Lessons Learned from Hydrogen Infrastructure Operation in the HyFLEET:CUTE Project

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Lessons Learned from Hydrogen Infrastructure Operation in the HyFLEET:CUTE Project

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1 Introduction

The main objective of the HyFLEET:CUTE project (January 2006 – December 2009) was to demonstrate hydrogen powered buses and their hydrogen infrastructures in everyday operation. 33 fuel cells buses and 14 buses with internal combustion engines ran in revenue service in ten cities on three continents (Amsterdam, Barcelona, Beijing, Berlin, Hamburg, London, Luxembourg, Madrid, Reykjavik and Perth / Western Australia).

This paper focuses on the experiences with on-site hydrogen infrastructure operation. Information on other project aspects can be found in an overall report [1]. Each infrastructure plant had a hydrogen refuelling station (350 bar rated pressure). The majority also comprised a unit for on-site generation of the fuel (water electrolysis, or steam reforming of liquefied petroleum gas or natural gas).

Figure 1 shows a generalised schematic of the HyFLEET:CUTE infrastructure facilities. The details of individual installations varied significantly.

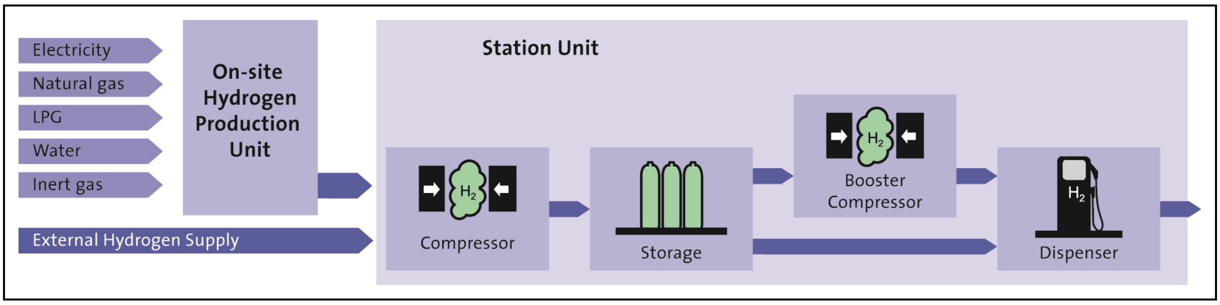

Figure 1: Generalised schematic of the HyFLEET:CUTE hydrogen infrastructures. Hydrogen was supplied by truck from external sources or generated on site from electrolysis of water, or by steam reforming of natural gas or liquefied petroleum gas (LPG). It was compressed, stored, and dispensed on demand to the buses. Dispensing required a pressure differential between the on-site storage and the vehicle tanks. In general, filling commenced using the pressure differential due to the empty bus tanks (decanting) and was completed with a booster compressor (booster mode). Some sites operated with decanting or booster mode only.

2 Performance Indicators

Qualitative and quantitative performance indicators were defined as part of the project's Assessment Framework. For a coherent analysis across all sites, the Production Unit and Station Unit as sketched in Figure 1 had to be treated individually. In particular, a meaningful comparison of facilities with and without on-site production of hydrogen only became possible this way. A similar set of indicators was first used in the CUTE project [2].

Quantitative indicators include:

- Availability of the Production Unit and of the Station Unit, respectively
- Distribution of downtime hours with respect to cause (such as maintenance, hydrogen supply, compressors and dispensing equipment)
- Specific energy demand of the Production Unit for on-site hydrogen generation including purification and drying
- Specific energy demand of the Station Unit for hydrogen, compression, storage and dispensing
- Efficiency of the entire on-site hydrogen supply chain
- Difference between hydrogen supplied (external delivery and/or on-site production) and hydrogen dispensed ("losses of hydrogen").

The scope of this paper is not to give a full account of all operating details of each of the sites but to provide an overview of findings and learnings. Girón [3] presented a thorough evaluation of the hydrogen refuelling installation in Madrid during the CUTE project.

