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Hydrogen Mobility Europe (H2ME): Vehicle and Hydrogen Refuelling Station Deployment Results

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Abstract: Hydrogen Mobility Europe (H2ME, 2015–2022) is the largest European Fuel Cells and Hydrogen Joint Undertaking (EU FCH JU)-funded hydrogen light vehicle and infrastructure demonstration. Up until April 2017, the 40 Daimler passenger car fuel cell electric vehicles (FCEVs) and 62 Symbio Fuel Cell-Range Extended Electric Vans (FC-REEV)-vans deployed by the project drove 625,300 km and consumed a total of 7900 kg of hydrogen with no safety incidents. During its first year of operation (to April 2017), the NEL Hydrogen Fueling HRS (hydrogen refuelling station) in Kolding, Denmark dispensed 900 kg of hydrogen, and demonstrated excellent reliability (98.2% availability) with no safety incidents. The average hydrogen refuelling time for passenger cars is comparable to that for conventional vehicles (2–3 min).

Keywords: demonstration; fuel cell vehicle; hydrogen vehicle; passenger car; van

1. Introduction

The European Commission [1] has identified fuel cell electric vehicles (FCEVs) among the technologies needed for Europe to meet its ambitious energy security objectives and to deliver a minimum 60% reduction of greenhouse gas emissions from transport by 2050 [2]. As vehicle manufacturers such as Daimler, Hyundai, and Toyota have begun to introduce FCEVs, the numbers of FCEVs and hydrogen refuelling stations (HRS) deployed in Europe has grown slowly, stimulated mainly by activities such as the following:

- Demonstration programmes funded by the European Fuel Cells and Hydrogen Joint Undertaking (FCH JU) (e.g., HyTEC, HyFIVE).
- National initiatives undertaken in several countries (e.g., H2 Mobility Deutschland, UK H2 Mobility, Mobilité Hydrogène France, and Japan H2 Mobility).

However, several market barriers to the widespread introduction of this technology have persisted, which, until now, have limited the penetration of this technology in Europe [3]. Hydrogen Mobility Europe (H2ME) aims to address some of those barriers [4].

Hydrogen Mobility Europe (H2ME)

H2ME (2015–2022) is the largest passenger vehicle and hydrogen refuelling station demonstration initiative co-funded by the Fuel Cells and Hydrogen Joint Initiative (FCH JU). H2ME is formed of two separate FCH JU-co-sponsored projects, listed below:

- H2ME-1 (2015–2020), which aims to deploy 300 FCEVs and fuel cell range-extended electric vehicles (FC REEVs) and 29 HRS.
- H2ME-2 (2016–2022), which aims to deploy 1200 FCEVs and FC REEVs and 20 HRS (hydrogen refuelling stations).

H2ME brings together Europe's leading national initiatives on hydrogen mobility to initiate a pan-European approach to the roll-out of a European hydrogen network. The project's aims are summarised in Figure 1.

