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# Airport Liquid Hydrogen Infrastructure for Aircraft Auxiliary Power Units

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## 1 Introduction

The aviation sector is increasingly facing challenges with potentially severe impacts on the business as we know it. Challenges are inter alia reduced availability, more volatile and increasing prices of liquid hydrocarbon fuels, greenhouse gas (GHG) emission regulations, and stricter noise and air pollutant emission regulations especially for on-ground pollution at large airports. While biofuels cannot tackle all these issues, and shifting to hydrogen propulsion appears to be a long-term remedy, hydrogen-powered fuel cell auxiliary power units (APUs) show near-term potential to decrease ground pollution and offer some economic opportunities. In addition to pollution and emission-free power supply and air conditioning while on ground, these APUs can also be operated while airborne to produce power, facilitating efficiency improvements and weight reductions at the main engines since generators can be avoided. Co-products of the fuel cell system can be used aboard, e.g. water for air humidification and sanitary system, and the oxygen-lean exhaust air for inertisation of the fuel tanks [1].

For the on-board supply of the APUs, liquid hydrogen ($LH_2$) is advantageous due to its high energy density and low hazard potential. A study was recently performed for aviation industry assessing the required ground infrastructure to supply aircraft APUs with liquid hydrogen. A build-up scenario of hydrogen demand at worldwide airports was established, and the most likely hydrogen supply options for different demand categories were elaborated. Potential 'killer criteria' along the supply chain were assessed and synergies between $LH_2$ supply to aircraft APU and other hydrogen applications inside or outside airports considered. This paper will highlight main results of the study.

Comparative environmental and cost performance of kerosene, hydrogen, and alternative fuels for use in aircraft APU have also been studied, but are not part of this paper.

## 2 Quantity Structure of Airport $LH_2$ Demand

A tentative quantity structure for hydrogen demand at airports was established for two penetrations of fuel cell APU aircrafts (50 / 6,500 short range aircraft with fuel cell APU in operation worldwide). To calculate the airport-specific demand, the largest airports in terms of passenger throughput in 2006 were identified per world region, and the $LH_2$ demand was scaled according to the number of passengers. Provided that aircraft $LH_2$ refuelling can be carried out once a day (with some flexibility) within the regular turnaround times, it was found that only a small number of airports worldwide would need to be equipped with $LH_2$ infrastructure for both penetration scenarios (~20 airports to supply 50 aircraft; ~130 airports to supply 6,500 aircraft). Assuming that an aircraft with fuel cell APU consumes about 70 kg

$LH_2$ per day, liquid hydrogen demand at the specific airports would amount to 100 – 400 kg/day for the 50 aircraft case, and 1 – 12 t/day for the 6,500 aircraft case (see Figure 1). In case refuelling is more time consuming and can only be done during night time, more airports will need to offer hydrogen and the average airport $LH_2$ demand per airport will be lower, leading to substantially higher costs. However, we expect the refuelling procedure to be quick enough to be done between two missions.

