Hydrogen Mobility Europe

cenex

H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021) – D5.17

Authored by	**Peter Speers**, Daniel Grist, Victor Lejona, and Tom Price
Approved by	Steve Carroll
Date	03rd November 2021
Document Status	Final
Deliverable	D5.17
Dissemination Level	**Public**
Contact Details	peter.speers@cenex.co.uk Cenex, Holywell Building, Holywell Park, Ashby Road, Loughborough, Leicestershire, LE11 3UZ, UK

A project co-funded by
under the Grant Agreements No 671438 and No 700350

FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Abbreviations

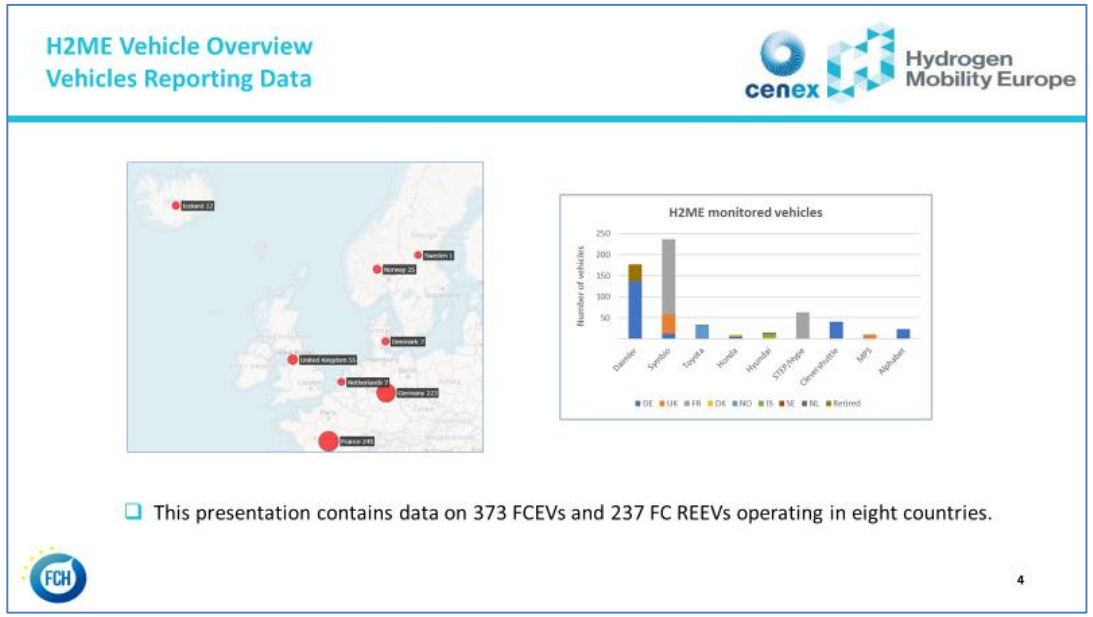
A-M		N-Z	
B2B	Back-to-Back (Refuelling)	NEDC	New European Driving Cycle
BEV	Battery Electric Vehicle	NREL	National Renewable Energy Laboratory
FCEV	Fuel Cell Electric Vehicle	OEM	Original Equipment Manufacturer
FCH2 JU	Fuel Cells and Hydrogen Joint Undertaking	PEM	Proton Exchange Membrane
FCH2 JU	Fuel Cells and Hydrogen Joint Undertaking	PHEV	Plug-in Hybrid Electric Vehicle
FE	Fuel Efficiency	SOC	State of Charge
H_2	Hydrogen	STEP	Société du Taxi Électrique Parisien
H2ME	Hydrogen Mobility Europe	TCO	Total Cost of Ownership
HRS	Hydrogen Refuelling Station	US DOE	US Department of Energy
HyTEC	Hydrogen Transport in European Cities	WLTP	Worldwide Harmonised Test Procedure
MDBRE	Mean Distance Between Refuelling Events	WTW	Well-to-wheel
MPS	Metropolitan Police Service (London, UK)	ZEFER	Zero-Emission Fleet vehicles for European Rollout

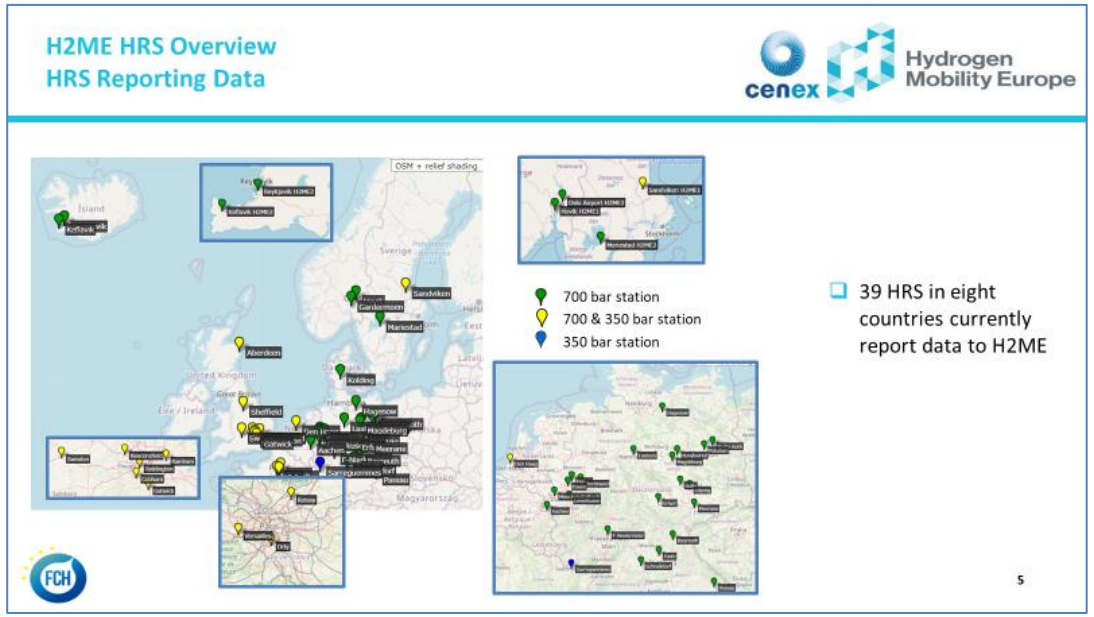
Executive Summary (1)
Data Presented in this Report

- Hydrogen Mobility Europe (H2ME, https://h2me.eu/, 2015-2023, which comprises sub-projects H2ME-1 H2ME-2, is the largest passenger and light duty hydrogen vehicle and hydrogen refuelling station (HRS) demonstration initiative co-funded by the Fuel Cells and Hydrogen Joint Undertaking (FCH2 JU).
- Supported by €67m of FCH2JU funding, the €170m H2ME project aims to deploy more than 1 400 vehicles and 49 HRS in eight countries by 2022.
- This report reviews all project vehicle and HRS data reported from June 2015 to March 2021.
  - **330** fuel cell electric vehicles (FCEVs) made by Daimler, Honda, Hyundai and Toyota.
  - **237** fuel cell range-extended electric vehicles (FC REEVs) from Symbio.
  - **39** hydrogen refuelling stations (HRS) supplied by Air Liquide, ITM Power, Linde (including its subsidiaries AGA and BOC), McPhy and NEL Hydrogen Fueling.
- This is the fourth of a series of periodic reports that review the performance of vehicles and HRS in the project. This report focuses on vehicles supplied by Honda and Symbio as part of H2ME-2. It also discusses the performance of HRS as their utilisation increases, which was one of the main aims of H2ME-2.
- H2ME (including most of the vehicles and HRS supported by H2ME-1) will continue to collect and report data under H2ME-2 until June 2023.

Executive Summary (2)
H2ME Vehicle and HRS Numbers

- Vehicles and stations reporting data to H2ME to the end of May 2021 featured in this report comprise:
  - **373 FCEVs** and **237 FC REEVs**
  - **39 HRS**

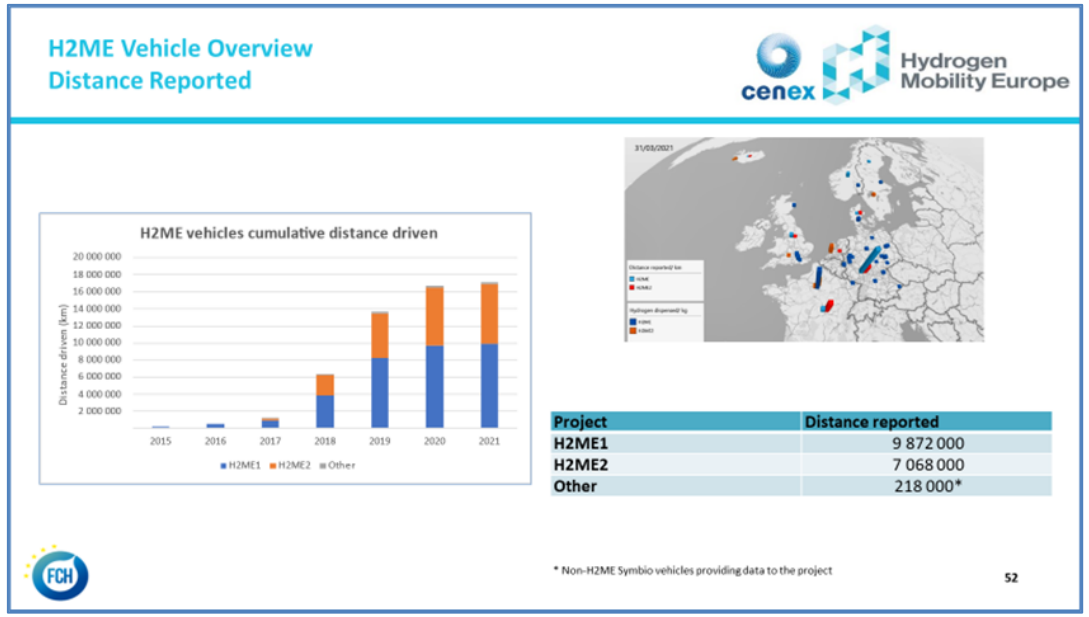


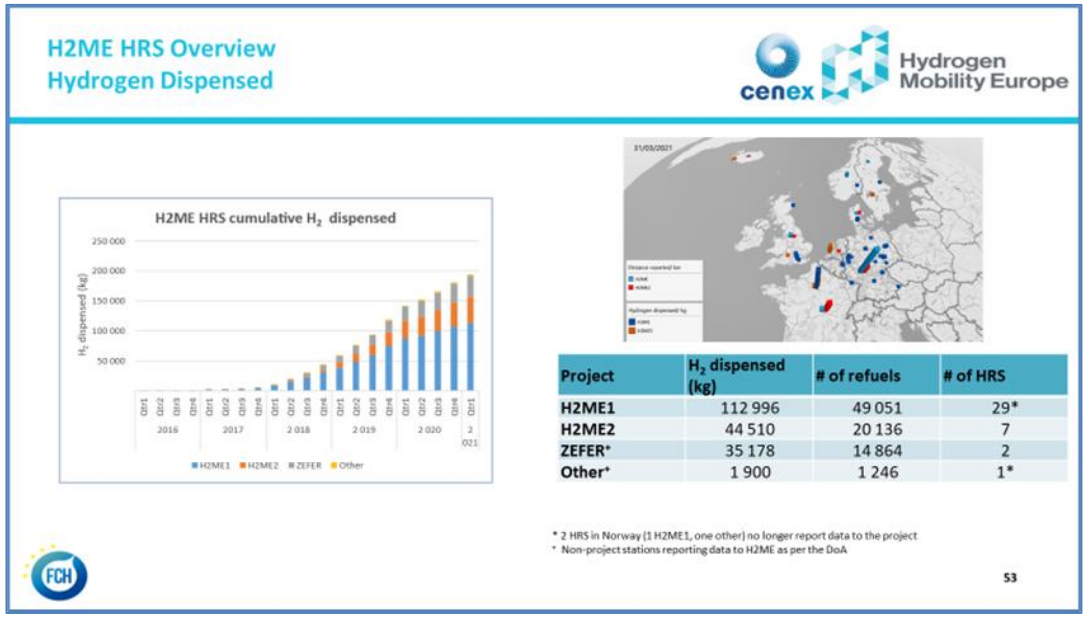


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (3)
Overall Results

- To the end of May 2021:
  - H2ME FCEVs and FC REEVs reported almost **17.2 million km** driven.
  - The 39 HRS reporting data to H2ME dispensed almost **193 000 kg** of hydrogen in **84 866** refuels.
  - Urban deployments of high-usage vehicles such as taxis dominate H2ME vehicle usage, and HRS deployed in locations where taxis operate continue to provide the bulk of HRS usage.