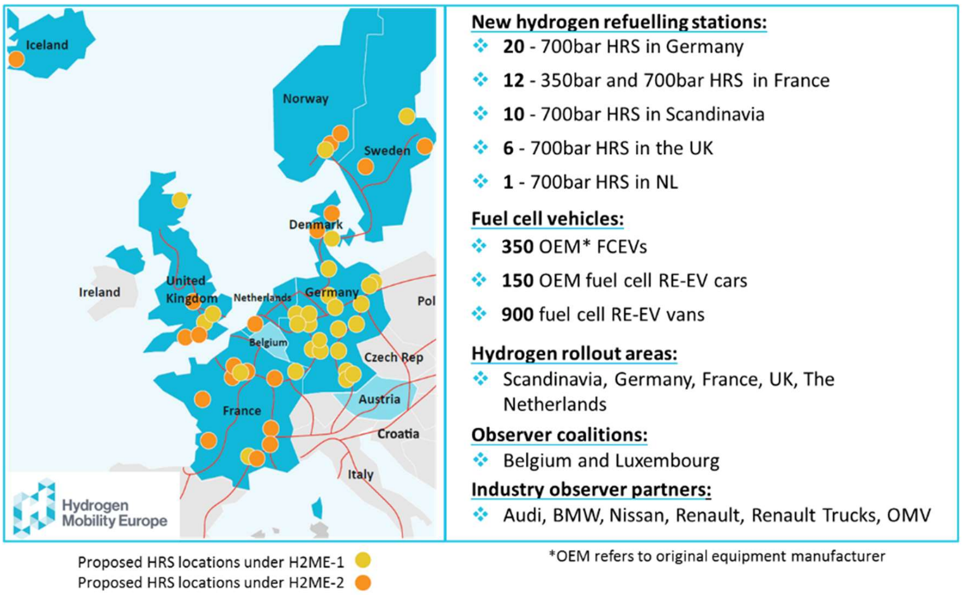


Figure 1. Hydrogen Mobility Europe (H2ME) deployment summary. HRS—hydrogen refuelling stations; FCEVs—fuel cell electric vehicles; RE-EV—range-extended electric vehicles.

The vehicle and HRS demonstration activities of H2ME aim to prove that fuel cell vehicles and HRS are capable of substituting for conventional vehicles in a number of test cases (e.g., passenger car deployments with individual users, van deployments with working fleets, etc.). The results of these demonstrations over the first two years of the project, and their implications for the wider rollout of hydrogen mobility across the EU, are discussed in the rest of this paper.

2. Results—Vehicles

2.1. Vehicle Types Used in H2ME

As shown in Figure 1, H2ME will eventually deploy 1500 vehicles from manufacturers including Daimler, Honda, Hyundai, Symbio, and Toyota. Table 1 summarises the characteristics, numbers, and operation of the vehicles that have been deployed by H2ME up until April 2017.

Table 1. Hydrogen Mobility Europe (H2ME) vehicles. FCEV—fuel cell electric vehicle; FC REEV—fuel cell range extended electric vehicles.

Parameter	Daimler B-Class F-Cell FCEV	Symbio Kangoo ZE H2 FC REEV
Vehicle architecture	Battery/fuel cell parallel hybrid	Battery electric Renault Z.E. with a fuel cell range extender
Range (km, New European Drive Cycle, NEDC)	380	300
Stack Continuous Power Rating (kW)	70	5
Tank Capacity (kg H_2)	3.7	1.8
Tank Pressure (bar)	700	350
Battery Pack Size	1.4 kWh Li Ion	22 kWh Li Ion
Number deployed	40 (in Germany)	62 (in France and the United Kingdom)
Distance driven (km)	542,330	83,000

2.2. How H2ME Vehicles Are Being Used and Refuelled

2.2.1. Fuel Cell Electric Passenger Vehicles (FCEVs)

The 40 Daimler B-Class F-Cell vehicles have been deployed to a variety of private and public customers across the whole of Germany since June 2015. Ten percent of the operational Daimler B-Class F-Cell fleet have been monitored in detail via on-board telemetry devices in order to obtain more granular data on journey patterns and daily usage. Figure 2 shows the distribution of distance driven per day by these vehicles. The average daily distance travelled by the vehicles was 68 km (the furthest distance travelled by a vehicle in one day was 517 km), and the average quarterly distance was 2880 km. These results show that the FCEVs are being used in the same way as typical German passenger cars [5,6].

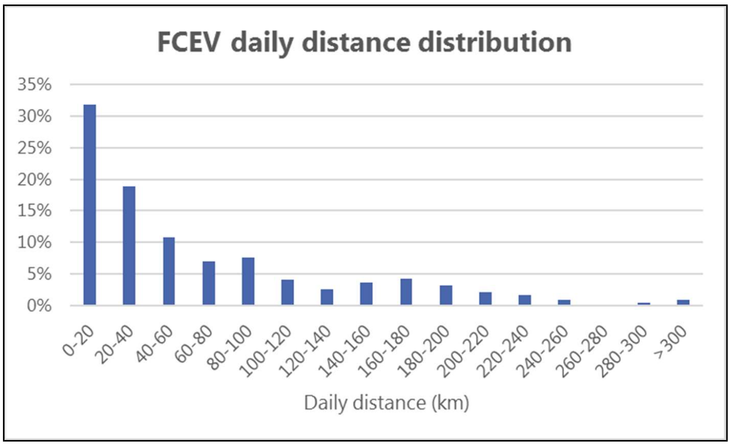


Figure 2. H2ME FCEV daily distance driven distribution.

