's recently published hydrogen roadmap shown in Figure 7, together with the DLR, as well as its delivery options via the Port of Hamburg, contribute to its pool position [18]. HAM is supported by the Cluster of Excellence Hamburg Aviation, as well as the progressive cooperation with DLR (German Aerospace Center), Airbus and Lufthansa Technik with its demo facilities on site.

From a logistical point of view, the jet fuel supply to Hamburg Airport has a simple setup: a tank farm belonging to Tankdienst-Gesellschaft Hamburg (TGH) and is operated by AFS. Since the pandemic, AFS has been the only Into-Plane service provider. The product is mainly delivered by truck from the refinery in Heide, formerly Shell, now owned by the Klesch Group, 40 km away.

As part of the "West Coast 100" project, Heide refinery had planned to produce green hydrogen for the supply of Hamburg Airport with SAF. Despite federal funding, the project was discontinued due to uncertain political conditions [19].

Ideally, up to 80% of air traffic at Hamburg Airport can be operated by hydrogen propulsion, therefore complex planning is required. The expected quantities are around 6,000 tons in 2035

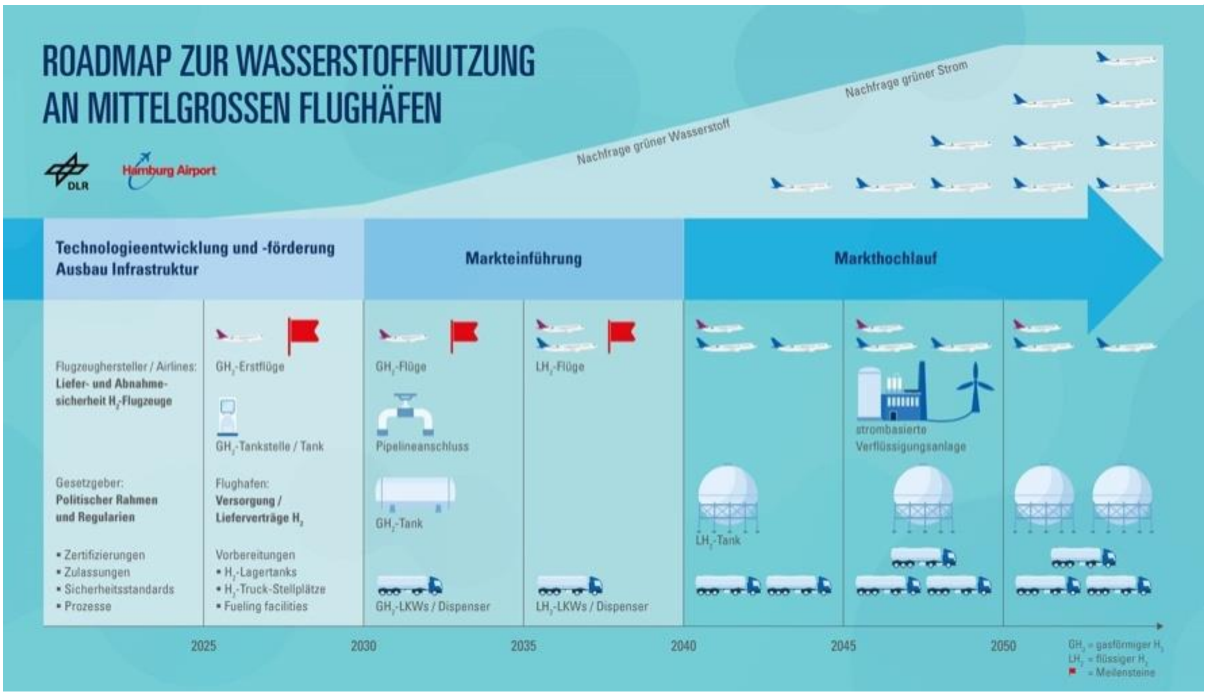


Figure 7: DLR / Hamburg Airport Roadmap for the use of hydrogen [18]

and 70,000 tons in 2050. Logistically, even 93,000 tons can be planned if all feasible routes are converted to hydrogen. This requires, for example, "two storage tanks with a diameter of 34 meters and a capacity of about 400 tons and accordingly free space of about 900 square meters."[4]

A connection to the Hamburg hydrogen gas grid is also planned. Ideally, a pipeline connection to the Port of Hamburg could deliver gaseous hydrogen directly. The main delivery route for liquefied hydrogen will be operated on trucks. Thus, only a liquefaction plant for smaller quantities of gaseous hydrogen would be necessary in the following decades due to increased demand. However, liquid hydrogen pipelines, in general, still lack the technical maturity to cover distances of ca. 30 km. These pipelines are expected to be used only for short distances at the airport in the future.