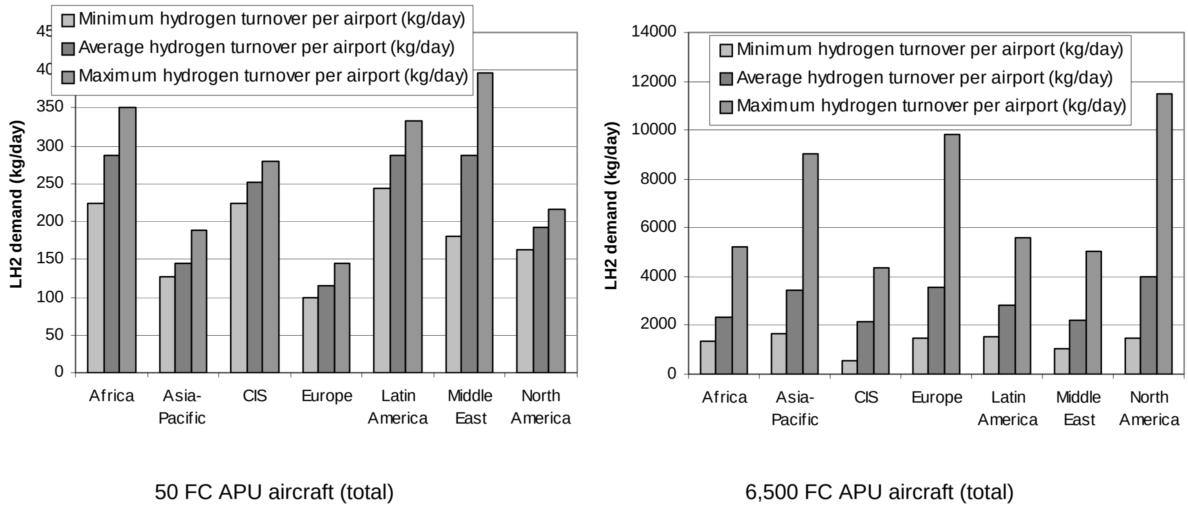


**Figure 1: Quantity structure for airport $LH_2$ demand.**

## 3 Options to Supply Aircraft APU with Liquid Hydrogen

Figure 2 shows options to supply liquid hydrogen to airports, along with potentials for usage of hydrogen at and around airports. Hydrogen is produced and used on a large scale in industry today and further demand increase is expected for the near future. Assuming that $LH_2$ APUs are the only consumers at an airport, for dedicated production at the airport forecourt, only hydrogen production methods suitable for small scale (i.e. electrolysis, steam methane reforming, and biomass gasification) are applicable. The in this case inevitable forecourt liquefaction is, however, only efficient enough if the daily $LH_2$ demand exceeds ~1 ton. In addition, central large-scale hydrogen production, liquefaction, and transport to the airport will be an option, where trailer trucks are the most flexible and suitable means of transporting $LH_2$ both land-side and at the apron, while ship and railway transport are suitable for longer distances and larger volumes. Pipeline transport of gaseous hydrogen is only viable in case of large volumes and shorter transport distances, or as part of a pipeline grid. In this case, liquefaction facilities are required at the airport forecourt.

To deliver $LH_2$ to the aircraft, apron tanker trucks, apron ring pipelines and exchangeable cartridges can be imagined. Because of the rather low volumes of hydrogen consumed by APUs, $LH_2$ pipelines will not be advantageous due to the high evaporation losses caused by heat entry. Cartridges will imply high investments for infrastructure (filling, exchange system) and be technologically more challenging onboard than a fixed tank, piping and a refuelling nozzle. Refuelling of an aircraft $LH_2$ tank by trucks is therefore seen as the most promising option. Experiences gained and technologies developed for refuelling cars with $LH_2$ tank, such as with the BMW Hydrogen 7, can be useful for an aircraft $LH_2$ refuelling system.