The refuelling behaviour of the FCEVs over the demonstration period is summarised in Figure 3. The average refuelling amount was 2.2 kg (ca. 60% of the tank capacity of 3.7 kg), and the average distance between refuellings was 170 km. These figures have remained almost constant throughout the trial, and show little evidence of any range anxiety effects, which otherwise might have revealed the average refuelling amount growing in the initial period of the deployment. This relative lack of variation in average refuelling amount for FCEVs over an extended period has also been shown in the long-running Hydrogen Fuel Cell Electric Vehicle Learning Demonstration (NREL) [7].

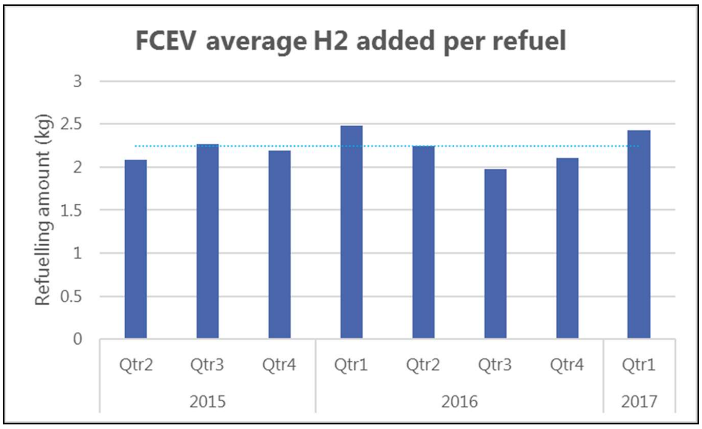


Figure 3. H2ME FCEV refuelling amount over time.

2.2.2. Fuel Cell Range Extended Electric Vans (FC-REEVs)

The 62 Symbio vehicles have been deployed to a variety of private and public fleets in France and the United Kingdom. Ten percent of the operational fleet has been monitored in detail via on-board telemetry devices since their deployment in the H2ME project in September 2015. Figure 4 shows the distribution of distance driven per day by these vehicles. The average daily distance travelled by the vehicles was 64 km, and the furthest distance travelled by a vehicle in one day was 288 km. The data shows that under the current demonstrated usage patterns, the Symbio Kangoo ZE H2 FC-REEV can fulfil the daily driving needs of most utility van drivers [8].

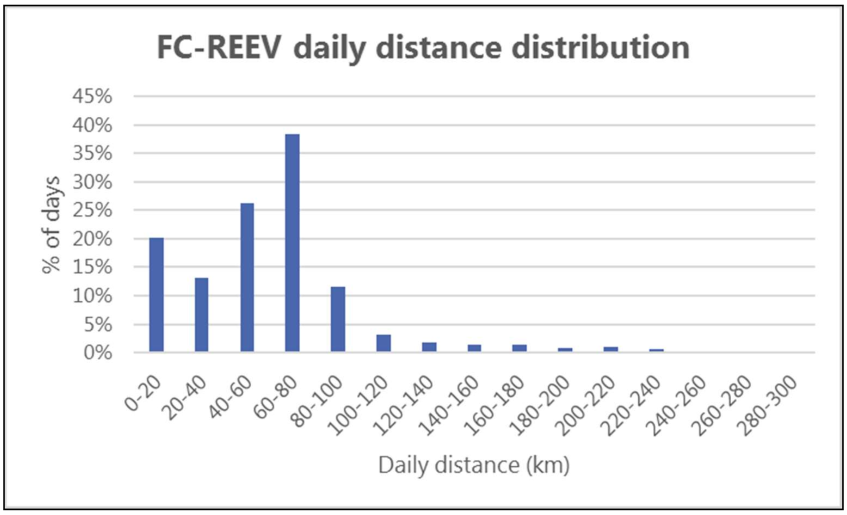
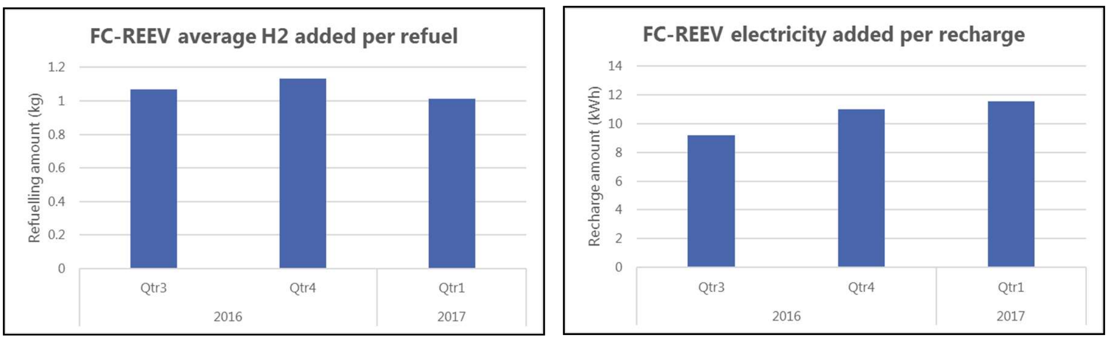