Prerequisites such as technological progress, fleet penetration, certification successes, availability of spherical tanks, usable cryogenics, and approved concepts for safety regulations to comply with are required.

Hamburg Airport is joining the international network "Hydrogen Hub at Airports" because "H_2-powered aircraft that are scheduled to take off and land in Hamburg in the future need destinations where they can refuel with hydrogen and take off again." [20]

In addition, H_2-powered feeder flights are also interesting for long-haul flights from Germany. This requires an appropriate hydrogen infrastructure at the reference airports.

The airport's hydrogen filling station is planned for 2026. For efficiency reasons, both ground-handling vehicles and H_2-powered aircraft are to be refuelled [21].

4.6 Cologne Airport

The Cologne-Bonn Airport is interesting to consider due to the distribution of traffic, a focus on cargo in combination with military use.

Since the relocation of DHL and LH Cargo to Leipzig in 2007, the airport has served as a hub for the cargo airlines UPS and FedEx and is also a base for Eurowings. Due to its proximity to the German Air Force, the fact that it has been home to the Ministry of Defense's air force for many years, and its mixed civilian use, Cologne-Bonn Airport has the great advantage of a direct connection to the NATO pipeline system CEPS. The nearby Shell refinery in Wesseling, which has been merged with the Shell site in Godorf, 6 km away, to form Germany's largest refinery, is also connected to the fuel depot at Cologne Airport by pipeline. This pipeline connection replaces 11,000 tanker journeys per year and helps to reduce CO_2. The CEPS pipeline was approved for the transportation of blended SAF at the beginning of 2023, with the first delivery being made to Brussels Airport. The tank farm at CGN Airport has a capacity of 9,000 m^3 and is operated by AFS.

As part of the H2 Mobility project (joint venture consisting of Air Liquide, Daimler, Linde, OMV, Shell and Total), a hydrogen filling station was built at CGN Airport in 2016. It has a supply storage tank with a capacity of 370 kgH_2 and, in addition to the 700 bar fuel pump, a device for an optional 350 bar fuel pump (car or bus refueling). There are

[4] Expert interview Hamburg Airport

currently plans to adapt the hydrogen filling station for airside operation.

The traffic units at CGN Airport as benchmark – in 2023 with a ratio of 52% passenger and 48% freight - also makes CGN an attractive place for future supply. In 2050, there could be an hydrogen demand for aviation at Cologne-Bonn Airport of around 49 kt [4]; developing a concept for government flights/cooperation with the military could also positively reinforce this.

Given the trend for the airport to actively position itself as a hydrogen provider and supplier, the idea of discussing possible concepts with the current kerosene supplier is evident. Shell describes the Wesseling and Godorf refineries as a relevant future location (Zukunftsstandort) and plans to produce green hydrogen there while at the same time ending crude oil processing in Wesseling in 2025.

4.7 Hanover Airport

The Hanover (HAJ) tank farm is owned by Tanklagergesellschaft Hannover-Langenhagen (TGHL) GbR and operated by AFS. The airport is supplied by trucks and can be supplied via three different sources. Deliveries are made by pipeline operated by Flughafen Hannover Pipelinegesellschaft mbH & Co. KG. One possible source of supply is Wilhelmshafen, which could also be a hub for imported green hydrogen in the future [22].

80% of Hannover Airport's main destinations are within a flight distance of less than 2,000 nm and could ideally be operated with H_2-powered aircraft.

Based on DLR's volumes of 136 kt p.a. calculated for HAJ in 2050, the transformation to hydrogen could result in a 10-15 ktH_2 per year by 2040 and onwards. The prerequisite is the correspondent transformation of the airlines` fleets that serve these routes.

A connection to the hydrogen core network might be possible. The alternative is a decentralised supply and thus requires the setup of alternative hydrogen logistics. Based on economics, an assessment is relevant to decide on a connection to the hydrogen core network receiving hydrogen in gaseous format. This would require a liquefying plant, or receiving hydrogen in a liquid form on a decentralised path would be sensible.

A hydrogen pipeline is planned to connect Lingen with Hannover [23].

4.8 Leipzig Airport

There are two fuel depots at Leipzig Airport, one owned by Turbo Fuel Services Sachsen GbR (TFSS) and one owned by European Air Transport Leipzig GmbH (EAT).