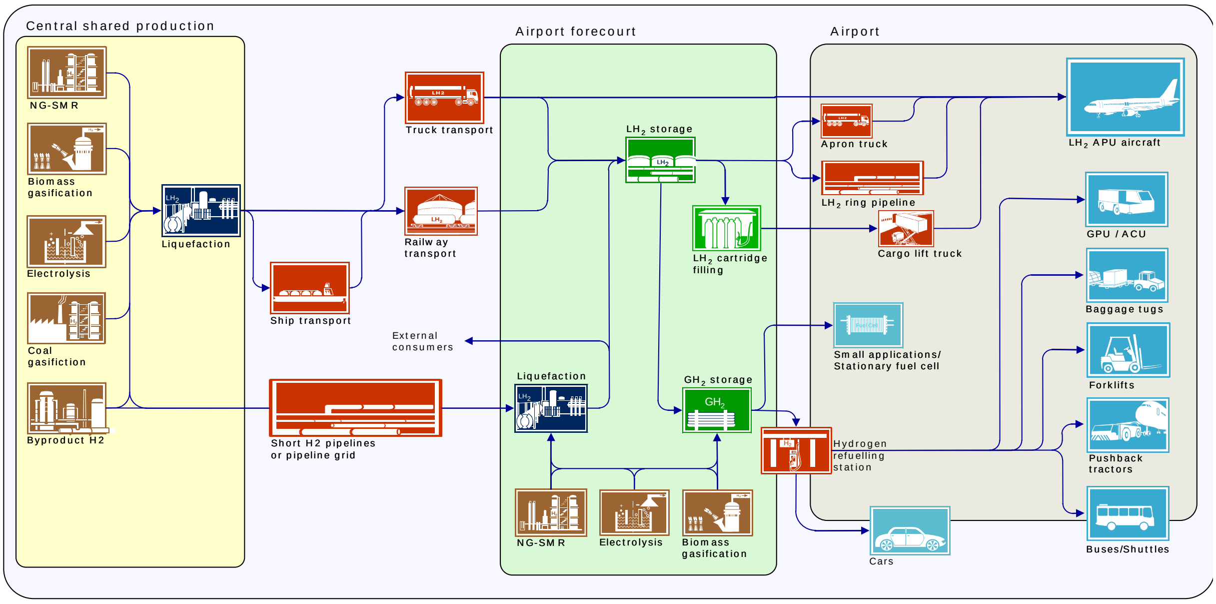


**Figure 2: Options for supply of airports with $LH_2$ and usage.**

If the supplying hydrogen liquefier is less than 200 km away from the airport and the airport $LH_2$ demand is below ~2.3 t/day[1], a single combined tank and refuelling truck would be sufficient to refuel the aircraft during daytime and drive to the liquefier to be refilled during night time (so-called “one-truck-solution”). This is believed to be a very interesting option especially for the early phase with very low hydrogen demand, because beside the truck practically no additional infrastructure is required. For higher demands and longer distances, several trucks and possibly a stationary liquid hydrogen tank will be required.

[1] Assuming an average of 2 refuellings per hour, 16 hours operation, and 70 kg per refuelling