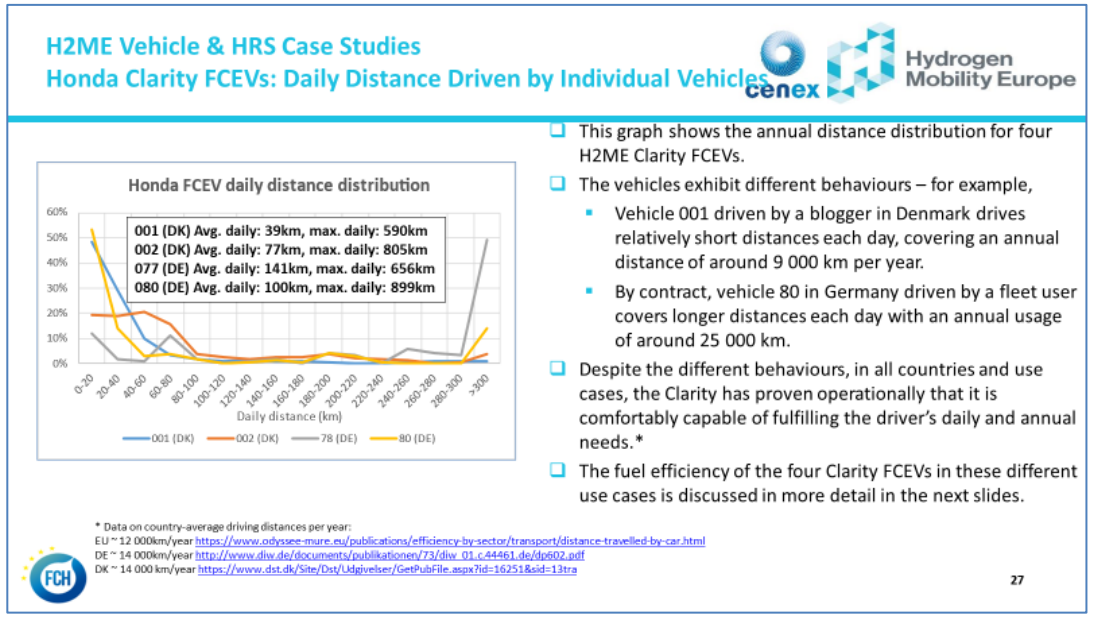


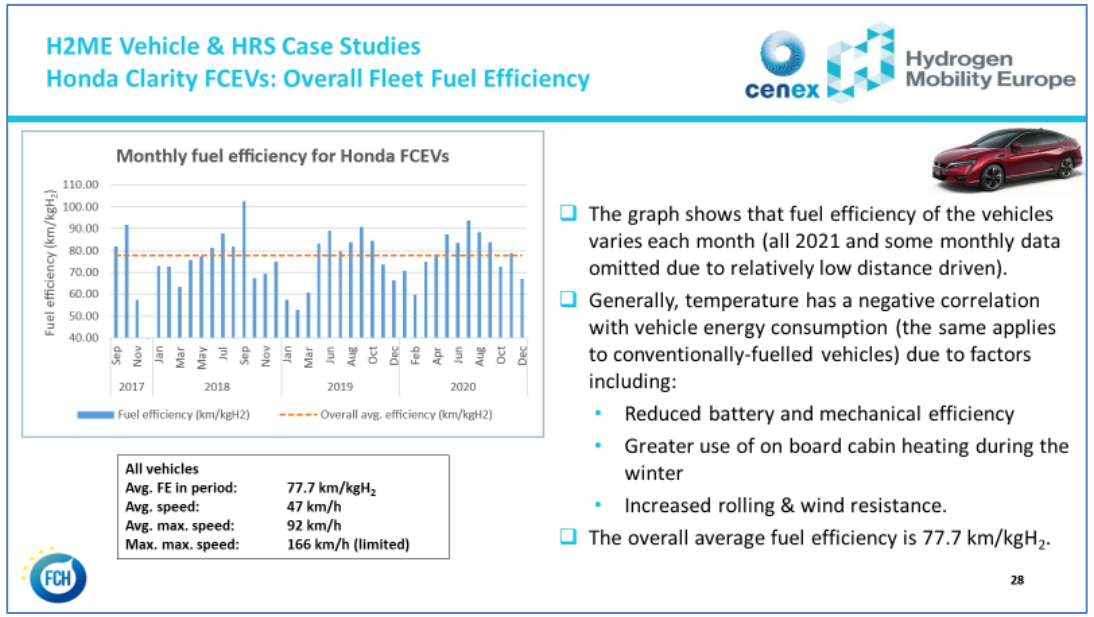


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (4)
Key Findings

Honda Clarity FCEV	Dates deployed and use cases	Learnings
	2017- Passenger and fleet vehicles in Denmark and Germany	• FCEVs are operationally capable of fulfilling the average driver's needs in terms of range and driving distance in different use cases. • Like conventional and battery electric vehicles, the fuel efficiency of FCEVs is higher in summer, and lower in winter, due to factors such as increased air and rolling resistance as the temperature decreases.

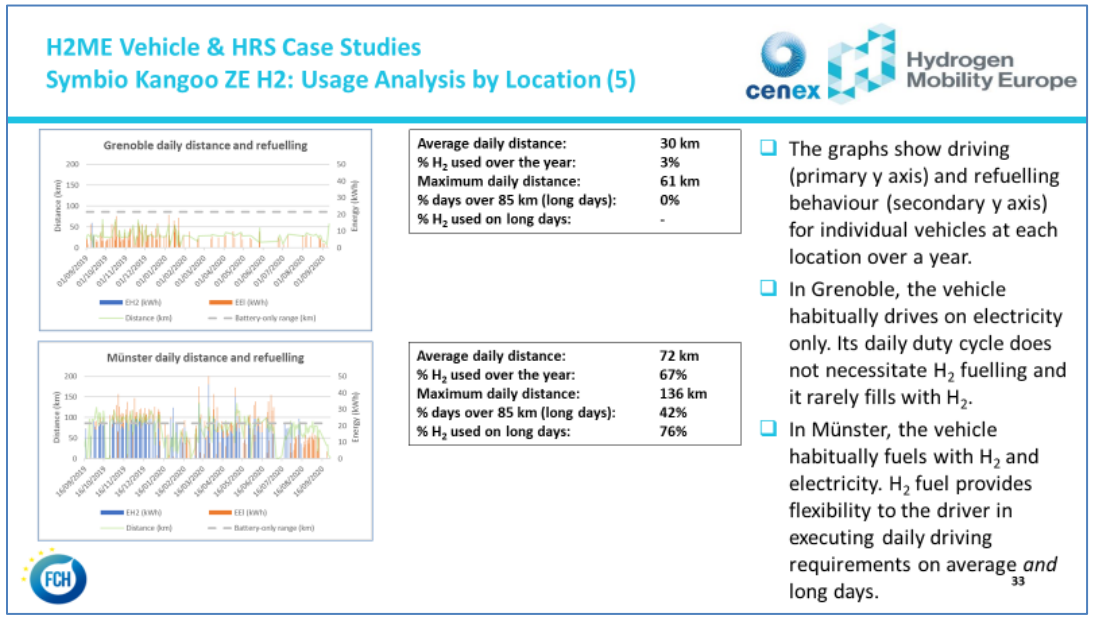


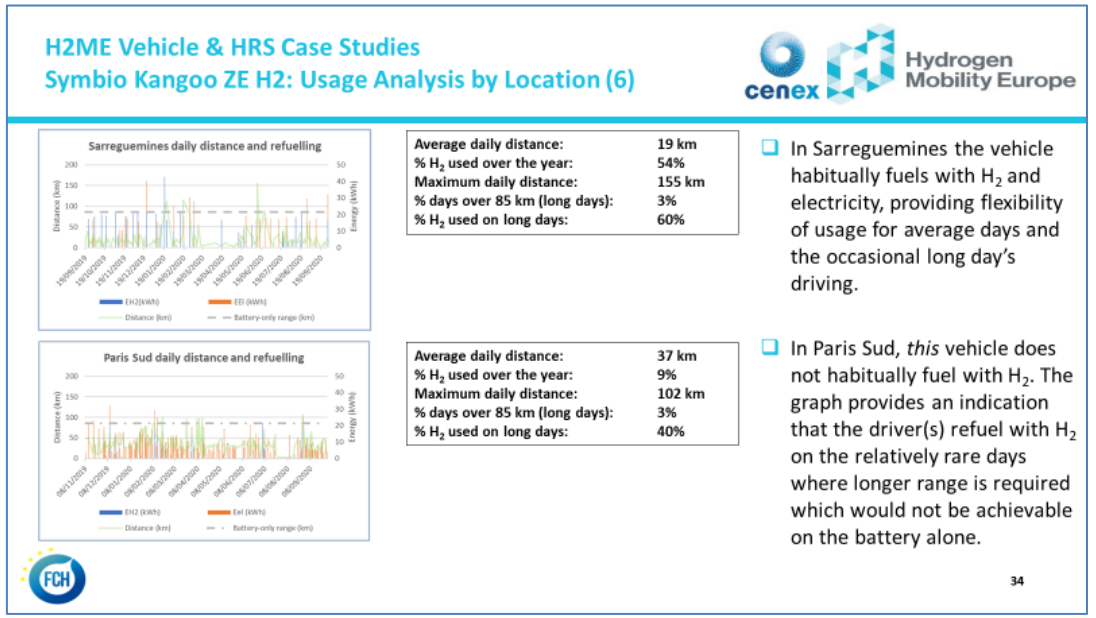


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (5)
Key Findings

Symbio Kangoo ZE H2	Dates deployed and use cases	Learnings
	2015- Fleet light vans in France, Germany and the UK	• FC REEV vans, which can be fuelled by hydrogen or electricity and have a range of up to 300km, are capable of fulfilling a driver's daily needs • The average H_2: electricity usage split varies by location and in some places is over 50%. HRS availability, local strategic priorities and vehicle management are key to maximising H_2 usage in a given deployment

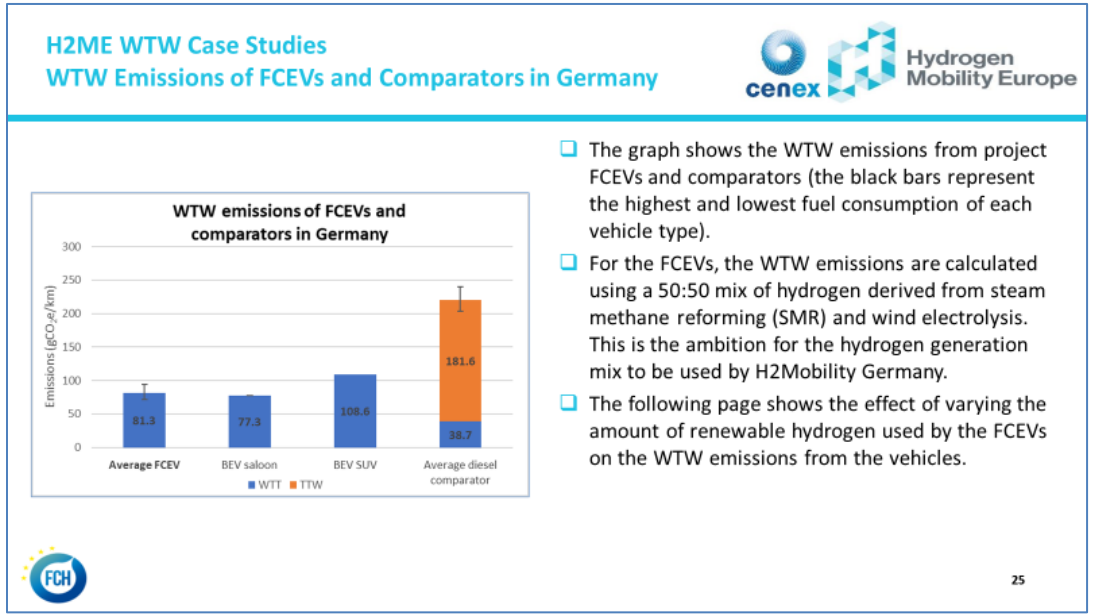


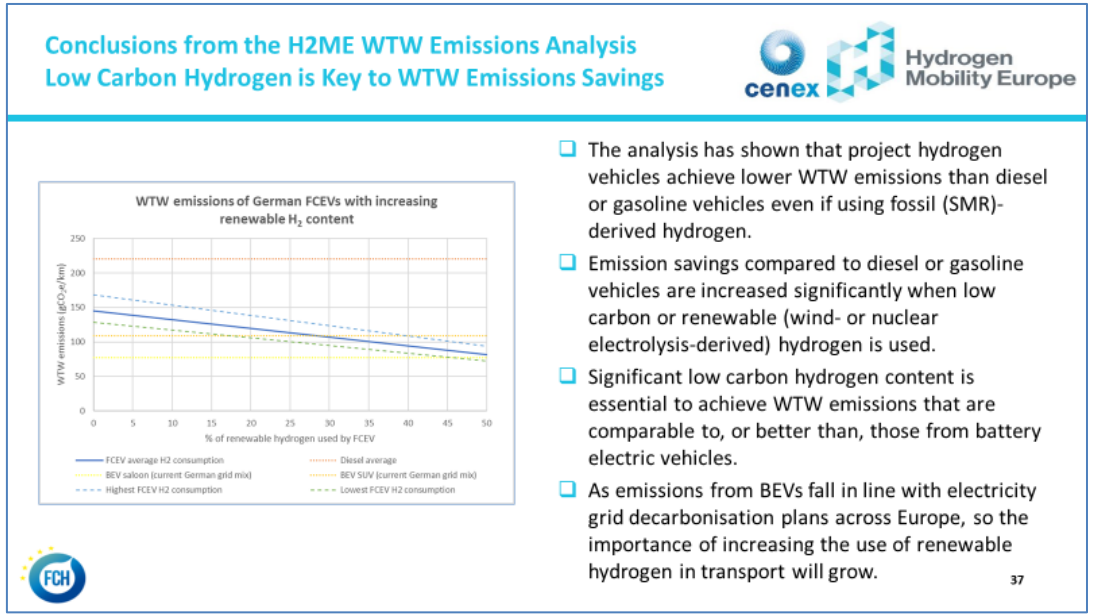


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (6)
Key Findings

All FCEVs	Dates deployed and themes	Learnings
	2015- Well-to-wheel (WTW) emissions	• Project FCEVs achieve lower WTW emissions than diesel equivalents. • Significant low or zero carbon hydrogen content is essential for FCEVs to achieve WTW emissions that are comparable to, or better than, those from battery electric vehicles.

