



Analysis of Airport Infrastructure with Regard to the Use of Sustainable and Alternative Aviation Fuels

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Abstract. One approach to reducing global CO₂ emissions from aviation is to improve the energy efficiency of aircraft concepts. Not only the requirements for the aircraft, but also for the infrastructure of airports are a relevant area of this research: Through the use of sustainable aviation fuels, the infrastructure of airports will inevitably adapt to new conditions. Even though airports are currently in an observer position, the required infrastructure effort must be researched at an early stage in order to provide airport customers with the infrastructure for the use of sustainable and alternative aviation fuels in good time. Exploring the feasibility of future airport requirements is the research focus of this thesis. The aim of this research is to identify future airport infrastructure measures that are required for the operation of hydrogen-powered aircraft concepts in order to be able to include necessary adaptations in airport infrastructure planning at an early stage. For this purpose, future and scenario analyses are used as methods to make an assessment based on selected criteria. It is assumed that even with a moderate future growth of hydrogen, considerable demands will have to be made on the infrastructure in general and the airport infrastructure in particular.

Keywords: sustainable air traffic · airport infrastructure · hydrogen-based aviation fuels

1 Infrastructural Requirements for the Use of Hydrogen-Based Aviation Fuel at German Airports

With the use of hydrogen-based aviation fuels, the infrastructure at airports will inevitably have to adapt to the new conditions. There are already several scientific papers in the literature that deal with the handling processes of aircraft and requirements at the airport with alternative fuels [2, 5, 8, 10]. Therefore, the focus of this research paper will be on the following research question: How airports may be impacted in terms of infrastructure when there is an increased demand for hydrogen-based aviation fuels?

1.1 Airport Supply Infrastructure for Hydrogen-Based Aviation Fuels

In order to meet the demand for green liquid hydrogen (LH₂), which is necessary for the propulsion technology of the corresponding aircraft, the supply industry must be expanded. Currently, LH₂ is produced in insufficient quantities [2, 4]. The literature shows that the supply of LH₂ is basically possible via three modes of transport: pipeline, rail and road [2–4, 7, 8]. The transport of LH₂ on regular inland vessels is technically feasible, but is still in its infancy and there are only a few practical examples so far (e.g. H₂-Ship and H₂Ports), which are still in the development and test phase [11]. However, the reliability of this mode of transport depends on the seasons and high and low water levels. Delivery by road has the lowest investment costs because, in contrast to pipeline and rail delivery, no investments have to be made for the route connection. Existing road connections can be used, but new boiler handling facilities and pipeline connections are also required for the connection. However, the logistical processes for hydrogen delivery by road would be difficult to realise and uneconomical with higher demand for LH₂ [4]. In addition, unloading the tanker takes longer, about 30–120 min, compared to kerosene [3].

Since the liquefaction of hydrogen is very cost-intensive, one variant could be to have it take place not at the airport but in larger, central plants. The hydrogen would then be transported to the airport in liquid form. Only in the case of pipeline supply is a liquefaction infrastructure at the airport necessary, since only gaseous hydrogen can be transported over longer distances by pipeline [5]. Throughout Europe, LH₂ pipelines are being developed and planned that can also be connected to airports (e.g. European Hydrogen Backbone). As other industries could also benefit from a pipeline network, planning and development is a cross-sectoral process. However, for the deployment of this technology in the context of a national transport scenario, some problems would have to be solved. For example, in the project “icefuel”, the transport of LH₂ by pipeline was investigated and a maximum transport distance of 10 km and a low maximum transport capacity of 100–200 kW were determined [8].

According to the FINE model [3], LH₂ demand is covered exclusively by imports until 2050. It is assumed that LH₂ production in Germany is not economical: as liquefaction is an energy-intensive process, it makes more economic sense to carry it out in export countries where the supply of renewable energy is cheaper than in Germany. For the domestic transport of LH₂, rail is the most economical option under the assumptions made. Domestic LH₂ transport is therefore only economically viable for transport between LH₂ sources (import ports) and LH₂ sinks (airports). A consideration of the last mile (e.g. transport from the freight station to the LH₂ receiver) is recommended [3].