The TFSS tank farm was built in 2003 and has since been operated by AFS. It consists of four horizontal tanks with a total capacity of 1,600 m^3. The tank farm was designed so that road tankers deliver the product from the refinery in Leuna, 40 km away. Although the delivery radius makes perfect economic sense, this creates a dependency on just one dominant supply source. The tank farm, operated by DHL since the end of 2007, has three tanks of 4,000 m^3 each with a total capacity of 12,000 m^3. The product can be delivered by tank wagon from the nearby refinery and the Amsterdam-Rotterdam-Antwerp (ARA) region. Despite the short delivery distance of only 40 km, it sometimes is more economic to deliver products from the ARA region, around 700 km away.

Mitteldeutsche Flughafen AG (Leipzig and Dresden Airports) is a member of the H2 innovation network HYPOS, with the common goal of helping a cross-sector green hydrogen economy achieve a breakthrough. The hydrogen network can draw on the existing 150 km long and therefore second largest pipeline in Germany to distribute hydrogen. The location of the industry and the high potential for electricity production from renewable energies also make the region attractive.

The Bad Lauchstädt industrial park, where green hydrogen is to be produced for the refinery in Leuna from 2026, is also contributing to the region's strong ambitions. The planning of the HH2E project in Thierbach for the production of green hydrogen in the Borna region (with partners Foresight and HydrogenOne) also underlines the region's potential [24].

Leipzig Airport is also setting an example in the area of hydrogen readiness as part of the Hypower project to convert the energy supply from natural gas to hydrogen and to use hydrogen for SAF [25].

The NetZeroLEJ project was presented in a letter of intent at the National Aviation Conference to prepare and implement the production and use of SAFs on an industrial scale [25]. This means that essential foundations have already been laid in the Central German region for the recognizable trend towards operating airports as (hydrogen) energy hubs in the future and becoming more actively involved in the supply.

4.9 Memmingen Airport

Memmingen Airport (FMM) has the highest traffic growth figures since COVID-19 in Germany. FMM has a tank farm that covers about four times the daily jet fuel requirement. Deliveries are made by road trucks (TKWs) mainly from the fuel depot Heilbronn, connected to the NATO pipeline. The fuel business is managed via an agency model. The agency partner is responsible for ordering, buying and selling the product. In addition, the partner provides the tank farm and the tankers. Airport employees carry out the operation. In return, the airport receives a premium from the agency partner. Agency models are specifically designed for smaller or regional airports to realize efficiencies from the workforce for the operation of the refueling business. Memmingen Airport has already published an innovative sustainability paper in 2021. With its Green Airport Memmingen project, the airport plans to be climate-neutral by 2030. For this purpose, "Airport Energie Management", a subsidiary of Flughafen Memmingen GmbH and e-con AG, was founded [26].

4.10 Kassel Airport

Since Kassel Calden Airport (KSF) was founded, the entire kerosene business has been in the hands of oil companies. Due to the airport's size and the annual fuel consumption, Kassel is a classic "solus" site where only one supplier is represented in the form of an agency. In this construct, the airport acts as a lessor of a plot of land and receives a fixed rent and a variable, volume-dependent share. The oil company builds the tank farm and provides the necessary infrastructure. The airport's staff operates the tank farm and into-plane business.

Kassel Airport decided to break away from the agency construct that had existed for many years and to operate the refueling business itself. Since then, the purchase and sale of kerosene has been in the hands of the airport, which, in addition to the risks involved in product purchasing, primarily means that the airport can actively control the sales business. In the early days, a "mobile tank farm" was used for this purpose, which is to be replaced in the near future by the construction of a new tank farm. The operation of the tank farm and the implementation of the Into-Plane service will continue to be carried out by the airport's personnel. In a tender process, a supplier was found who collects the kerosene from a storage facility 200 km away or a refinery, also approx. 200 km away. The product allocation is the responsibility of the tank farm manager, who orders the kerosene 2-3 times a week from the responsible forwarding agent in consultation with the supplier.

KSF Airport is part of the HyLand initiative and has been appointed HyExpert with partners from the North-East Hessen region with funding from the BMVI. The focus is on the production of green hydrogen and its regional marketing. This endeavour is also underlined by the "Hydrogen Valley Wolfhagen" project, in which the construction of an electrolyser for the production of green hydrogen is being planned. Due to its central location, Kassel Airport also has market potential for electric aviation. In a current study, the DLR sees opportunities for 588 routes within Germany and to neighbouring countries that could be created by using electric aircraft from Kassel. 114 of these are direct connections, for example, Kassel - Hamburg or Kassel - Dresden. The remaining 474 routes would be possible with a transfer in Kassel. Irrespective of this, in the event of a successful test on the route between HAM and GWT, German domestic routes from KSF, such as GWT and HDF, and the route to BZO, could be supplied with hydrogen.