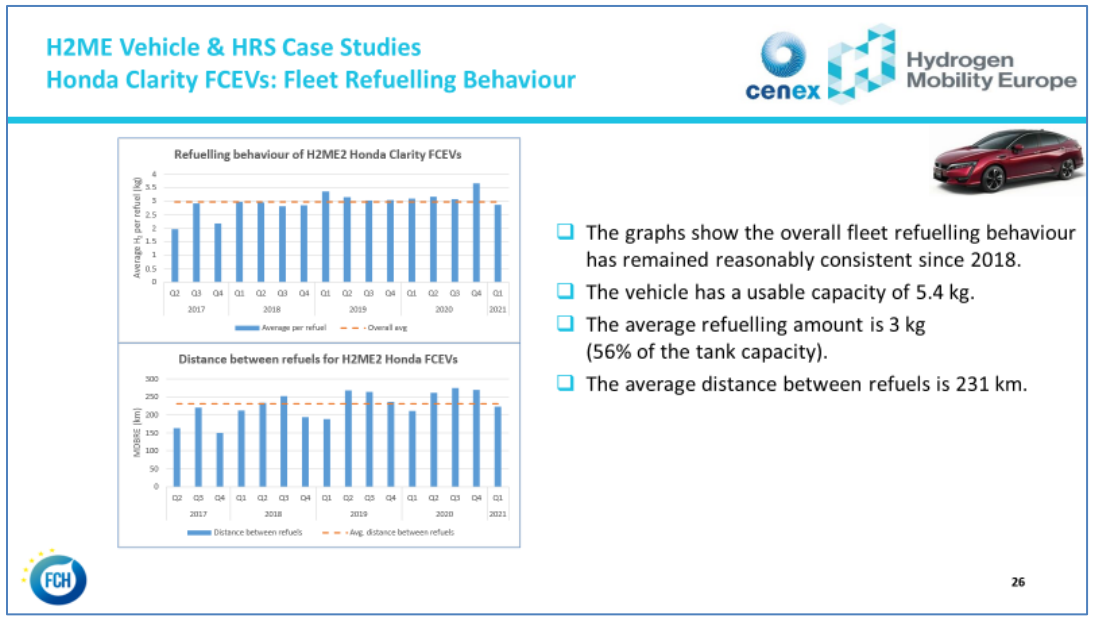


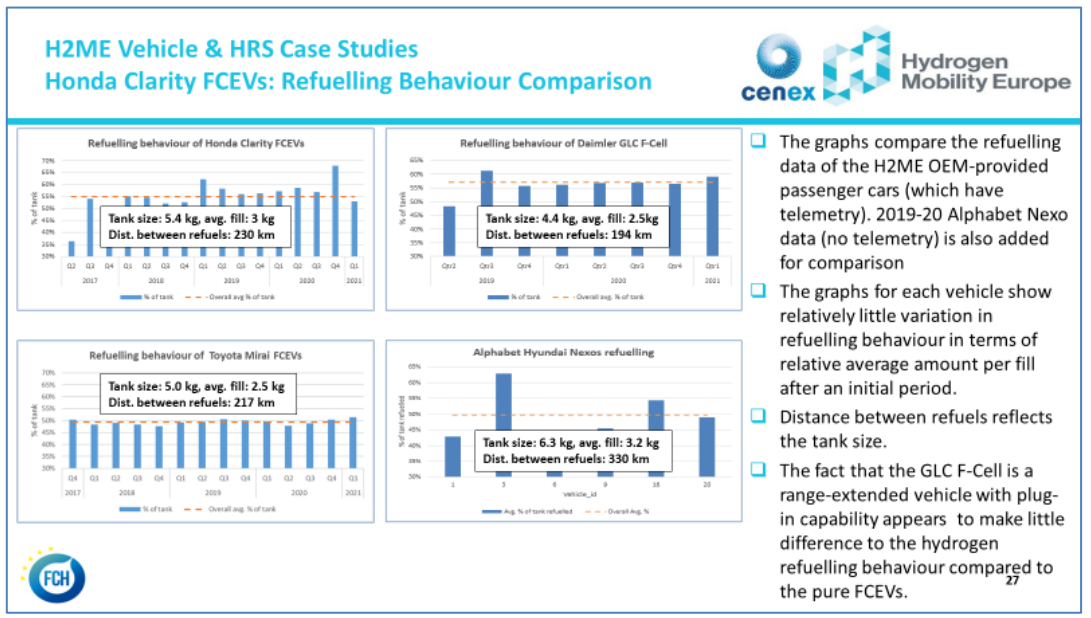


Source: *H2ME-1 Well to Wheels Report For H2ME Vehicles D4.19*
https://h2me.eu/wp-content/uploads/2020/11/H2ME-D4.19-Public-FV-Public-summary-Well-to-Wheels-%E2%80%A6.pdf

Executive Summary (7)
Key Findings

All FCEVs	Dates deployed and themes	Learnings
	2015- Refuelling	• After an initial period of user adjustment to the FCEV, the average fill stays relatively constant at between 50 and 57% of the tank capacity. • Average refuelling amount and distance between refuels increases as the vehicle H_2 tank size increases

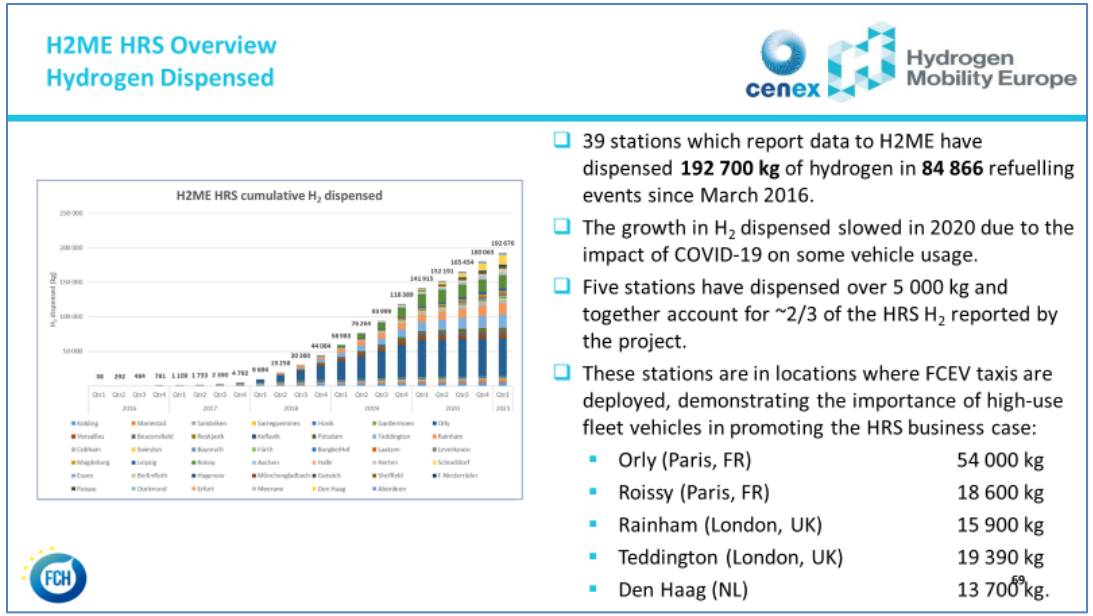


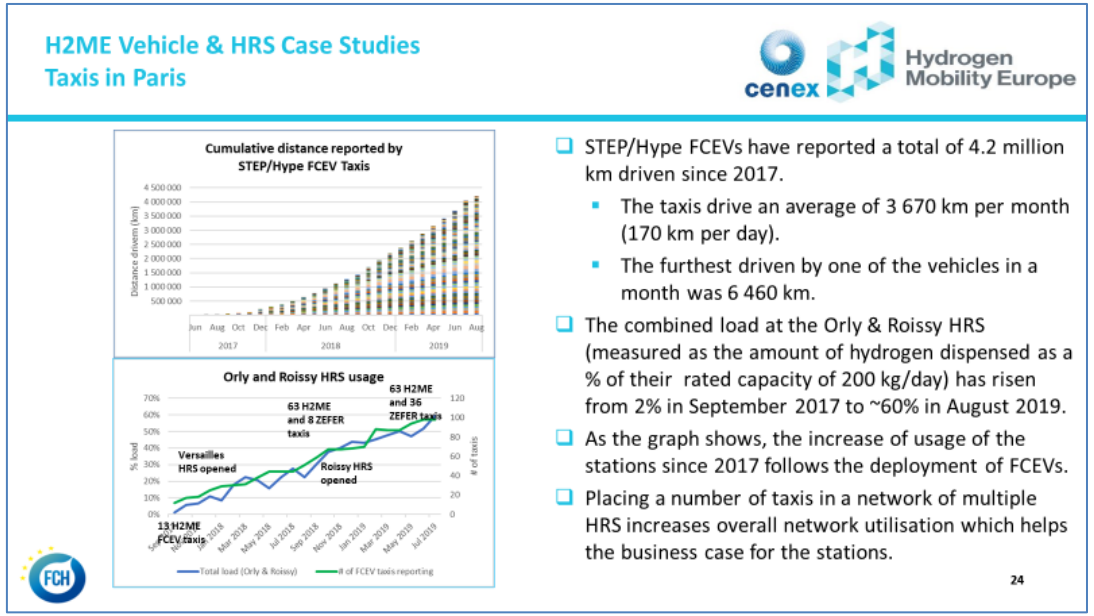


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (8)
Key Findings

All HRS	Dates deployed and themes	Learnings
	2015- Location and usage	• H2ME HRS from country-wide networks (e.g., Germany) and focused city-based deployments (e.g., Paris) exhibit differing levels of usage. • Over 60% of the project's H_2 is dispensed at five (13%) of the HRS. These HRS are in city locations where FCEV taxis are deployed, demonstrating the importance of high-use fleet vehicles in promoting the HRS business case.

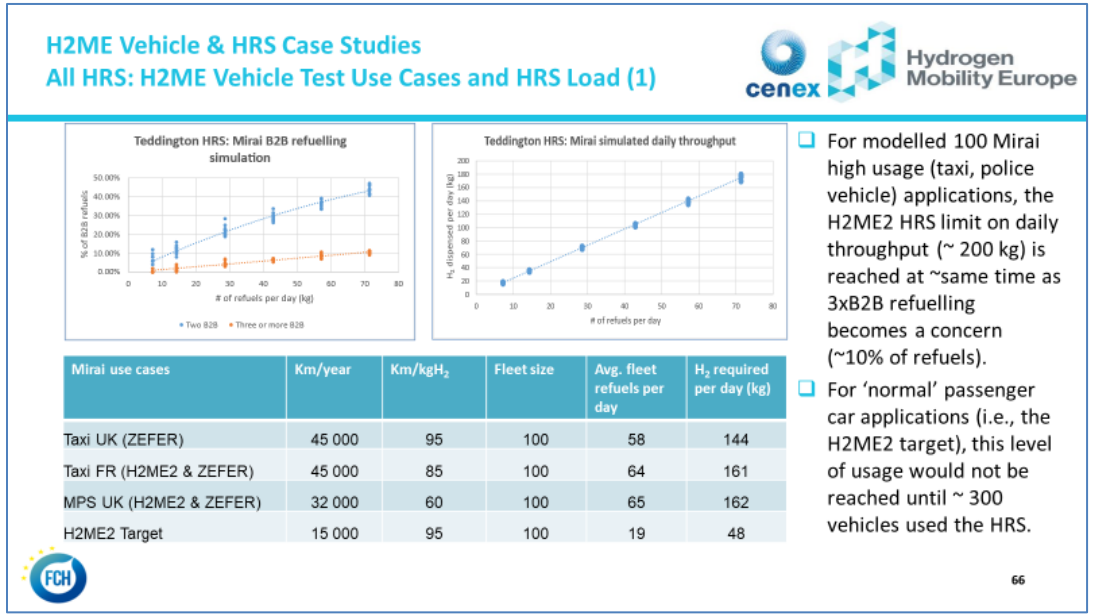




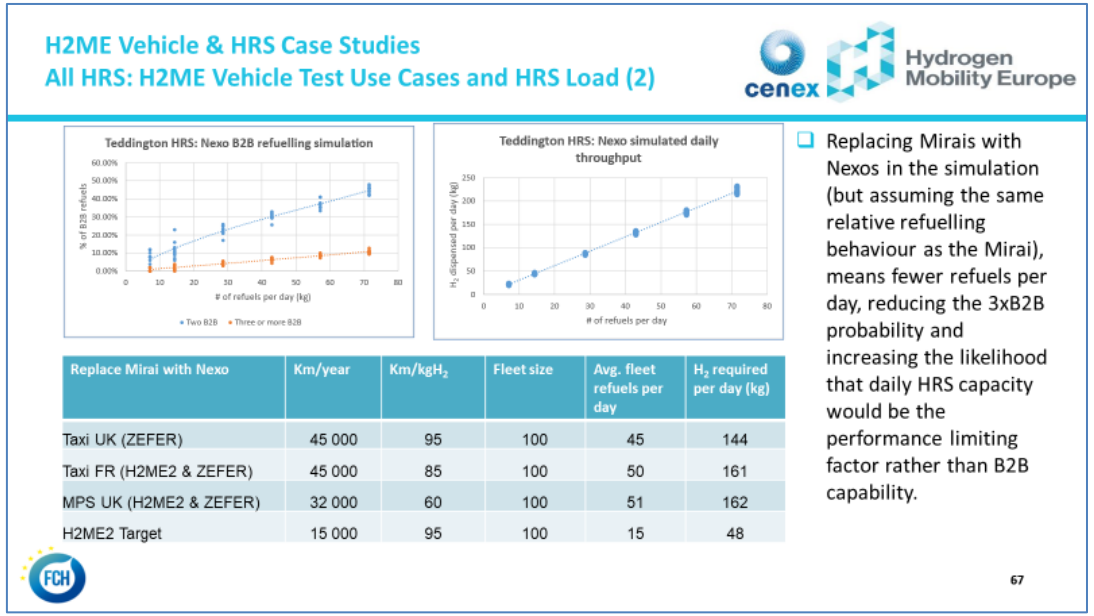
Sources: Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)
H2ME-1 Vehicle and Infrastructure Performance Report 3 (2015-2019),
https://h2me.eu/wp-content/uploads/2020/11/H2ME-D4.12-Public-FV-Public-yearly-technical-reports-%E2%80%A6.pdf

Executive Summary (9)
Key Findings

All HRS	Dates deployed and themes	Learnings
	2015- Back-to-back (B2B) refuelling	• Simulation of increasing HRS load based on real-world H2ME Mirai refuelling behaviour shows that the daily station throughput limit (typically 200kg/day) will be reached the same time that the probability of three B2B refuels reaches10%, a level which likely to cause issues at some HRS. • This usage is reached when 100 taxis or 300 cars use the station daily.