Figure 4. H2ME fuel cell range-extended electric vehicles (FC-REEV) daily distance driven distribution.

As a range-extended vehicle, the Symbio Kangoo ZE H2 FC-REEV can refuel with electricity and hydrogen, and can operate on electricity provided by the battery, or fuel cell, or a combination of both. The refuelling/recharging behaviour of the FC-REEVs over the demonstration period is summarised in Figure 5. The average hydrogen refuelling amount was 1.1 kg (62% of the tank capacity), and the average distance between refuellings was 210 km. These figures have remained almost constant throughout the monitoring period. The average battery recharge was 10.6 kWh (48% of the full battery capacity), and the average distance between recharges was 73 km.



(a) (c)

Figure 5. H2ME FC-REEV (a) hydrogen refuelling and (b) electrical recharging amounts over time.

2.3. Vehicle Energy Usage

2.3.1. Fuel Cell Electric Passenger Vehicles (FCEVs)

The near-two years of operation of the Daimler FCEVs in Germany has permitted a study of the variation in the vehicle's fuel efficiency (measured in terms of the number of kilometres driven per kg of hydrogen used by the vehicle) with temperature in each month over the period. The variation of efficiency with temperature is shown in Figure 6. The data shows a broad correlation of increasing ambient temperature (measured in Stuttgart [9]) with decreasing fuel usage (and thus increasing vehicle efficiency) over the period.

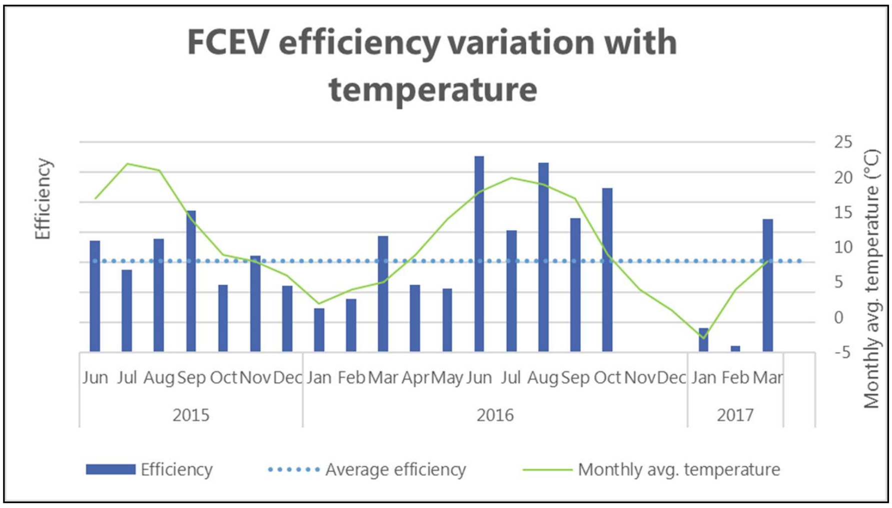


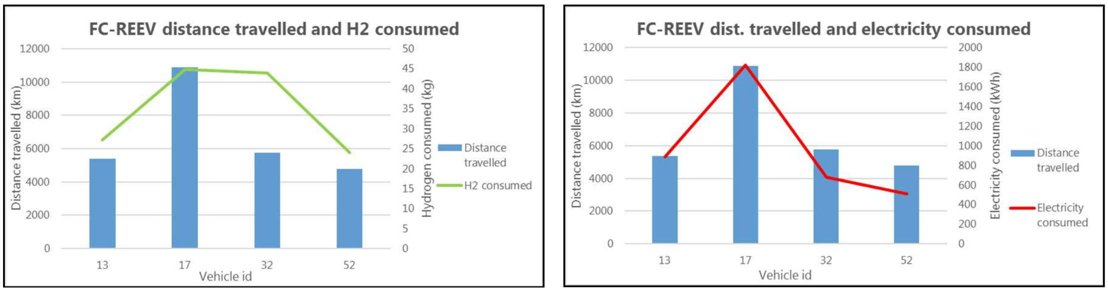
Figure 6. H2ME FCEV fuel efficiency variation over time (*y* axis scale not shown at the request of the data provider).