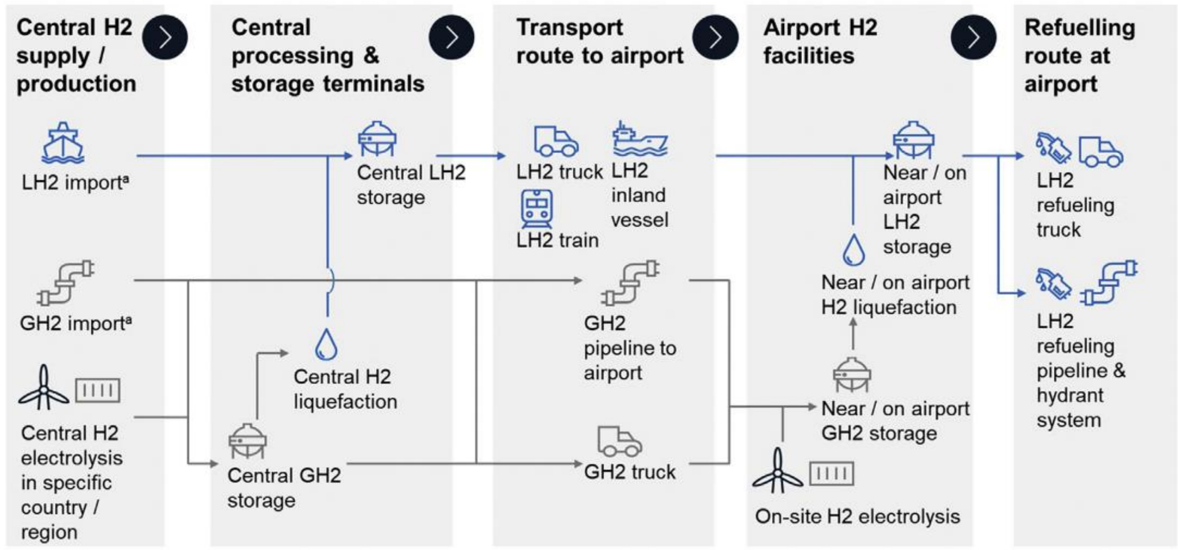
5 Impact of hydrogen supply from today's perspective

In this section, the impact of hydrogen supply and the associated infrastructure required on airports and their fuel supply is discussed.

5.1 Development of hydrogen infrastructure

In contrast to the SAF supply, which relies on the existing supply infrastructure, the liquid hydrogen infrastructure must be built parallel to the existing refuelling and supply infrastructure and requires high investments. The market ramp-up for the domestic production of green hydrogen in Germany is expected from 2030. To supply the demand volumes for all industrial sectors it is assumed that an import of approximately 60% of the total hydrogen is necessary [27]. This requires the development of a large-scale import infrastructure for all sectors, which could be beneficial for hydrogen use in aviation.

The hydrogen supply infrastructure for aviation consists of water electrolysis, liquefaction, storage, refueling and optional transport in liquid or gaseous state as shown in Figure 8. In order to supply the aircraft with green hydrogen, for the whole supply chain, only renewable energies are an option as energy supply [28]. The produced hydrogen can be stored in a gaseous or liquid state. Gaseous hydrogen is stored compressed in either aboveground storages or cavern storages using compressors. Liquid hydrogen storage



a. H2 import and transport in form of LOHC, NH3 or metal hydrides not shown here

Figure 8: Liquid hydrogen supply routes for H_2-powered aviation [28]

at the airport is carried out in spherical, multi-layer vacuum-insulated tanks.

Hydrogen can be transported in a gaseous state in a pipeline or using high-pressure containers, depending on the production site. High-pressure trailers are already available, but the storage volume is limited, which would lead to a very high number of necessary trips and trucks to supply an airport. The TransHYDE project GET H2 investigates how existing natural gas pipelines can be converted on a test field. An essential part of a supply network could be a hydrogen core network consisting of new and repurposed pipelines.