Mirai use cases	Km/year	Km/kgH_2	Fleet size	Avg. fleet refuels per day	H_2 required per day (kg)
Taxi UK (ZEFER)	45 000	95	100	58	144
Taxi FR (H2ME2 & ZEFER)	45 000	85	100	64	161
MPS UK (H2ME2 & ZEFER)	32 000	60	100	65	162
H2ME2 Target	15 000	95	100	19	48

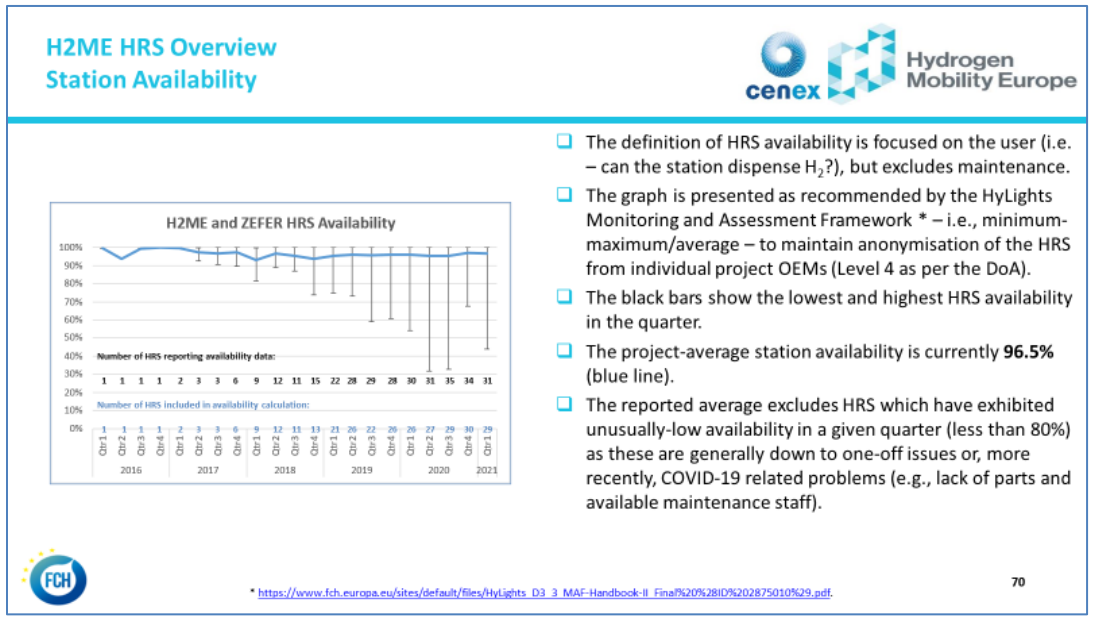


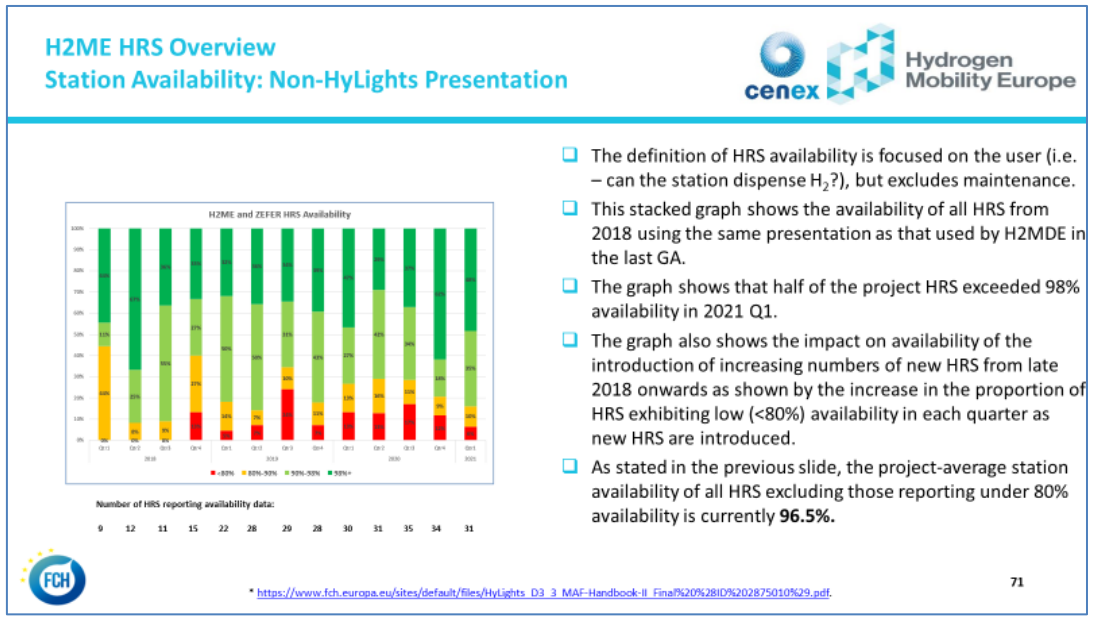
Replace Mirai with Nexo	Km/year	Km/kgH_2	Fleet size	Avg. fleet refuels per day	H_2 required per day (kg)
Taxi UK (ZEFER)	45 000	95	100	45	144
Taxi FR (H2ME2 & ZEFER)	45 000	85	100	50	161
MPS UK (H2ME2 & ZEFER)	32 000	60	100	51	162
H2ME2 Target	15 000	95	100	15	48

Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (10)
Key Findings

All HRS	Dates deployed and themes	Learnings
	2015- Availability	• The average availability for all H2ME and ZEFER HRS (excluding HRS undergoing maintenance and long-term issues) was 96.5% in Q1 of 2021. • Almost half (48%) of the HRS exceeded the H2ME-2 availability target of 98% in Q1 of 2021.

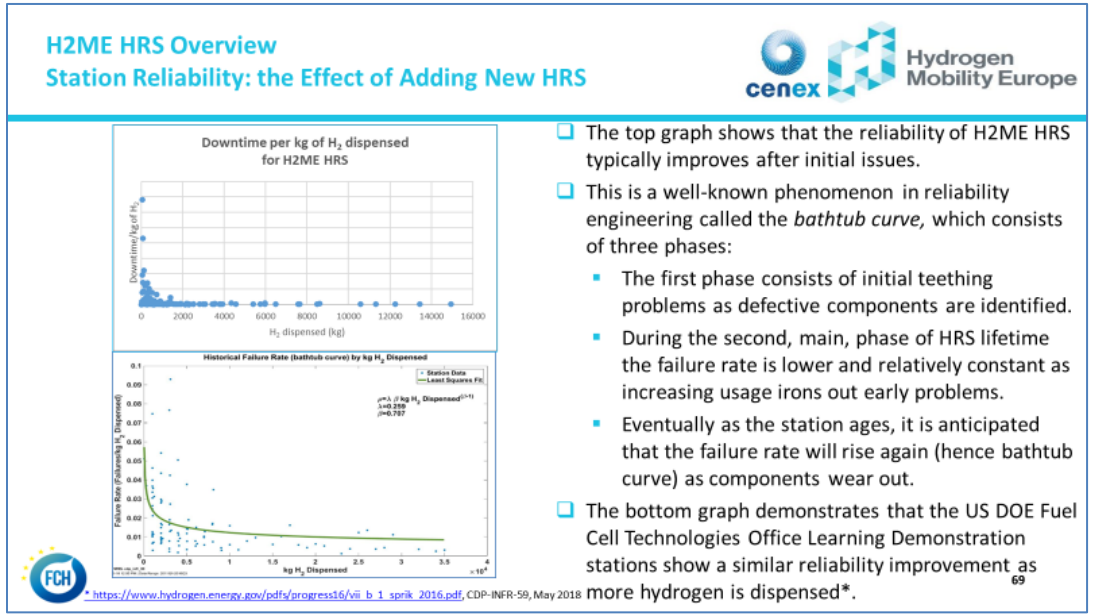


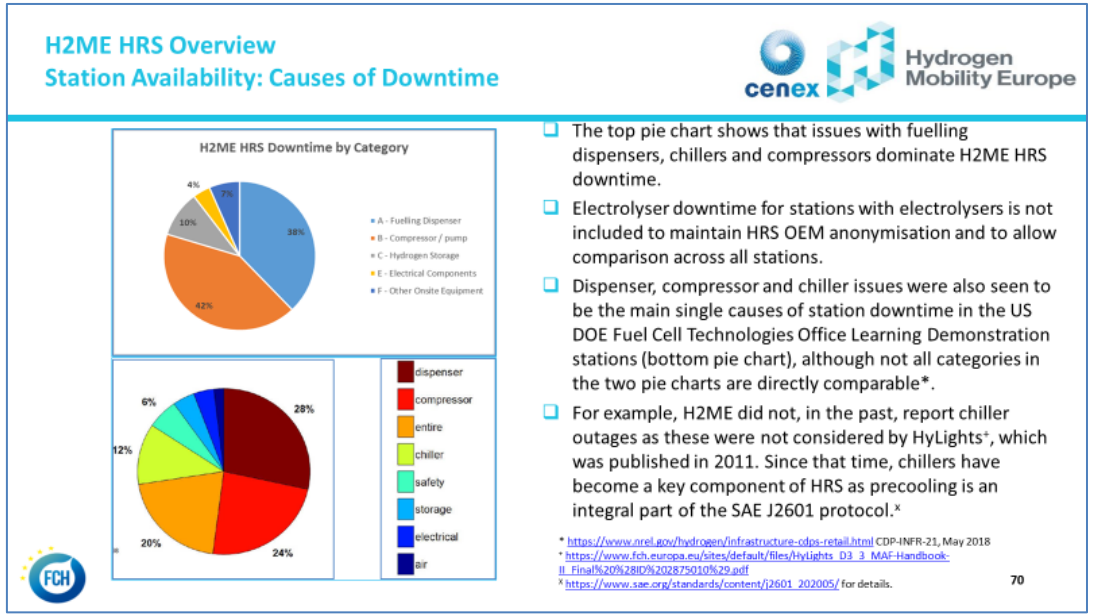


Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (11)
Key Findings

All HRS	Dates deployed and themes	Learnings
	2015- Reliability	• Reliability of project HRS improves and reaches a steady-state after initial teething problems, a well-known phenomenon called the *bathtub curve*. • Dispenser, compressor & chiller issues are the main causes of station downtime, as found in other large-scale demonstration projects.





Source: *H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021)* (this report)

Executive Summary (11)
Vehicle and HRS Operation by Numbers

- To the end of May 2021, H2ME FCEVs and FC REEVs reported almost **17.2 million km** driven.
- The distance reported by the project has increased significantly since late 2017 due to deployments with high-utilisation use cases, particularly taxis. For example, the STEP taxis in France have recorded over 4 300 000 km driven in H2ME since Q2 2017.
- To the end of May 2021, the 39 HRS reporting data to H2ME dispensed almost **193 000 kg** of hydrogen over **84 500** refuelling events. Five HRS in locations where FCEV taxis are deployed accounted for over 2/3 of the hydrogen dispensed the importance of high-use fleet vehicles in promoting the HRS business case.
- Vehicle and HRS utilisation is increasing after a significant slowdown in the first half of 2020 which was due to the impact of COVID-19 on some vehicle (particularly taxi) usage.
- FCEV refuelling patterns show that vehicles average 50-57% of the tank capacity per refuel. The distance between refuels is between ~200-230km, depending on the vehicle model and tank size.
- Early results for the Hyundai Nexo shows an average amount per refuel of over 3.2 kg (~50% of tank capacity) and a distance between refuels of over 300km, reflecting the larger size (6.3 kg) of the Nexo's hydrogen tanks compared to that of other project FCEVs (~5 kg).
- The project-average vehicle fuel efficiency is **84 km/kgH_2 (1.25 kgH_2/100 km)**.