3 Key Data

Most cities operated their three fuel cell buses and infrastructure for a one-year period as a continuation of their activities under the CUTE [4], ECTOS [5] and STEP [6] projects. A few of them extended their period of operation beyond the schedule of HyFLEET:CUTE voluntarily and at their own expenses. The Hamburg fleet with up to nine buses remained in service during the entire project. Berlin was the only site where a new hydrogen production and refuelling facility was built for HyFLEET:CUTE. It served a growing fleet of up to 14 buses with internal combustion engines from June 2006 plus two stationary fuel cells and vehicles outside the project (the latter with both liquid and gaseous hydrogen).

More than 344.000 kg of hydrogen were dispensed to the project buses between during over 13.960 fillings (January 2006 – November 2009). When also considering figures from CUTE, ECTOS and STEP, about 574.000 kg of the fuel were distributed to the vehicles from 2003 to end of 2009.

Under HyFLEET:CUTE, more than 170.000 kg of hydrogen were generated on site, mainly from water electrolysis. About 240.000 kg liquid and gaseous hydrogen were trucked in.

4 Example Performance Indicators: Availability of the Station Unit and Downtime Causes[1]

The average availability of the Station Units was 89,8% with the individual sites ranging between 61% and 99,6%. In fact, all Stations Units but one were operational for 80% of the time or more.

Calculation of this indicator was based on counting the time hours (unit not operational) and subtracting them from the total operating period on a “24 hours / 7 days per week” basis.

It is important to distinguish root causes for downtime. Ideally, downtime would be caused by (scheduled) maintenance.

Figure 2 shows that downtime across all sites was dominated by five factors that contributed more than 90% of all downtime hours. Problems with Production Units and compressors alone caused more than two thirds of all downtime. Maintenance contributed by less than 10%.