"On 15.11.2023, FNB Gas e.V. (Association of Gas Transmission System Operators) applied a draft for the hydrogen core network to the Federal Network Agency and the Federal Ministry for Economic Affairs and Climate Action (shown in Figure 9). This is the next milestone for the realisation of the core network." [29]

The fundamental decision to be connected to the German hydrogen core network could play an essential role in discussing the de/centralisation of hydrogen production and supply. Only airports not connected to the core network must set up decentralised logistics and supply. Nevertheless, producing hydrogen on-site or using other supply routes could be more economical.

In a liquid state, hydrogen can be transported via ship, truck or train. Liquid hydrogen trailers, with a transport capacity of around 4,000 kg (pressure 1-4 bar, cryogenic), could be especially relevant for aviation supply [30]. The supply option that is the most viable for aviation depends on each airport. The main factors for the decision are the location of the airport and the natural conditions for renewable energy in the airport region, as well as the land availability at and around the airport [31].

Importing liquid hydrogen can be economically viable, especially for smaller airports, as they would not necessarily need a liquefaction plant on site. This could be different for larger airports: "The hydrogen liquefaction plant is usually located directly at the site of hydrogen production" or at a location with high hydrogen consumption, "as it requires a large throughput to operate economically." [32]

Finally, refuelling at the airport could be carried out by refuelling trucks or a liquid hydrogen pipeline and dispenser system. The second option is particularly suitable for airports with a high hydrogen demand [33].

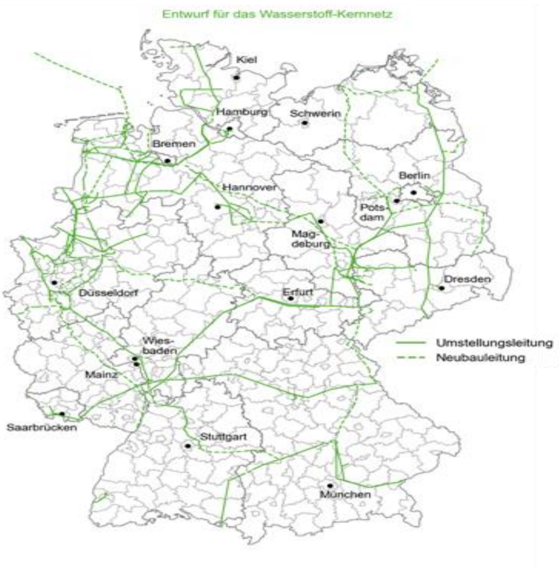


Figure 9: German hydrogen core network expansion Plan [25]

5.2 Involvement and responsibility of airports as energy hubs

Airports will need to take more responsibility when setting up a hydrogen or energy supply concept. In contrast to the conventional fuel supply, they can integrate the hydrogen supply into an overall energy supply system at the airport [34]. This could also support the airport's efforts to meet Scope 1 and 2 targets. If an airport opts for its own hydrogen filling station, landside and airside air traffic could be refuelled to use the highest capacity options.

The unique opportunity to become less dependent on the existing dominant supplier construct of the oil companies is provided to airports and the aviation market by investing in hydrogen production. First ideas of investing in their electrolysers have already been developed. However, smaller plants are operating in the megawatt (MW) range, which is not sufficient for the hydrogen requirement of a medium-sized airport. For example, an electrolyser with a capacity of 8.75 MW at continuous operation will have an output of hydrogen, which would only be sufficient for refuelling a few flights for short-distance routes per day [35]. Despite long transportation routes, imported hydrogen could be available more economically than locally produced hydrogen.

From 2024 onwards, smaller airports will be requested to develop hydrogen infrastructure, especially when approached by airlines planning hydrogen propulsion early. In order to realise these initial projects, funding from the federal government is required.

5.3 Beginning of market penetration

Airbus, aims to bring hydrogen-powered aircraft into service by 2035 with its model ZEROe [36]. Due to high efficiency and lower emissions, the first regional aircraft are expected to be powered by fuel cells. Aircraft manufacturers such as ZeroAvia, H2Fly, Cranfield Aerospace, and others are planning to enter the aviation market commercially in 2026 with a fuel cell powered regional aircraft.

If the regional aircraft models from the smaller aircraft manufacturers successfully penetrate the market after certification, individual airports must be prepared to set up hydrogen logistics for a significant amount of hydrogen from 2026 onwards. Ideally, hydrogen feeder flights, a hydrogen transport network, or point-to-point connections (hydrogen airport hubs) will be set up to use the maximum range.