1.2 Airport Fuel Storage Infrastructure for Hydrogen-Based Aviation Fuels

The infrastructural expenses at the airport for the use of LH₂ are primarily the tank farms and the filling stations. If airports want to have a similar storage capacity as for fossil kerosene, they should be able to store about three times the average daily demand [4]. For kerosene, IATA considers a storage capacity of up to four days of flight operations necessary, depending on the circumstances [11]. In the tank farm, hydrogen

is stored in liquid form by isolating and deep-freezing the LH2. The single-phase storage of LH2 at the airport has advantages over the storage of H2 for economic and safety reasons, especially to avoid boil-off effects (escaping gas due to evaporation) [8]. NASA currently has the largest cryogenic storage tank in the world. It is located in Florida and has a capacity of 270 tons of liquid hydrogen. JAXA in Japan has a storage container with a capacity of 38 tons. Future liquid hydrogen tanks are expected to be about 13 times larger than NASA's existing tank. These new tanks will be able to safely store up to 3,500 tons of hydrogen [12]. According to current knowledge, safety regulations have not yet been fully clarified, e.g. whether hydrogen tank farms should be built at a different distance from airport operations compared to kerosene.

1.3 Airport Distribution Infrastructure for Hydrogen-Based Aviation Fuels

For the distribution of hydrogen to the aircraft, an Airfield Tanker (FTKW) on the one hand and an LH2-Underground Pipeline System (UPS) with the use of dispensers on the other hand could be used at the airport in the future. Which of these two distribution systems is chosen depends on the airport's daily fuel requirements [8]. At the beginning of the integration phase of LH2 as fuel at airports, the FTKW are considered more advantageous up to a certain demand. However, especially in the long term, UPS are more advantageous at hub and major secondary airports serving long-haul routes, as each FTKW can only carry a certain amount of LH2 (about 3–5 tones) [5, 8]. As a result, too many FTKWs would be needed at hub and larger secondary airports, making airport turnaround processes no longer economical and safe due to space constraints [1, 8]. The use of a UPS or FTKW also has an effect on the possibility of levying various charges. For LH2 short- and medium-haul aircraft (e.g. DLR EXACT project), a range of up to 2,777 km requires approximately up to 31 m³ of LH2. With a capacity of a FTKW of up to 70 m³ LH2 (5 tons), an LH2 FTKW, similar to a kerosene FTKW, can refuel up to two medium-haul or several short-haul routes with one load from the LH2 tank farm, depending on the flight route [5, 8]. Due to the limited pressure and pumping capacity, an LH2-UPS can only be about two kilometers long, so several pipelines would have to run from the tank farm to the individual refueling positions [8]. In addition, a recovery pipeline is needed at the airport to transport the gases escaping during refueling to an intermediate storage facility back to the tank farm [4, 5]. The quantity-independent refueling time of LH2 is, depending on the connection, similar with the Clean Break Disconnect (6 min) as with kerosene (5 min), with the Johnston Disconnect (9 min) it is almost twice as long. It is still unclear which connection will be used. However, LH2 has a significantly higher energy flow rate during refueling, so less time is needed for volume-dependent refueling [5, 8].

2 Analysis of the Effects of Increased Demand for Hydrogen-Powered Aircraft on German Airports

In order to determine the possible effects of the demand for hydrogen-powered aircraft at airports, the data from the DLR's Air traffic forecast & LH2 demand model were used as the basis for the analysis. The 25 largest commercial airports in Germany were

analysed for infrastructure bottlenecks in terms of supply, fuel storage and distribution if hydrogen were to develop as a propulsion alternative for aircraft in a moderate continuous scenario (Table 1). The annual demand was converted to a daily consumption (without considering peaks on weekdays or holiday periods). In order to be able to better estimate these values, the filling quantity of the currently largest tanker truck for liquid hydrogen with four tones was used as a kind of “currency”. This should make it clear how the demand could be mapped with the means of transport by truck or by road.

Table 1. Future Airport Infrastructure Analysis – German Airports.