Executive Summary (12)
Vehicle & HRS Availability, Reliability & Safety

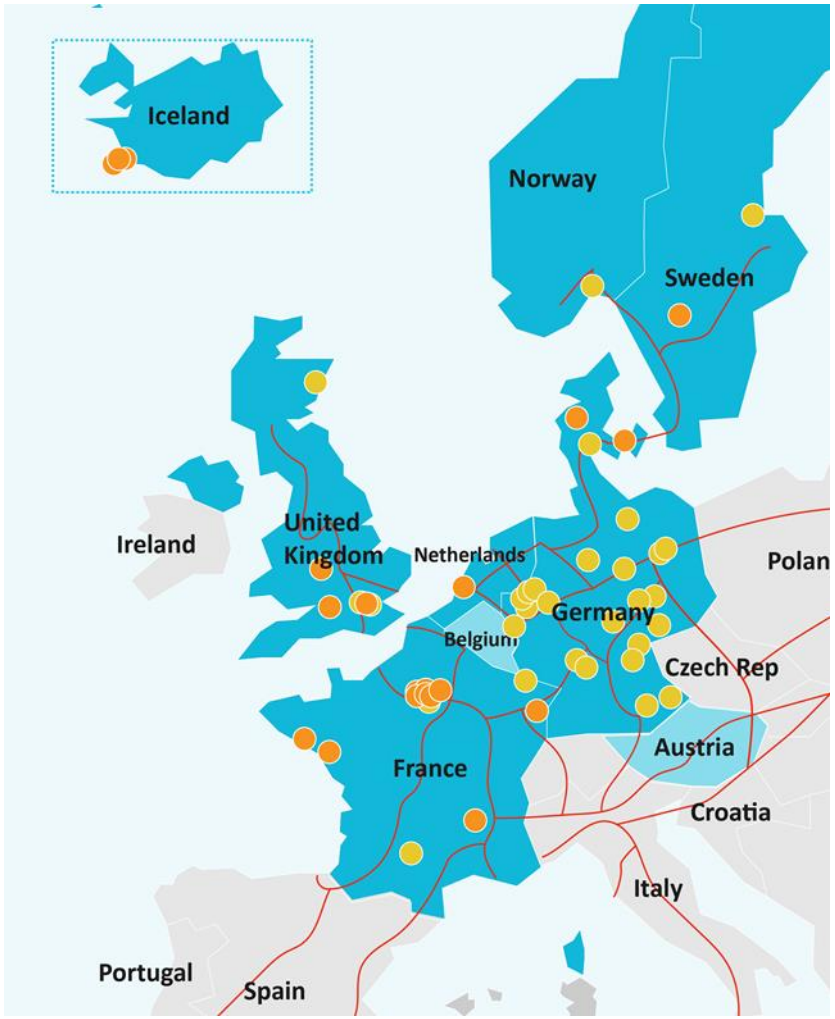
- The FCEVs have been deployed with working fleets in a variety of roles, including as taxis and police vehicles, as well as with private customers.
- In general, the FCEVs have been integrated into fleets with minimal disruption and are used in the same ways (in terms of distance travelled per day, etc.) as conventionally-fuelled vehicles.
- The FCEVs are serviced regularly; for example, the Toyota Mirais that are used as taxis in London and Paris are serviced every 10 000 km in France, and every 10 000 miles in the UK.
- The FCEVs have proven to be reliable (> 99% availability overall).
- The taxis and other vehicles have experienced a small amount of off-road time associated with normal use (minor impacts and tyre replacements). **None of the incidents involved any release of hydrogen or problems with the fuel cell system.**
- The reliability of project hydrogen refuelling stations typically improves and reaches a steady-state after initial teething problems. This is a well-known phenomenon in reliability engineering called the *bathtub curve*.
- The average availability for all HRS reporting data to H2ME, excluding maintenance and one-off issues, is currently **96.5%**. Dispenser, compressor & chiller issues are the main causes of station downtime, which confirms the findings of other large-scale hydrogen demonstration projects.
- **There have been no vehicle or HRS safety issues reported to Cenex.**

Contents

H2ME Initiative (2015 - 2022)
Project Overview

- Hydrogen Mobility Europe (H2ME, https://h2me.eu/, 2015-2022) is the largest passenger and light duty hydrogen vehicle and hydrogen refuelling station (HRS) demonstration initiative co-funded by the Fuel Cells and Hydrogen Joint Initiative (FCH2 JU).
- Supported by €67m of FCH2JU funding, the €170m H2ME project aims to deploy more than 1 400 vehicles and 49 HRS in eight countries by 2022.
- H2ME is formed of the two separate FCH JU-co-sponsored projects, as summarised in the slide overleaf:
  - **H2ME-1** (2015-2020), which has deployed 300 fuel cell electric vehicles (FCEVs) and fuel cell range-extended electric vehicles (FC REEVs) and aims to deploy 29 hydrogen refuelling stations (HRS).
  - **H2ME-2** (2016-2023), which aims to deploy 1,100 FCEVs and FC REEVs and 20 HRS.
- This report summarises the comprehensive body of data accumulated on hydrogen vehicle and HRS performance by H2ME from 2015 to the end of September 2020 (the end of data collection for H2ME-1):
  - **330** fuel cell electric vehicles (FCEVs) made by Daimler, Honda, Hyundai and Toyota.
  - **233** fuel cell range-extended electric vehicles (FC REEVs) from Symbio FC.
  - **39** hydrogen refuelling stations (HRS) supplied by Air Liquide, ITM Power, Linde (including its subsidiaries AGA and BOC), McPhy, Nel Hydrogen Fueling and Resato.

H2ME Initiative (2015 - 2022)
Project Overview



HRS locations under H2ME-1
Illustrative HRS locations under H2ME-2

New hydrogen refuelling stations:

- **20** - 700bar HRS in Germany
- **11** - 350bar and 700bar HRS in France
- **11** - 700bar HRS in Scandinavia
- **6** – 350bar and 700bar HRS in the UK
- **1** - 700bar HRS in NL

Fuel cell vehicles:

- **500** OEM (Original Equipment Manufacturer) FCEVs
- **900** fuel cell FC REEV vans

Hydrogen rollout areas:

- Scandinavia, Germany, France, UK, The Netherlands

Observer coalitions:

- Belgium, Luxembourg, and Italy

Industry observer partners:

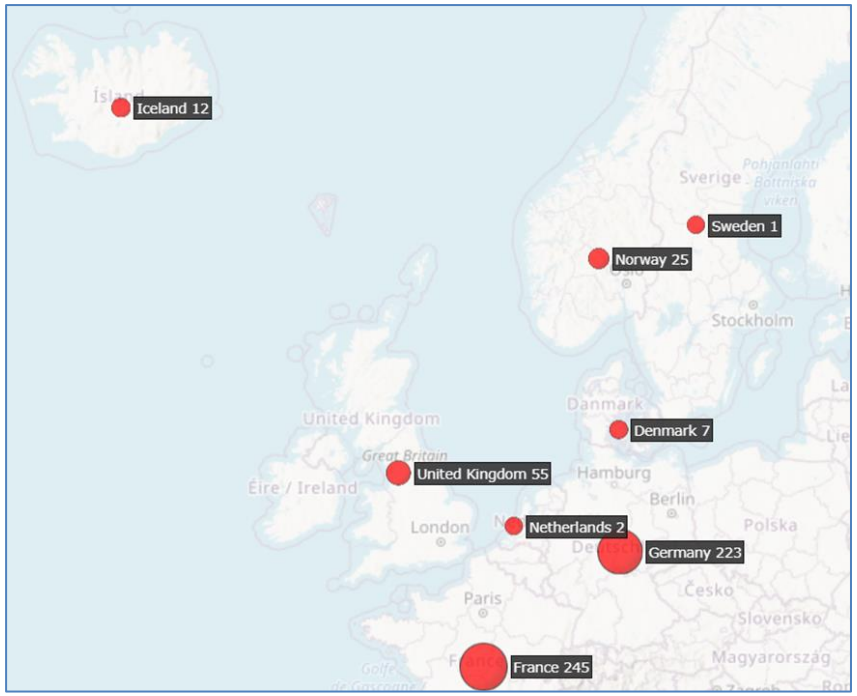
- Audi, BMW, Nissan, Renault, Renault Trucks, AGA, OMV

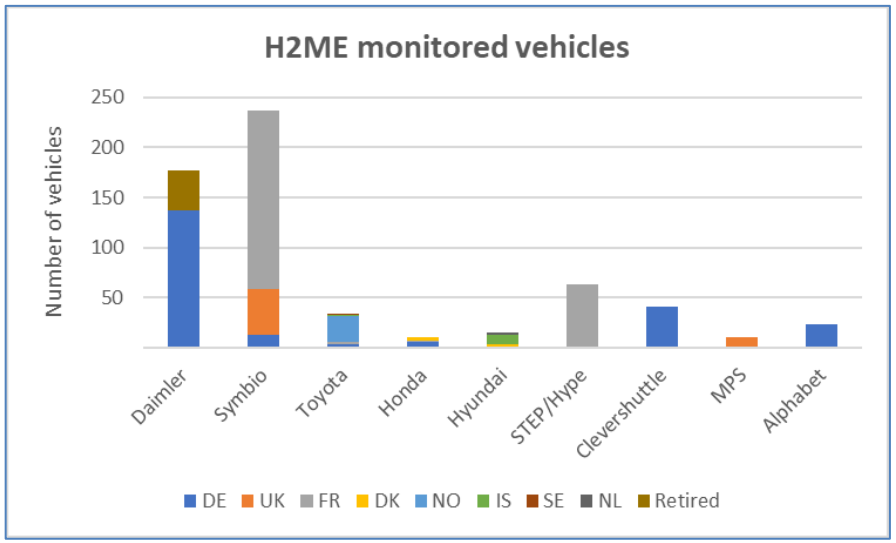
Contents

H2ME Project Overview
Vehicles Reporting Data to H2ME

	Daimler B-Class F-CELL FCEV	Daimler GLC F-CELL FCEV/PHEV	Honda Clarity FCEV	Hyundai ix35 FCEV	Hyundai Nexo FCEV	Toyota Mirai FCEV	Symbio ZE H2 FC REEV
							
Project and dates reporting data	H2ME-1 2015-2018 (retired)	H2ME-1 & 2 2019-	H2ME-2 2017-	H2ME-2 2017-	H2ME-2 2019-	H2ME-1 & 2 2017-	H2ME-1 & 2 2015-
H2ME use-cases	Passenger and fleet car	Passenger and fleet car	Passenger and fleet car	Passenger and fleet car, taxi	Passenger and fleet car	Passenger and fleet car, police car, taxi	Light van in company fleets
NEDC range	380 km	478 km	650 km	590 km	756 km	605 km	300 km
H_2 tank capacity and pressure	3.7 kg (700 bar)	4.4 kg (700 bar)	5.5 kg (700 bar)	5.6 kg (700 bar)	6.3 kg (700 bar)	5.0 kg (700 bar)	1.8 kg (350 bar version)
Battery capacity	1.4 kWh	13.5 kWh (9.3kWh usable)	1.7 kWh	0.95 kWh	1.6 kWh	1.6 kWh	22 kWh

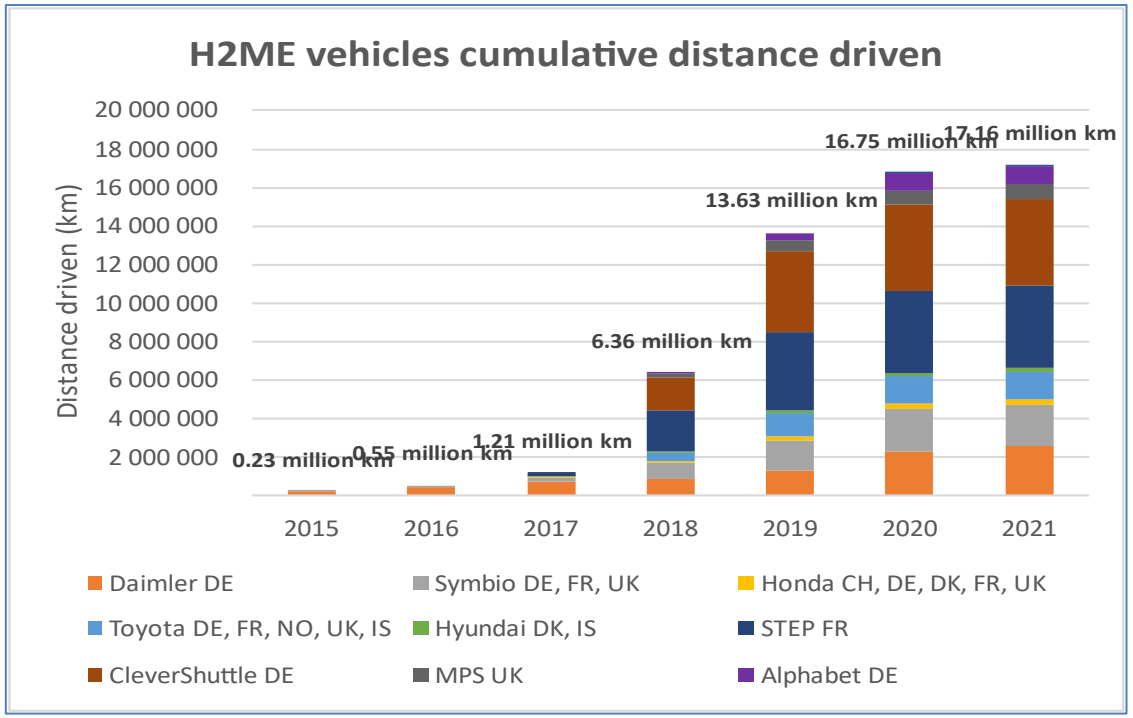
H2ME Vehicle Overview
Vehicles Reporting Data





- This presentation contains data on 373 FCEVs and 237 FC REEVs operating in eight countries.