The variation of vehicle efficiency with temperature is a well-known phenomenon for both conventional [10] and alternatively-fuelled vehicles [11]. Reasons for the reduction in overall vehicle efficiency with reduced temperature include:

- reduced battery and mechanical efficiency
- greater use of on board cabin heating during winter
- increased rolling and wind resistance.

2.3.2. Fuel Cell Range Extended Electric Vans (FC-REEVs)

The Symbio Kangoo ZE H2 is a fuel cell range-extended electric vehicle that can refuel with electricity and hydrogen. Therefore, as shown in Figure 7, there is no simple direct correlation between distance driven and hydrogen and electricity consumption for the set of vehicles that has been monitored in detail (i.e., vehicles that drive similar distances, such as vehicles 32 and 52 in Figure 7, do not necessarily use the same amount of hydrogen, as they may fuel more with electricity than with hydrogen).



(**a**) (**b**)

Figure 7. H2ME FC-REEV (**a**) hydrogen and (**b**) electricity consumption variation with distance driven.

To understand the variation of hydrogen and electricity consumption of the vehicles, a simple model was used to translate fuel usage to energy usage:

- H_2 conversion via the FC to electricity is 45% efficient (Value Provided by Symbio FCell).
- The efficiency of energy transfer from the battery to the wheels is 90%

Figure 8 shows how the overall energy consumption of the vehicles varies with distance under the simplified assumptions of this model. The figure shows that, under these assumptions, the overall vehicle energy consumption (i.e., hydrogen plus electricity) per km is approximately the same for three of the vehicles, while the fourth (vehicle 52) appears to be driven more efficiently. In practice, this means that, to the driver, the vehicle drives as a normal electric vehicle irrespective of whether the fuel is hydrogen, electricity, or a combination of both.

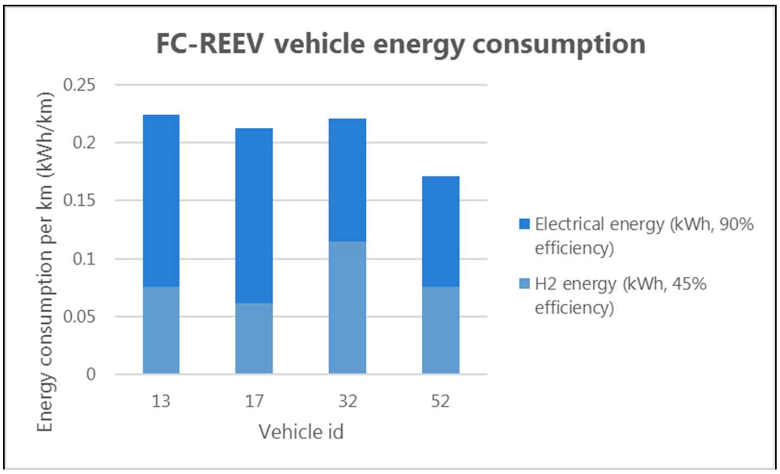


Figure 8. H2ME FC-REEV energy consumption variation with distance driven.

As with the FCEVs, monitoring of the FC-REEVs over time allows for study of the variation in the vehicle's fuel efficiency (measured in terms of the number of kilometres driven per kg of hydrogen used by the vehicle) with temperature in each month over the deployment period. This is shown in Figure 9 for one of the vehicles operating in Paris. The data shows a good correlation of increasing ambient temperature with decreasing fuel usage (and thus increasing vehicle efficiency) over the period. As discussed in Section 2.3.1, this is a well-known phenomenon for conventional and alternatively-fuelled vehicles.