GERMAN AIRPORTS		Liquid Hydrogen in tons														
Top 25		2040					2045					2050				
	Code	Forecast	per day	# Trucks	Stock	# Tanks	Forecast	per day	# Trucks	Stock	# Tanks	Forecast	per day	# Trucks	Stock	# Tanks
MUNICH	MUC	12,380	33.9	8	136	1	72,759	199.3	50	797	3	124,749	341.8	85	1,367	5
FRANKFURT	FRA	12,328	33.8	8	135	1	69,636	190.8	48	763	3	117,007	320.6	80	1,282	5
BERLIN	BER	6,950	19.0	5	76	1	39,630	108.6	27	434	2	67,266	184.3	46	737	3
DUESSELDORF	DUS	5,421	14.9	4	59	1	31,525	86.4	22	345	1	53,806	147.4	37	590	2
HAMBURG	HAM	4,189	11.5	3	46	1	24,021	65.8	16	263	1	40,853	111.9	28	448	2
STUTTGART	STR	2,449	6.7	2	27	1	14,127	38.7	10	155	1	23,604	64.7	16	259	1
COLOGNE	CGN	1,944	5.3	2	21	1	10,586	29.0	7	116	1	17,677	48.4	12	194	1
HANNOVER	HAJ	1,198	3.3	1	13		6,719	18.4	5	74	1	11,293	30.9	8	124	1
NUERNBERG	NUE	589	1.6	0.40	6		3,507	9.6	3	38	1	5,981	16.4	4	66	1
BREMEN	BRE	527	1.4	0.36	6		2,961	8.1	2	32	1	4,919	13.5	3	54	1
DRESDEN	DRS	418	1.1	0.29	5		2,662	7.3	2	29	1	4,569	12.5	3	50	1
LEIPZIG	LEJ	299	0.8	0.20	3		1,743	4.8	2	19	1	2,972	8.1	2	33	1
MUENSTER/OSNA	FMO	180	0.5	0.12	2		1,064	2.9	1	12		1,763	4.8	1	19	1
DORTMUND	DTM	137	0.4	0.09	2		538	1.5	0.37	6		758	2.1	1	8	
KARLSRUHE	FKB	111	0.3	0.08	1		605	1.7	0.41	7		1,038	2.8	1	11	
SAARBRUECKEN	SCN	103	0.3	0.07	1		583	1.6	0.40	6		930	2.5	1	10	
FRIEDRICHSHAFEN	FDH	88	0.2	0.06	1		574	1.6	0.39	6		1,003	2.7	1	11	
PADERBORN	PAD	70	0.2	0.05	1		317	0.9	0.22	3		499	1.4	0.34	5	
WESTERLAND	GWZ	37	0.1	0.03			239	0.7	0.16	3		415	1.1	0.28	5	
HAHN	HHN	34	0.1	0.02			100	0.3	0.07	1		131	0.4	0.09	1	
MEMMINGEN	FMM	22	0.1	0.02			105	0.3	0.07	1		171	0.5	0.12	2	
WEEZE	NRN	22	0.1	0.02			50	0.1	0.03	1		58	0.2	0.04	1	
LAAE	RLG	17	0.05	0.01			93	0.3	0.06	1		145	0.4	0.10	2	
ERFURT	ERF	13	0.04	0.01			71	0.2	0.05	1		107	0.3	0.07	1	
MANNHEIM	MHG	10	0.03	0.01			71	0.2	0.05	1		145	0.4	0.10	2	
		49,536.4	135.7	33.9	541.1	6.0	284,286.9	778.9	196.1	196.1	16.2	481,859.5	1,320.2	330.0	5,280.7	24.1
Code : IATA Airport Code Airports in gray color : Airports with railway connection per day : Average of 365 days, no peaks # Trucks : Number of trucks with a loading capacity of four tons of LH2, which are necessary to cover the daily requirement (rounded up or decimal places) Stock : Storage capacity for LH2 for up to four days of flight operations (Liquid Hydrogen in tons). # Tanks : How many tanks with the capacity between 38 and 270 tones would be need to cover the four day																

Source: Data based on the “DLR - Air traffic forecast & LH2 demand modelling Data from DLR Institute of Air Transport and Airport Research 2022.

The first result of the analysis of the data is that there are two groups: One group of airports (lower range) gets by with less than one four-ton tanker fill per day, per week or even per month. The higher range airports have significantly higher to very high demand. The last group grows steadily over time and could overload the framework of the road mode from 2045 onwards under the given conditions: FRA and MUC would need 80–85 tankers per day from 2050 onwards. Other ways would have to be found for these cases. Be it through pipeline supply or by connecting to the rail network. In the latter case, only 4 airports (table: marked grey) are currently connected to the rail network. It should be noted that the rail connections and the required facilities for passenger and freight transport differ significantly and that here no 1:1 implementation are possible and structural adjustments are necessary. Several German airports are located near inland waterways and are connected to inland waterways via rivers or canals. This makes it possible to transport not only goods and freight between airports and inland ports, but

also LH2 by water. This is particularly important for the transport of LH2 arriving by sea. Almost all airports in the top 15 can boast proximity to an inland port.