## 4 Availability of Liquid Hydrogen and Airports for Early Adoption

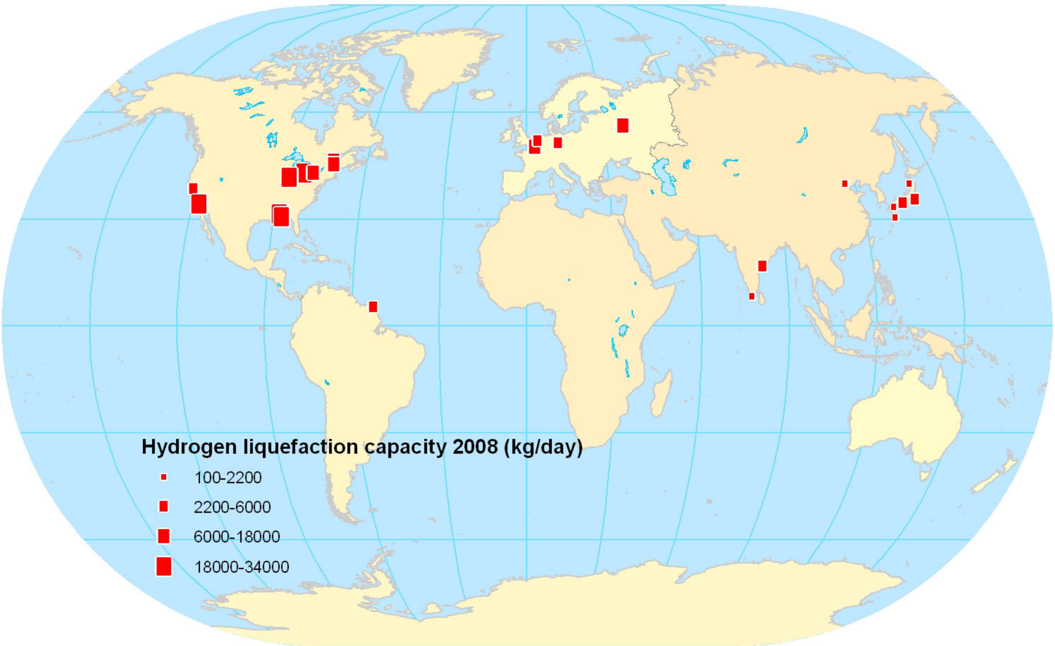


**Figure 3: Map of existing hydrogen liquefiers (state: December 2008).**

An option for some airports during the early phase of low hydrogen demand is to build on existing production and liquefaction capacity. Out of various sources [2, 3, 4], the total worldwide liquefaction capacity of the year 2008 has been estimated and the results can be seen in Figure 3. The global capacity for $LH_2$ is ~120,000 t/year (i.e. only about 0.1% of all hydrogen consumed). Most liquefiers are operated in North America, Japan and Europe. For comparison: 50 short-range aircraft with fuel cell APU would require app. 1,300 t (1.1% of the overall capacity), and 6,500 aircraft would require 166,000 t/year (1.4 times the overall capacity). Depending on the capacity utilisation of the existing liquefiers, a number between 50 and 500 aircraft APUs can probably be supplied without installing new liquefaction capacity.

With regard to the above introduced “one-truck-solution”, especially airports where the next liquefier with free capacity is close appear most promising as a starting point. Furthermore, due to higher flexibility in logistics planning and public visibility, it is assumed that large airports are best suited as early adopters of this technology. A ranking of international airports was done based on their number of departures 2006 (data from [5]) and their distance to the next liquefier[2]. It can be seen that due to size and vicinity to liquefiers, a number of airports in the USA (Chicago, Los Angeles, Ontario) and Japan (Tokyo, Osaka) have favourable conditions to provide liquid hydrogen for aircraft APUs, and furthermore

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[2] A score was calculated based on the departures in 2006, and multiplied with a factor of three, if the next liquefier is less than 20 km away (linear distance – road distances might be some 20-40% more), and a factor of two if the distance is less than 50 km. Airports above 100 km distance were excluded.

Beijing, Toronto and Amsterdam airports could be hubs for such aircraft. Provided that the liquefiers have sufficient capacity available, this offers initiation of $LH_2$ supply at very limited investment. Since the aircrafts need to be refuelled with $LH_2$ only once a day, one stop per day at one of the hubs is theoretically sufficient; in between, also other airports can be approached.

**Table 1: Ranking of airports according to departures and distance to next liquefier.**

| Rank | Airport name | City | Country | Departures 2006 | Linear distance next liquefier (km) |
|---|---|---|---|---|---|
| 1 | CHICAGO OHARE INTERNATIONAL | CHICAGO | USA | 479322 | 51 |
| 2 | CAPITAL | BEIJING | CHINA | 188322 | 38 |
| 3 | LOS ANGELES INTERNATIONAL | LOS ANGELES | USA | 328421 | 89 |
| 4 | TOKYO INTERNATIONAL | TOKYO | JAPAN | 162026 | 26 |
| 5 | CHICAGO MIDWAY INTERNATIONAL | CHICAGO | USA | 149274 | 28 |
| 6 | SCHIPHOL | AMSTERDAM | NETHERLANDS | 220077 | 60 |
| 7 | LESTER B PEARSON INTERNATIONAL | TORONTO | CANADA | 208961 | 84 |
| 8 | ONTARIO INTERNATIONAL | ONTARIO | USA | 68131 | 7 |
| 9 | OSAKA INTERNATIONAL | OSAKA | JAPAN | 65413 | 7 |
| 10 | NARITA INTERNATIONAL | TOKYO | JAPAN | 95063 | 39 |

## 5 Possible Killer Criteria and Synergies

Potential killer criteria for the application of aircraft with $LH_2$-powered fuel cell APU were evaluated. From a technological perspective, general killer criteria could not be detected. However, at specific airports the large distance to the next liquefier and limited forecourt site space could be obstacles to a cost-efficient supply of these airports. Remedies include erecting hydrogen plants near the airport or at other airports, or waiting with the hydrogen deployment at these airports until the hydrogen turnover in aviation has increased. For apron distribution and refuelling, venting of larger quantities of boil-off hydrogen should be prevented, which appears to be technically possible.