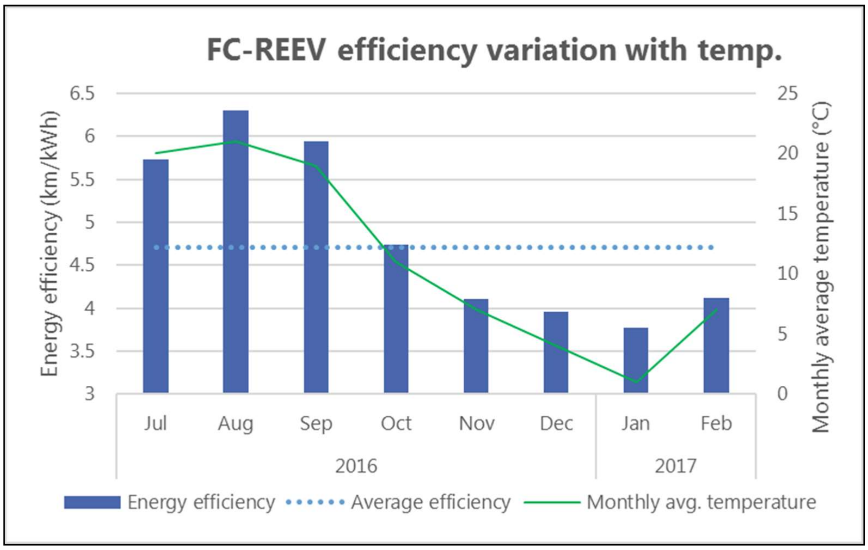


Figure 9. H2ME FC-REEV efficiency variation with temperature.

3. Results—Hydrogen Refuelling Stations (HRS)

Up to the end of April 2017, the project deployed three 700 bar HRS: one in Kolding, Denmark (supplied by NEL Hydrogen Fueling); one in Mariestad, Sweden (also supplied by NEL Hydrogen Fueling); and one in Sandviken, Sweden (also capable of 350 bar fuelling, supplied by AGA). The station in Kolding has been operational since March 2016, and therefore will be the focus of the discussion of this paper. The technical and performance characteristics of the Kolding HRS are summarised in Table 2.

Table 2. Kolding hydrogen refuelling stations (HRS).

Parameter	Value
Station supplier	NEL Hydrogen Fueling
Accessibility	Public 24/7
Hydrogen dispensing pressure (bar)	700
Hydrogen supply	Offsite
Capacity	100 kg/day
Back-to-back capacity	2.5 vehicles
Hydrogen dispensed	900 kg
Availability	98.2%

3.1. Station Usage

The Kolding station was opened in March 2016. The HRS is publicly-accessible, open 24/7, and serves FCEV passenger vehicles as part of the wider Danish hydrogen refuelling station network. Figure 10 shows the observed refuelling patterns of the station over a 24 h period. The figure shows evidence of a morning peak between 08:00–09:00 h, presumably as people are travelling to work, and then consistent usage between 12:00–17:00 h, until usage falls away in the evening. The HyTEC project observed similar evidence of refuelling peaks with fleet vehicles in Copenhagen, although in that case, the peak was shifted later because FCEVs tended to be fuelled after they had been collected from their overnight parking place [11]. The variation of HRS usage over the day, and user's refuelling and station-usage preferences as the network grows, are among the main questions that H2ME is trying to answer to aid planning of future HRS networks, and will be reported in more detail over the project as further stations and vehicles are deployed.