The second result can be seen when applying the IATA guidelines for the minimum requirements for airport kerosene stocks, which stipulates that fuel should be kept in stock for up to 4 days based on the size of the airport. If you transpose this 1:1 to the Liquid Hydrogen, then this shows a bottleneck in the infrastructure at the airport: For the year 2045 alone, this would be a reserve of almost 800 tons for the FRA and MUC airports. In 2050 up to 1,400 tons. If you take the currently largest LH2 storage tank in the world (NASA) with a capacity of 270 tons, then at least three of them would have to be built in FRA and MUC by 2045 and two more each by 2050. The open space requirements for above-mentioned LH2 tanks is approximately 2,300 m² [11] - without considering the safety distances between the tanks - this would be an additional space requirement at the MUC and FRA airports with each 11,500 m² by 2050.

The third result can be seen when looking at the total numbers and their increase from 2045 onwards: The increase figures for the forecast hydrogen consumption at airports are remarkably high and would indicate an active increase in the use of hydrogen as an energy source for airport operations. These increases will depend on many factors, including technological advances, political decisions, environmental goals and economic factors. The availability and efficiency of hydrogen technologies, especially in aviation, are crucial. Advances in hydrogen production, storage and use could promote the use of hydrogen as fuel for aircraft and airport vehicles. If the predicted increases in hydrogen consumption at airports materialize, this would pose significant challenges for the airport infrastructure. The production of hydrogen in sufficient quantities and its reliable supply at airports are crucial. This requires significant hydrogen production, storage and distribution infrastructure that must be operated safely and efficiently.

Increased use of hydrogen as fuel may impact capacity requirements at airports. Airport operators would have to ensure that they can cope with the increasing demand for hydrogen services. These challenges are not insurmountable, but they require careful planning, investment in research and development, and collaboration between airport operators, aircraft manufacturers, energy companies, governments and other relevant stakeholders. The introduction of hydrogen as an energy source in aviation would be an important step towards reducing the industry's environmental impact, but it requires a comprehensive and coordinated effort.

3 Summary and Outlook

The evaluation of the literature and the analysis of our own data have shown that some problems in the provision of liquid hydrogen for airports need to be solved by 2045: If delivery with road tankers would still be sufficient for regional and smaller secondary airports, larger ones should be used. Secondary airports should consider having the hydrogen delivered via rail transport due to the higher demand, as larger quantities can be transported more safely and economically via rail transport. For hub airports, a pipeline supply to the airport would certainly be advantageous, as the logistical processes via rail and road transport would no longer be feasible at a certain scale. The chances of inland shipping still need to be clarified, but are obvious, as large quantities of LH2 will

arrive in Germany by sea in the future. The installation of hydrogen infrastructure may require additional space at airports. Airports would need to allocate land and facilities for hydrogen fueling stations, storage, and pipeline infrastructure. Building or retrofitting hydrogen fueling infrastructure, storage facilities, and pipeline systems can be costly. Airports will need to allocate funds for the initial construction and ongoing maintenance of this infrastructure. Airports need to invest in renewable energy infrastructure, which can be costly upfront but could offer long-term environmental and cost benefits. Complying with safety and environmental regulations related to hydrogen fuel handling may require investments in compliance measures, documentation, and reporting. Airports may explore mechanisms for cost recovery, such as charging airlines or passengers a premium for using hydrogen-based fuels, to offset some of the infrastructure and operational expenses. It is important to emphasize that the use of hydrogen as a fuel in aviation is still in its early stages and it will require significant effort and investment to establish this technology on a large scale. It will require close collaboration between industry, governments and other stakeholders to make the vision of hydrogen-based aviation a reality. Furthermore, the most likely scenario for airports in the future will be a diversified mix of different sustainable fuel options. A follow-up study will show how the infrastructure and supply chain requirements for each fuel type may differ and how these different systems can be integrated.

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