H2ME Vehicle Overview
Distance Reported



- The total distance reported by vehicles monitored by H2ME from Q3 2015 to Q1 2021 was **17 160 000 km** (not all data yet in).
- There has been a significant increase in the distance driven since late 2017 due to deployments with end-users including:
  - STEP taxis in France which have recorded 4 300 000 km driven in H2ME since 2017 (plus a further 1 740 000 km in ZEFER)
  - CleverShuttle vehicles in Germany which have reported 4 400 000 km driven since 2018.
- The growth in distance driven slowed in mid-2020 due to the impact of COVID-19 on some vehicle (particularly taxi) usage, but is now beginning to increase again.

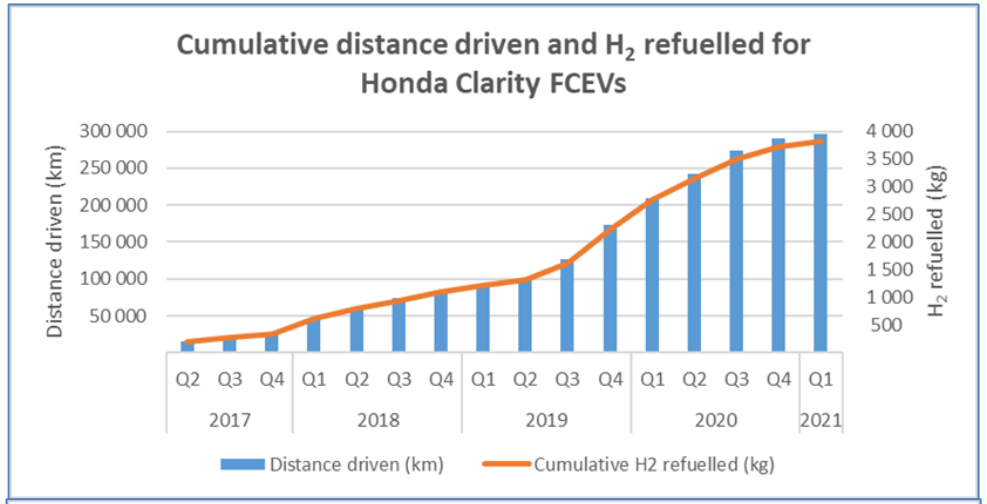
Contents

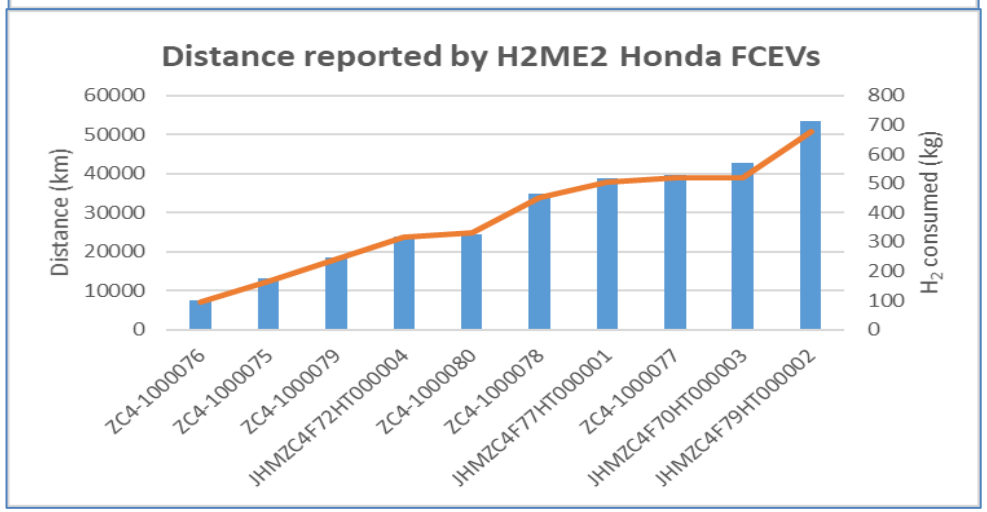
- Introduction to H2ME
- Summary of vehicle results
- Case studies of FCEV operation during H2ME-2:
  - **Honda Clarity FCEVs in Denmark, Germany and Switzerland**
  - Symbio FC REEV operation in France, Germany and the UK: electricity and hydrogen usage and refuelling
- FCEV efficiency, safety and reliability
- HRS performance with increasing levels of utilisation
- Summary of HRS results
- Summary results by project

H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Where Vehicles Operate

- Honda Motor Europe deployed ten vehicles which began reporting data to H2ME-2 in 2017.
  - 4 left hand drive (LHD) vehicles were funded and deployed specifically for H2ME-2.
  - 6 right hand drive (RHD) vehicles were transferred from HyFive and are not H2ME-2 funded.
- The initial locations of the vehicles are shown in the top map. The vehicles have since moved around to maximise their usage. In May 2021 there were:
  - 3 customers in Denmark
  - 1 customer in Switzerland
  - 5 vehicles in Germany
  - 1 RHD Clarity was not in operation.

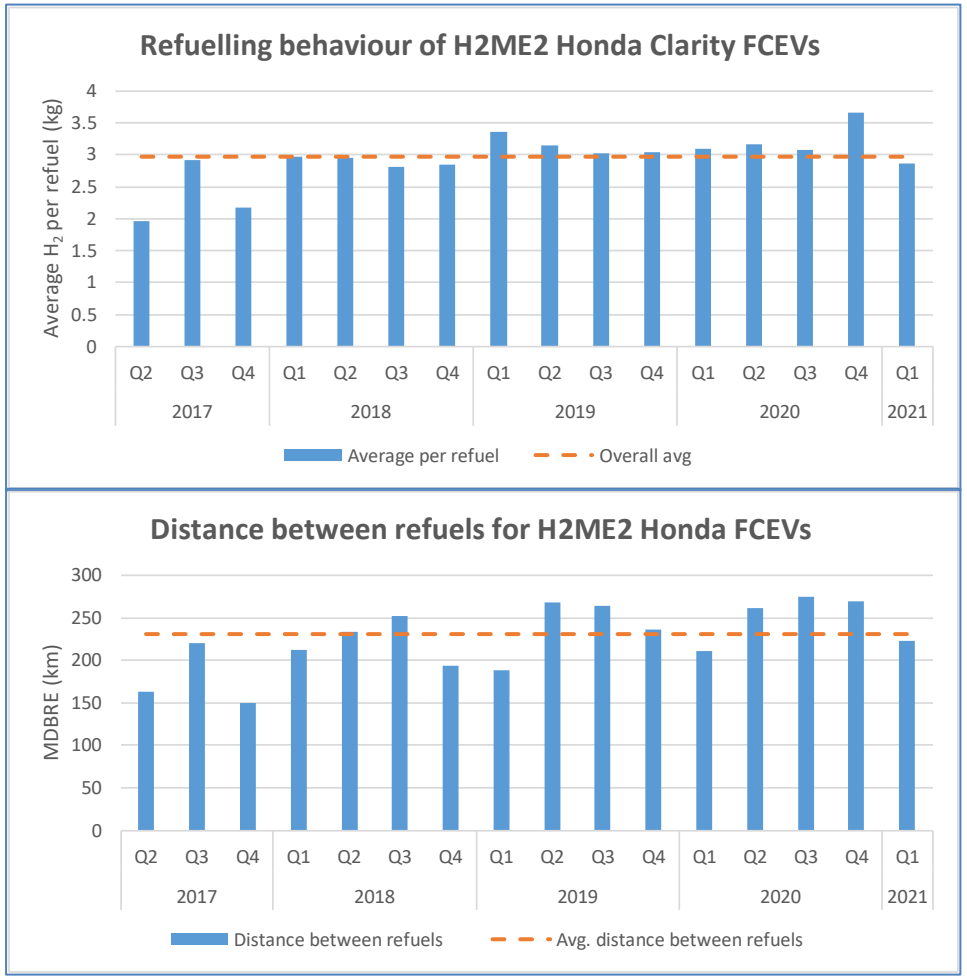
H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Distance Driven and H_2 Refuelled





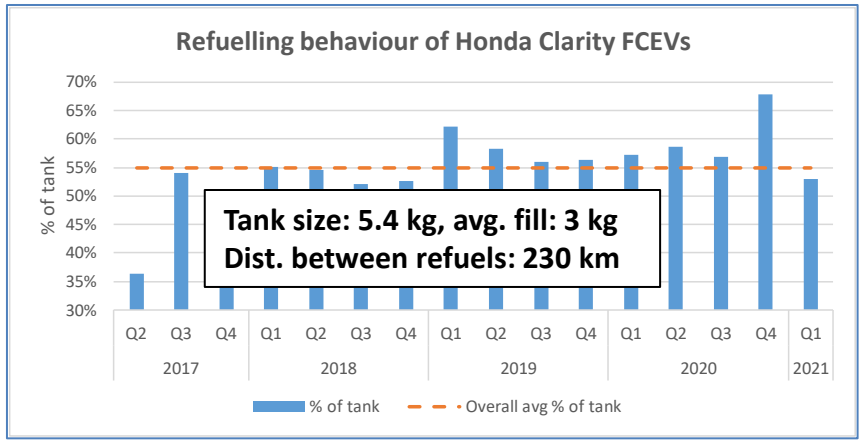
- Detailed daily summary data (distance, speed, H_2 consumed, refuels) is provided by Honda for all ten vehicles from their own telemetry fitted to the vehicles.
- Total distance reported by the ten Honda Clarity vehicles subject to detailed monitoring in H2ME2 is 297 000 km.
- H_2 consumed by the vehicles is 3 818 kg.

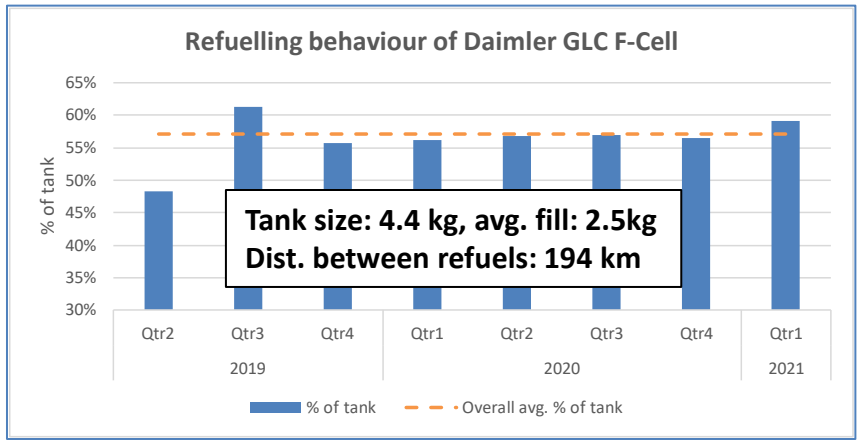
H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Fleet Refuelling Behaviour

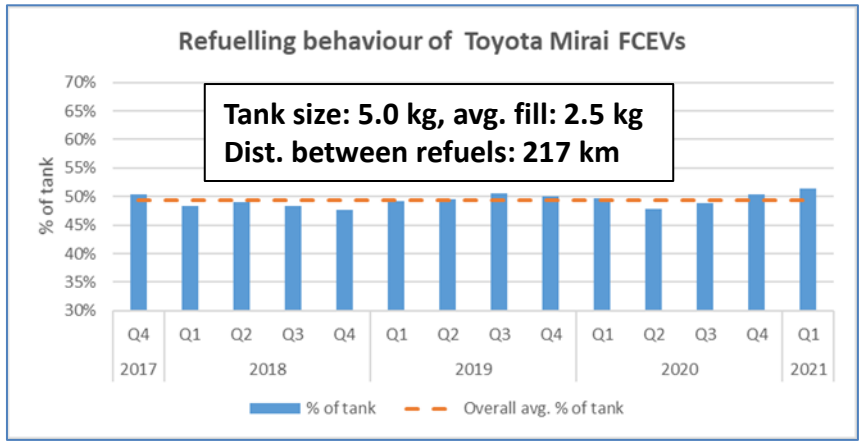


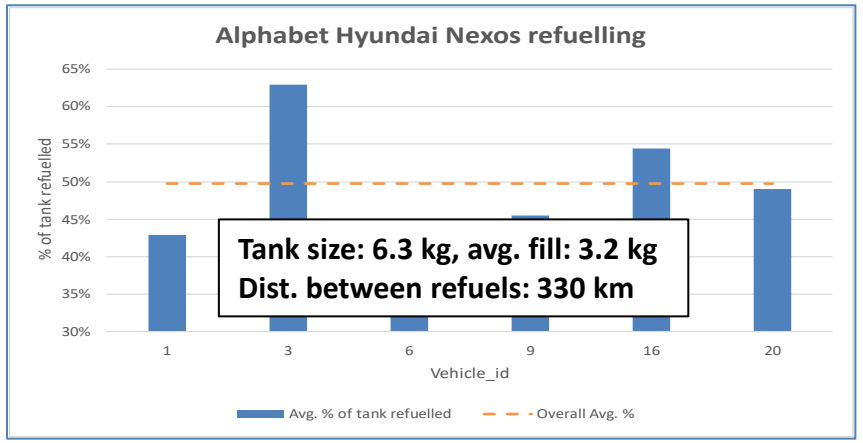
- The graphs show the overall fleet refuelling behaviour has remained reasonably consistent since 2018.
- The vehicle has a usable capacity of 5.4 kg.
- The average refuelling amount is 3 kg (56% of the tank capacity).
- The average distance between refuels is 231 km.