Rather than on the technical side, potential barriers could appear on the economic side. This technology can only enter the market with investors committed to foster market commercialisation despite low revenues in the early phases and the usual risks of new technology ventures. Also, acceptance by the public and involved players could bear a risk. Since air travel safety tends to be an issue of public concern, airlines may fear rejection by their customers and thus hesitate to employ the new technology. Further, airport operators may face a conflict of interests, since $LH_2$ APUs with flexible refuelling patterns would make aircraft independent of supply of ground power and preconditioned air, which are a source of airport income.

Synergies with other hydrogen applications were assessed. From existing and near-term planned hydrogen demonstration projects at airports, the main synergy effect that can be expected in conjunction with $LH_2$ infrastructure for APUs is the build-up of expertise on handling hydrogen, approval questions, and supplier contracts, which will facilitate a quicker start for the $LH_2$ infrastructure at these airports.

Hydrogen fuelled ground support equipment and vehicles, small applications inside the airport, and airport-bound land-side traffic (e.g. buses, taxis, etc. refuelling primarily at the airport) will increase the overall hydrogen demand at the airport, and hence cause economy of scale effects (see Figure 2). The effect will be largest for land-side traffic, which has a potential hydrogen demand in the same order of magnitude as the APUs. For the APU infrastructure this might lead to cost reductions through common procurement of equipment, enabling an earlier shift to forecourt production, and utilisation of the boil-off of liquid hydrogen applications. Also for the other applications, the hydrogen supply costs will in most cases be lower than if they were the sole consumers of hydrogen at the airport (even if they might prefer gaseous instead of liquid hydrogen then). Since aircraft APUs are the only applications that rely exclusively on hydrogen in liquid state, these synergies can only be secured if the APU players are early out to make the case for an $LH_2$ supply solution (with evaporation step for vehicles with pressure storage). If at first a gaseous supply for other applications is established, the synergy potential from joint procurement is void.

The future use of hydrogen in the road transportation sector is expected to have a significantly higher hydrogen demand than projected for aircraft APUs. This will lead to a better availability of hydrogen, higher density of supply, and hence shorter delivery distances. Further cost reductions will come from market pricing and competition in an upturning market, larger scales for common production and liquefaction, and reduction of component costs (e.g. electrolysis, fuel cells). Also public acceptance will increase with a successful introduction of hydrogen in road traffic. In turn, the hydrogen mobility sector could benefit from aircraft APU applications through an increased availability of $LH_2$ which is a suitable supply vector for e.g. remote areas.

## 6 Conclusions

Overall, our study showed that supplying aircraft APUs with liquid hydrogen appears technologically feasible and, if suitable airports are chosen for early adoption, only moderate equipment and investment is required. Up to a certain penetration level, most airports will be able to rely on $LH_2$ from existing liquefaction capacity. Later, when new capacity is required, this can be shared with other applications and possibly even located on-site the airport.

In addition to risks inherent to novel technologies, potential barriers rather relate to economic interests and strategies of the players. Synergies can be expected from sharing the infrastructure with other large-scale applications such as hydrogen fuelled ground support equipment, apron vehicles, as well as airport-bound vehicles.

Consequently, with any next steps taken, it is recommended to ensure that all required players are sharing the vision, possibly co-ordinate and align infrastructure deployments, and are jointly working for public acceptance of hydrogen in (air) transportation.

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