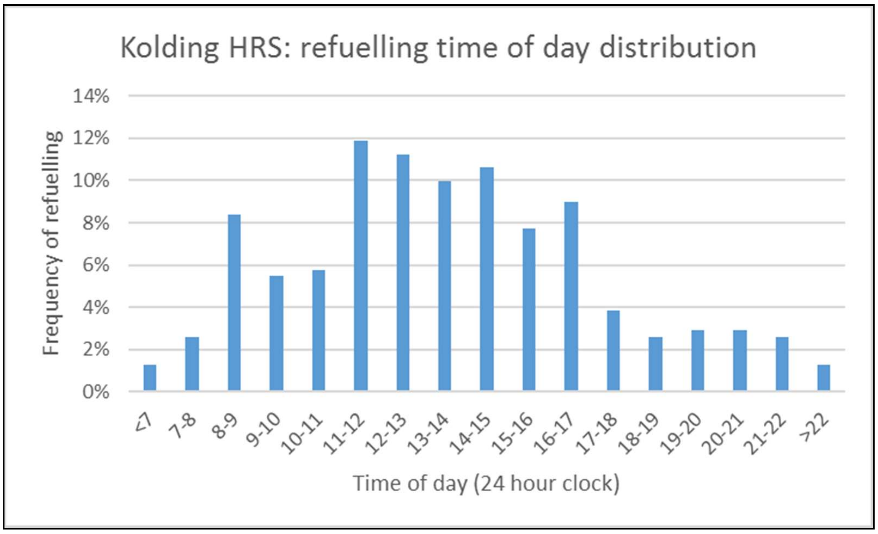


Figure 10. H2ME Kolding HRS refuelling time distribution.

3.2. Station Vehicle Refuelling Time

The Kolding station is a state-of-art, SAE J2601 compliant facility [12] that incorporates precooling to −40 °C and was built according to ISO/TS20100:2008 *Gaseous hydrogen—Fuelling Stations* (since revised to ISO19880:2016). Figure 11 demonstrates that the Kolding HRS refuels vehicles at a rate of ca. 1 kg H_2 per minute, as specified by the protocol.

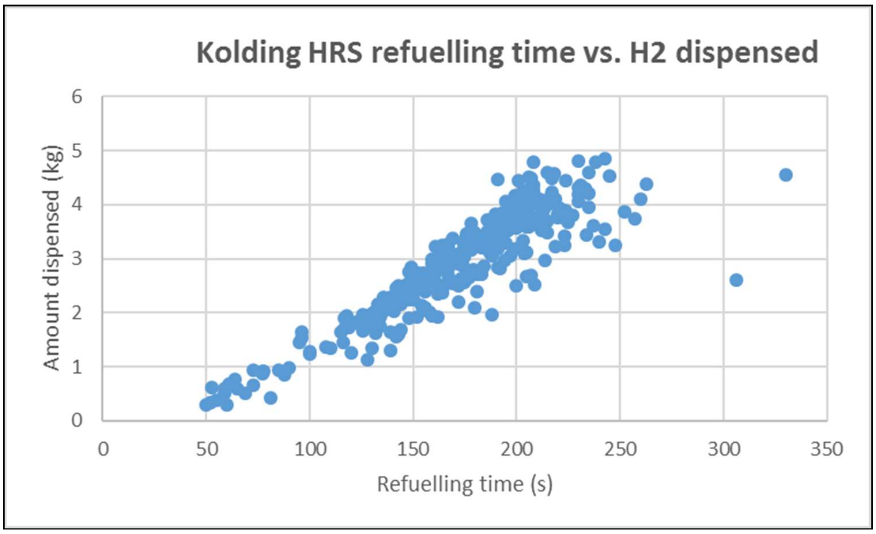


Figure 11. H2ME Kolding HRS refuelling time.

The average vehicle refuelling time (Figure 12) was just under three minutes, demonstrating that FCEVs refilling at 700 bar under J2601 refuel in comparable times to conventionally-fuelled vehicles.

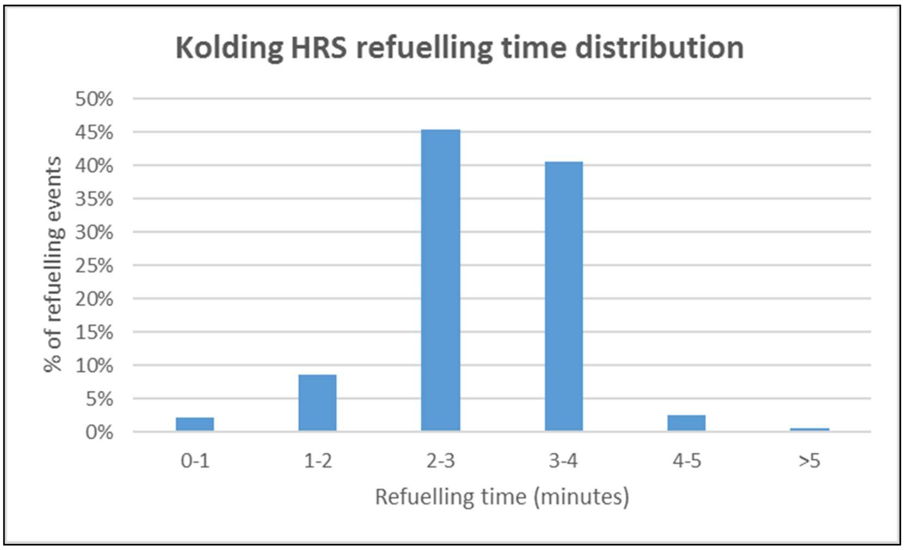


Figure 12. H2ME Kolding HRS refuelling time distribution.