H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Refuelling Behaviour Comparison



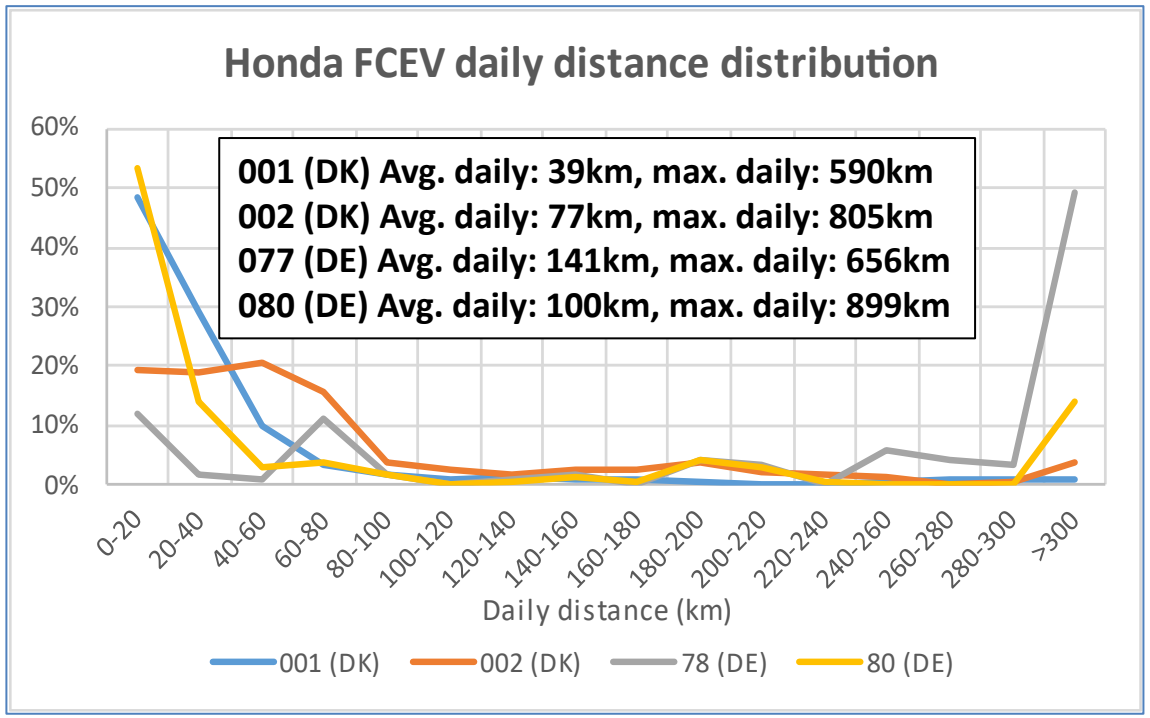






- The graphs compare the refuelling data of the H2ME OEM-provided passenger cars (which have telemetry). 2019-20 Alphabet Nexo data (no telemetry) is also added for comparison
- The graphs for each vehicle show relatively little variation in refuelling behaviour in terms of relative average amount per fill after an initial period.
- Distance between refuels reflects the tank size.
- The fact that the GLC F-Cell is a range-extended vehicle with plug-in capability appears to make little difference to the hydrogen refuelling behaviour compared to the pure FCEVs.

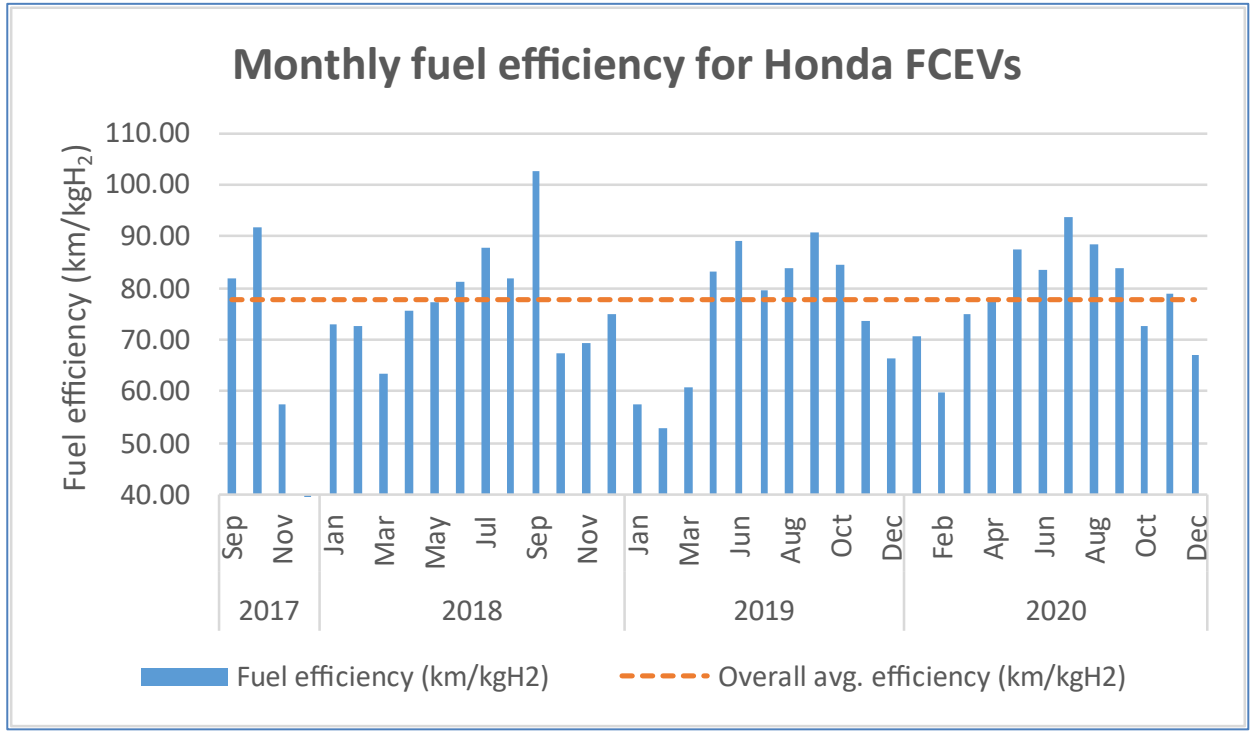
H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Daily Distance Driven by Individual Vehicles



- This graph shows the annual distance distribution for four H2ME Clarity FCEVs.
- The vehicles exhibit different behaviours – for example,
  - Vehicle 001 driven by a blogger in Denmark drives relatively short distances each day, covering an annual distance of around 9 000 km per year.
  - By contract, vehicle 80 in Germany driven by a fleet user covers longer distances each day with an annual usage of around 25 000 km.
- Despite the different behaviours, in all countries and use cases, the Clarity has proven operationally that it is comfortably capable of fulfilling the driver's daily and annual needs.*
- The fuel efficiency of the four Clarity FCEVs in these different use cases is discussed in more detail in the next slides.

* Data on country-average driving distances per year:
EU ~ 12 000km/year https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html
DE ~ 14 000km/year http://www.diw.de/documents/publikationen/73/diw_01.c.44461.de/dp602.pdf
DK ~ 14 000 km/year https://www.dst.dk/Site/Dst/Udgivelser/GetPubFile.aspx?id=16251&sid=13tra

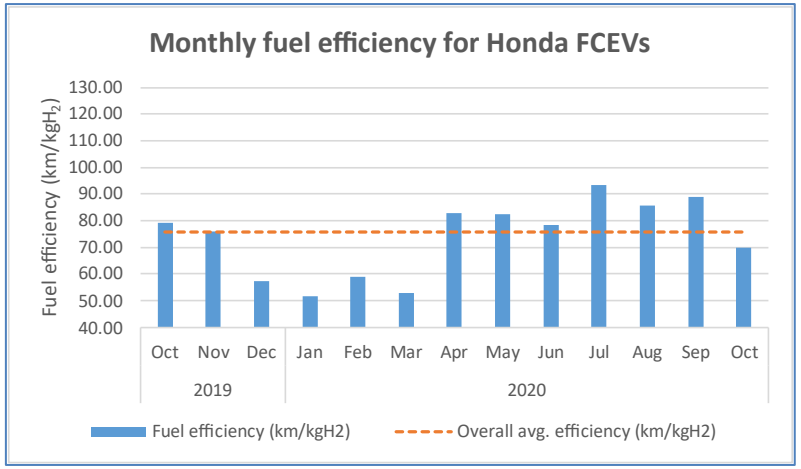
H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Overall Fleet Fuel Efficiency



All vehicles	
Avg. FE in period:	**77.7 km/kgH_2**
Avg. speed:	**47 km/h**
Avg. max. speed:	**92 km/h**
Max. max. speed:	**166 km/h (limited)**

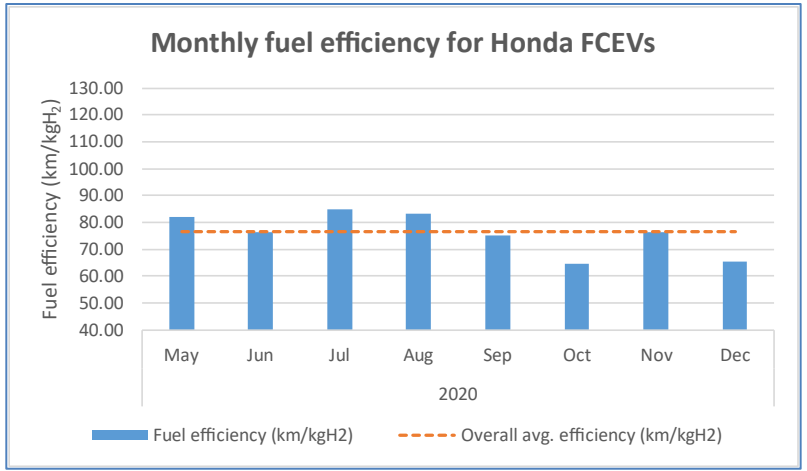
- The graph shows that fuel efficiency of the vehicles varies each month (all 2021 and some monthly data omitted due to relatively low distance driven).
- Generally, temperature has a negative correlation with vehicle energy consumption (the same applies to conventionally-fuelled vehicles) due to factors including:
  - Reduced battery and mechanical efficiency
  - Greater use of on board cabin heating during the winter
  - Increased rolling & wind resistance.
- The overall average fuel efficiency is 77.7 km/kgH_2.

H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Individual Vehicle Fuel Efficiency (1)



RHD vehicle 077

User:	**Germany west corridor**
FE in period:	**75.9 km/kgH_2**
Avg. speed (est.):	**67 km/h**
Avg. max. speed:	**127 km/h**
Max. max. speed:	**166 km/h**
Avg. distance per day:	**141 km**
Avg. # of trips per day:	**5**
# of refuels:	**137**



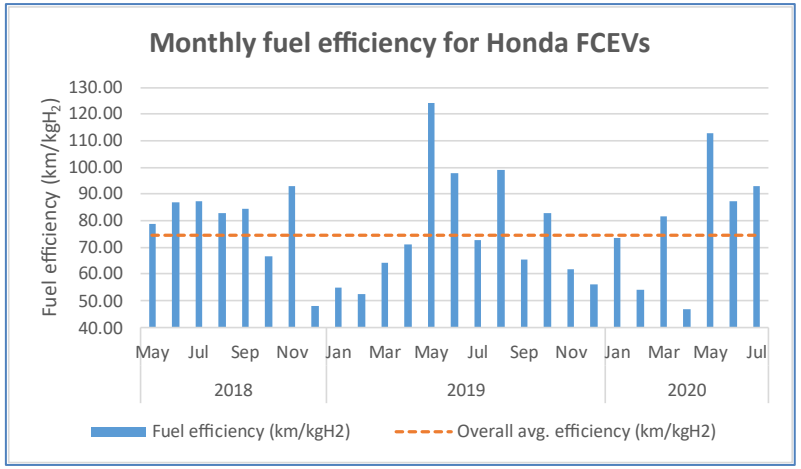
RHD vehicle 080

User:	**Germany east corridor**
Avg. FE in period:	**76.4 km/kgH_2**
Avg. speed (est.):	**63 km/h**
Avg. max speed:	**89 km/h**
Max. max. speed:	**166 km/h**
Avg. distance per day:	**100 km**
Avg. # of trips per day:	**4**
# of refuels:	**73**

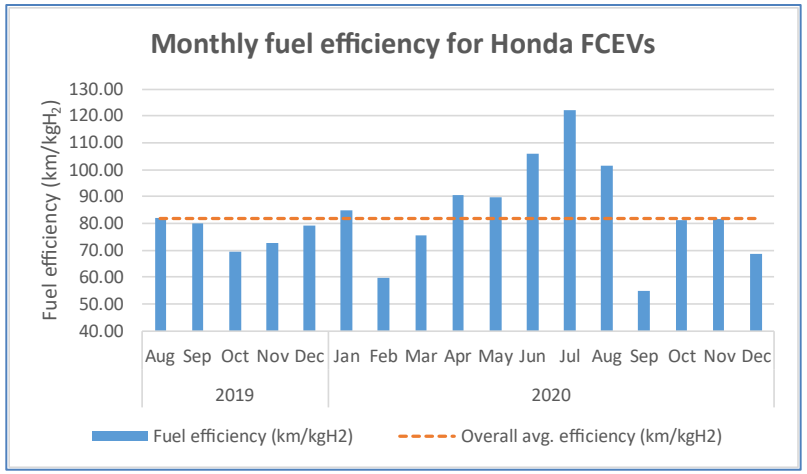
- The Honda FCEVs in Germany exhibit relatively high avg. speeds compared to other H2ME vehicles.
- Therefore, the effect of speed on the fuel efficiency (FE) of individual vehicles* was investigated (data shown for months where the vehicles drove > 500km).
- Findings, for German vehicles :
  - Average FEs fall within relatively narrow range.
  - Driving style statistics available from daily summary data don't give enough insight to determine the origin of relatively subtle FE differences.