The analysis of medium-sized airports shows there is the potential for a substantial transformation from fossil jet fuel to green hydrogen when 70-80% of their flight routes are below 2,000 nm. Therefore, an early roadmap is needed on how these airports can be supplied with hydrogen. The supply options need to be evaluated early in advance to plan a connection to the German hydrogen core network or a hydrogen hub. From 2030, 60% of green hydrogen is expected to be imported for the German market, including derivatives. In addition to Amsterdam, the Port of Hamburg could become Europe's logistics hub for green hydrogen. "Green Hydrogen Hub Europe – "Hamburg as a hub for hydrogen imports to Germany and Europe" [37].

6 Synthesis and Outlook

Until the first H_2-powered aircraft, such as Airbus' ZEROe, are ready for use on the market in 2035, other measures are needed to achieve the net-zero target. SAF is often seen as a solution for the aviation industry, especially for long-haul operations.

The aviation industry needs a holistic initial spark that ultimately encourages airlines, airports, infrastructure providers and, last but not least, passengers to fly fossil-free and CO_2-free as quickly as possible. As SAF supply is limited and will require many resources in the future, an electric or H_2-powered propulsion system could significantly contribute to the GHG reduction [38]. Research and development of practicable implementation options for liquid hydrogen storage, especially on aircraft, have been one of the major challenges so far.

Analogue to H2 Global, which uses funds raised from the ETS to financially offset hydrogen trading in a double auction model [39], the aviation industry needs further incentives for all market participants within the hydrogen value chain to enable the implementation of H_2-powered aviation as quickly as possible. These include, in particular, airlines and infrastructure providers.

The final impact will not necessarily arise from the future price of hydrogen, compared to today's fossil jet fuel or future SAF, but rather the investment costs of replacing an existing aircraft fleet (unless a fleet renewal has already been targeted) that will influence the decision for a H_2-powered fleet. In addition, there are costs for setting up parallel hydrogen logistics or refuelling structures, which are charged to the airline via throughput fees. The uniformity of the fleet in terms of flight operations and maintenance also contributes to the fleet decision. All these factors could make airlines choose SAF for as long as possible.

Even with a volatility of more than 400% (approx. 300 USD/ton to 1400 USD/ton) in the years 2003-2008, the price of jet fuel showed only a marginal influence on the flight behaviour of passengers, ticket prices as well as on route planning, which is often not based on the actual costs of a route, but instead on entrepreneurial strategic decisions.

However, as long as the OPEC countries do not abandon crude oil processing - at COP 28 (Conference of Parties), only phase down instead of phase-out was decided - with economic and political uncertainties in parallel, net zero goals are moving into a distant future.

List of Abbreviations

AFS	Aviation Fuel Services GmbH
ARA	Amsterdam-Rotterdam-Antwerpen
BADV	Regulation on Groundhandling Services
BER	Berlin Brandenburg Airport
BMVI	Federal Ministry of Transport and Digital Infrastructure
CI	Centralised Infrastructur
Ca.	Circa
CEPS	Central European Pipeline System
CGN	Köln- Bonn Airport
CO_2	Carbon dioxide
COP	Conference of Parties
DFS	Düsseldorf Fueling Service
DJS	Düsseldorf Jet Service
DLR	German Aerospace Center
DUS	Düsseldorf Airport
EAT	European Air Transport GmbH
EBV	Petroleum Stockpiling Association
ETS	Emission Trading System
FMG	Münich Airport GmbH
FMM	Memmingen Airport
FNB Gas e.V.	Association of Gas Transmission System Operators e.V.
FRA	Frankfurt Airport
FTKW	Airfield Tanker
GWT	Sylt Airport
H_2	Hydrogen
HAJ	Hannover Airport
HAM	Hamburg Airport
HBG	Hydrant Operating Company
HRS	Hydrant System
IATA	International Air Transport Association
ITP	Into-Plane
JV	Joint Venture
KSF	Kassel Airport
LH_2	Liquid Hydrogen

m^3	Cubic Metre
MED	Mediterranean
MW	Megawatt
NATO	North Atlantic Treaty Organization
nm	nautical miles
NWE	North West Europe
p.a.	per annum
PCK Schwedt	Petrochemical Combine Schwedt
PtL	Power to Liquid
RMR	Rhine-Main Pipeline Transport Company
ROT	Rotterdam
SAF	Sustainable Aviation Fuel
T	Ton
TAL	Transalpine Ölleitung
TFSS	Turbo Fuel Services Sachsen GbR
TGHL	Tanklager Gesellschaft Hannover Langenhagen GbR
THG	Greenhouse Gases
TKW	Tanker/ Truck

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