3.3. Station Availability

A crucial factor in the wider public acceptance of hydrogen vehicles is that HRS should be reliable and available when needed. To aid user's confidence in its stations, NEL Hydrogen Fueling provides mobile telephone text updates on whether its stations are working, and the Kolding station is equipped with state-of-art diagnostic and reporting tools that allow NEL to report and repair any station issues that arise. Figure 13 summarises the Kolding HRS's availability over the first year of its deployment.

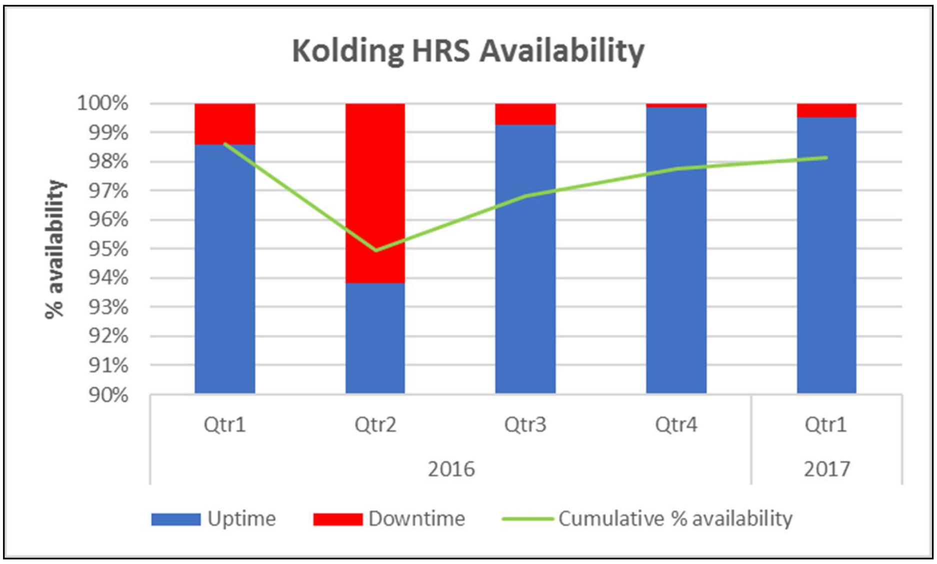


Figure 13. H2ME Kolding HRS availability over time.

The overall station availability was found to be 98.2% (98.3% if maintenance is excluded), and the total amount of time that the station was not available over the year was seven days. Downtime incidents ranged from ca. 1 min to 99 h in length. As found in other HRS demonstrations, such as HyTEC and the NREL Fuel Cell and Hydrogen Technology Validation [7,11], the main source of station downtime was compressor issues, principally one four-day compressor failure in Quarter 2 of 2016.

4. Conclusions

Hydrogen Mobility Europe (H2ME) is the FCH JU's largest light vehicle and infrastructure demonstration project. H2ME is beginning to accumulate a significant body of data on how real customers are using vehicles and stations. Amongst the key findings of the demonstration so far are the following:

- FCEVs are used in the same way as conventional vehicles regarding daily usage patterns, and their rapid refuelling rate and long range allow them to travel distances of over 500 km in a single day.
- FC-REEV vehicles have demonstrated that they can fulfil the work-related needs of utility van drivers, whether fuelled primarily by hydrogen or electricity, travelling up to 300 km per day.
- The Kolding HRS dispensed 900 kg of hydrogen in a year and displayed excellent reliability (98.2% availability).
- The technology is safe, and there were no vehicle or HRS safety incidents reported during this period.

H2ME will continue until 2022, by which time 49 hydrogen refuelling stations and 1500 hydrogen vehicles will be deployed. The data gathered will form a crucial evidence base for policy makers, manufacturers, and consumers toward the wider European rollout of hydrogen vehicles and infrastructure.

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Conflicts of Interest: The authors declare no conflict of interest.

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