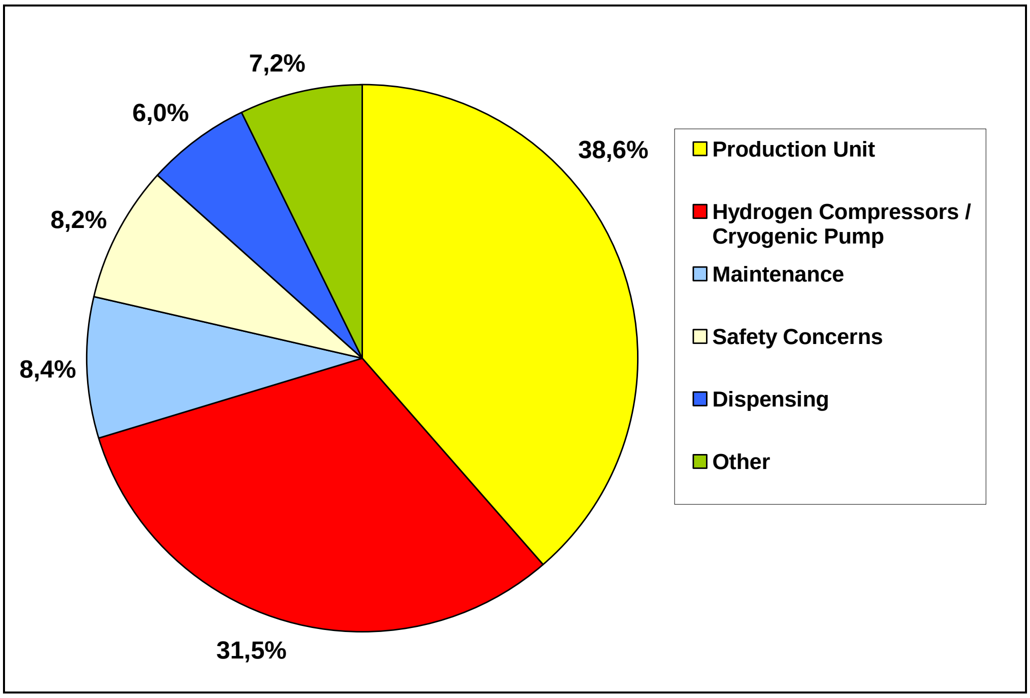

Figure 2: Normalised distribution of downtime hours of the Station Units with respect to cause.
As the operating period was different at the individual sites, downtime hours were normalised to one year. “Maintenance” stands for scheduled maintenance; “Safety Concerns” for periods when the station was technically OK but taken out of service due to safety concerns; all other categories stand for failure and repair of the components and their auxiliaries as stated.

[1] Figures in this section are based on data between January 2006 and December 2008 when operation was planned to end at the last site (Berlin) according to the project schedule. Note that the Berlin partners continued their demonstration activities on a voluntary basis, similar to other HyFLEET:CUTE cities, as mentioned.

The issues with hydrogen supply affected bus operation (usually “no fuel”) but, from perspective of the Station Unit, were an external cause rather than being connected to technical difficulties with the Unit itself. Disregarding such “external problems” with hydrogen supply, the Station Units display an average availability of 93,8%, with each of them accomplishing of 89% or better.

“Hydrogen compressors”, including a cryogenic pump for liquid hydrogen in London, is the only category with contributions from all project sites. This is a matter of great concern since the compressors constitute the “heart” of the station units.

The dispensing equipment only caused 6% of all downtime and therefore less than maintenance. However, any matters related to these components deserve special attention since they constitute the “user interface”.

Comparison with the findings under the CUTE project reveals that similar types of problems prevailed. [2]

5 Lessons Learned

5.1 Production units

Electrolysers performed well overall. In particular, there were no problems with the core of the plant, i.e. the stack. The only major issue was corrosion in the lye loop of the Hamburg unit. Flexible operation is technically feasible. Energy consumption should be reduced in the future (stack and auxiliaries). As a rule of thumb, a well-maintained system can operate without difficulties.

The reformers failed to meet expectations. Severe problems with the core of the plant, the reformer tubes, were faced both in Berlin (feedstock: liquefied petroleum gas) and Madrid (natural gas). Process temperatures tended to exceed the allowed limits. In Madrid, auxiliaries caused significant downtime as well.

Start-stop cycles of reformers are energy and time consuming. Instead, the units were usually operated at part-load when the hydrogen storage was running full. Surplus hydrogen often had to be vented. Part-load operation reduced process efficiency. Flexible operation of the reformers therefore remains a big issue.

5.2 Station units

Availability of the Station Unit was most severely affected by on-site Production Units. Accordingly, arrangements for backup supplies by trailer delivery are vital.

The main internal factor reducing availability was hydrogen compressors, as mentioned. Redundancy would be beneficial but it is a cost issue.

5.3 Entire hydrogen supply chain

Sites with on-site electrolysis displayed an efficiency of the supply chain of about 50% (total end energy consumption divided by the energy content of the total amount of hydrogen dispensed).

Inaccuracies of hydrogen meters were proven or suspected at individual sites. This kind of unreliability also impeded quantifying losses of hydrogen due to (de-) pressurisation of pipes and hoses, purging, regeneration of driers, boil-off etc. These known mechanisms can sum up to significant amounts.

In HyFLEET:CUTE, hydrogen impurity (i.e. not according to specifications) was not a matter of great concern, unlike in CUTE.

6 Outlook

The challenges of the future include:

- Hydrogen compressors, the most critical component at present
- Durable dispensing equipment (nozzles, hoses, etc.) and hydrogen meters in particular
- Improved system integration, standardisation and simplification
- Increasing energy efficiency and reducing hydrogen losses
- Accounting for variable load patterns, intermittent and part-load operation

Modular design is required for scaling up hydrogen infrastructure facilities with growing fleets and increasing intensity of operation. Manufacturers need to advance on series development for infrastructure.

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