* FCEV fuel consumption is typically quoted as kg of hydrogen used per 100 km (kg/100 km), which gives *lower* values for more efficient vehicles. In this report fuel efficiency is shown as the number of kilometres driven per kg of hydrogen (km/kg) in order to display graphically *higher* values *for more efficient driving*.

H2ME Vehicle & HRS Case Studies
Honda Clarity FCEVs: Individual Vehicle Fuel Efficiency (2)



LHD vehicle 001	
User:	Blogger in DK
Avg. FE in period:	74.6 km/kgH_2
Avg. speed (est.):	34 km/h
Avg. max speed:	88 km/h
Max. max. speed:	165 km/h
Avg. distance per day:	39 km
Avg. # of trips per day:	5
# of refuels:	127



LHD vehicle 002	
User:	Fleet user in DK
Avg. FE in period:	81.8 km/kgH_2
Avg. speed (est.):	52 km/h
Avg. max speed:	102 km/h
Max. max. speed:	165 km/h
Avg. distance per day:	77 km
Avg. # of trips per day:	5
# of refuels:	122

- The more extensive dataset for vehicles in Denmark shows more monthly variation in FE compared to the German vehicles shown on the previous slide.
- However, again on an average/max speed level, the data and this analysis does not reveal why there is an ~ 10% difference in overall FE between the two vehicles.

H2ME Vehicle & HRS Case Studies
FCEVs: Fuel Efficiency

Country			
Vehicle role	Taxi	Passenger car	Police IRV
Fuel efficiency	++		--
Max. speed			--
Avg. speed			
% time idling	-	+	--
Avg. dist. per trip	+		-
Comments	Eco driving		Aggressive driving
	High idling	Low idling	High idling
	Longer trips		Short trips
Key:	+ factors improving fuel economy, - factors worsening fuel economy		

- For comparison, data presented in a previous report for Toyota Mirai FCEVs shows that different use cases and driving styles unlock significant FE differences such as the examples shown for vehicles in Germany and the UK.*
- The next steps of this Honda analysis will be a detailed analysis of acceleration etc. for individual vehicles using granular trip-based telemetry data provided by Honda to see if any further insight into FE can be uncovered.
- This will be reported in a subsequent version of this report.

* Source: *H2ME-1 Vehicle and Infrastructure Performance Report 5 (2015-2020)*

Contents

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2

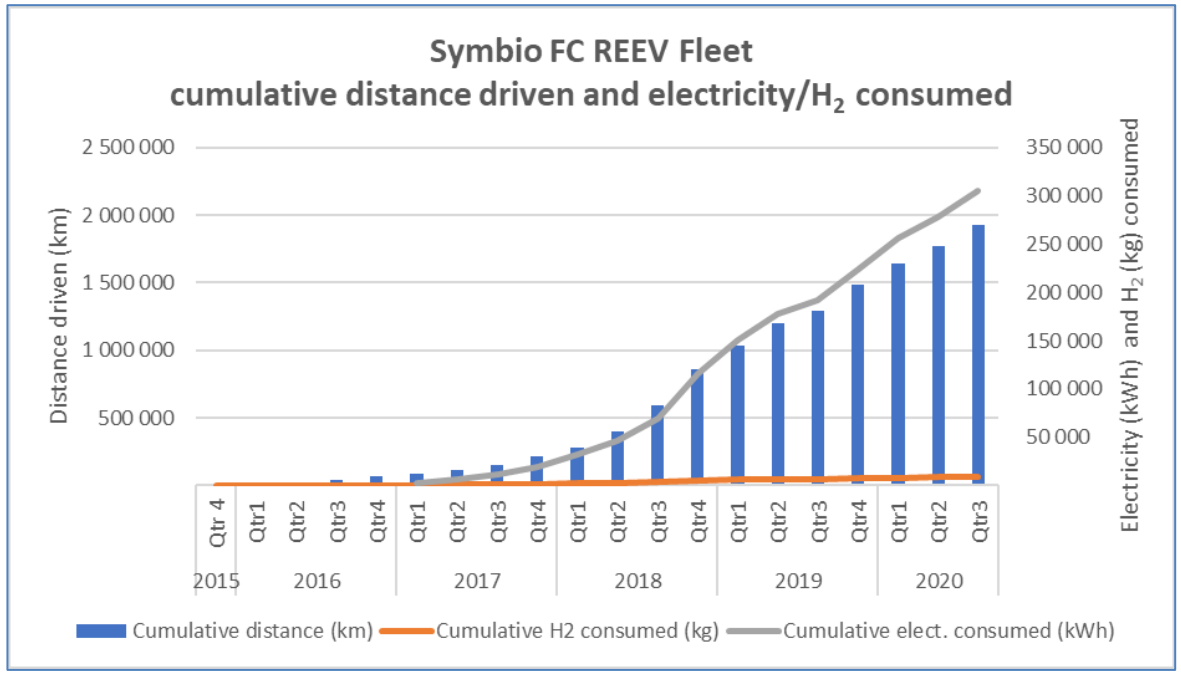
Parameter	Value
Vehicle architecture	Fuel cell range-extended vehicle (FC REEV)
Top Speed	130 km/h
Net Weight	1 505 kg
Fuel Consumption (NEDC)	1 kg H_2/100 km
Range	300 km + NEDC
Stack Technology	PEMFC
Stack Power Rating	5 kW
Tank Capacity	1.8 kg H_2
Tank Pressure	350/700 bar
Battery Pack Size	22 kWh

- The Symbio is an FC REEV so can refuel with electricity as well as hydrogen.
- It has four operating modes set by the driver:
  - Auto (FC power dependent on vehicle speed)
  - Fuel cell (Max FC power, typical operation mode)
  - Battery (essentially battery only)
  - Stop (fuel cell off)
- The vehicle operates only on battery between 100% SOC and 90% battery SOC.
- Symbio experience has shown that the drivers generally operate the vehicle in fuel cell mode which starts when the battery is at or below 90% SOC.

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Where Vehicles are Located

- Symbio has telematics on all its vehicles. They provide summary data each quarter on all vehicles (distance, H_2 refuelled and electricity used) and detailed daily usage data on 10% of the fleet.
- Currently the project receives data from 237 vehicles:
  - France 179
  - Germany 13
  - UK 45

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Overall Fleet Data

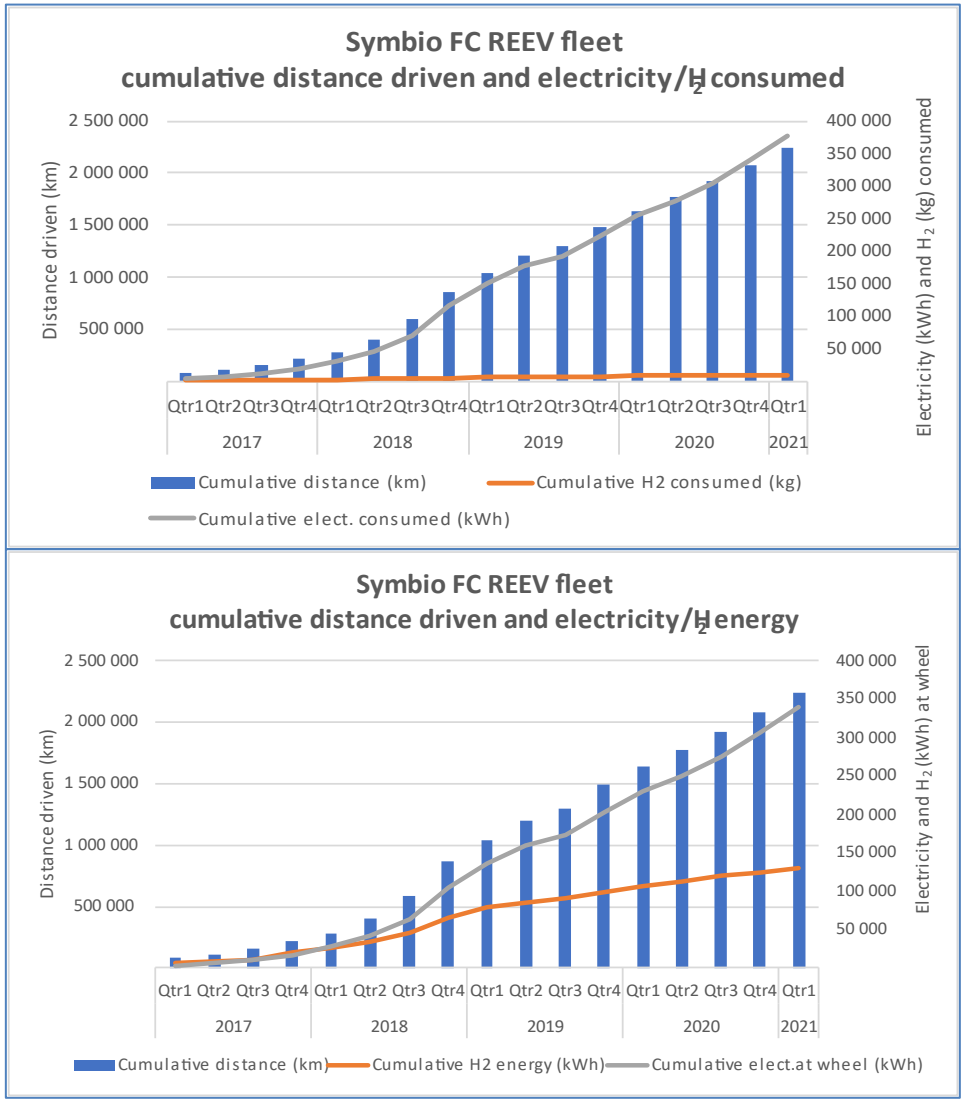


- Since 2015, Symbio vehicles providing data to H2ME have reported over 2.2 million km driven:

Project	# of vehicles	Distance	H_2 (kg)	Elect. (kWh)*
H2ME1	125	1 396 722	6 348	213 092
H2ME2	72	611 428	2 357	115 842
Other	40	228 585	861	48 380
Total	**237**	**2 236 785**	**9 566**	**377 314**

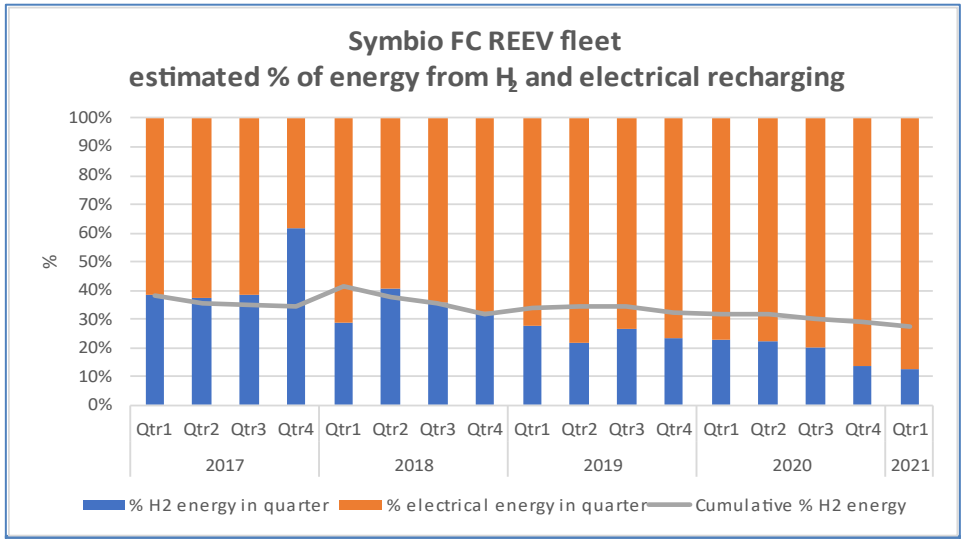
* Electrical consumption reported from 2017 onwards

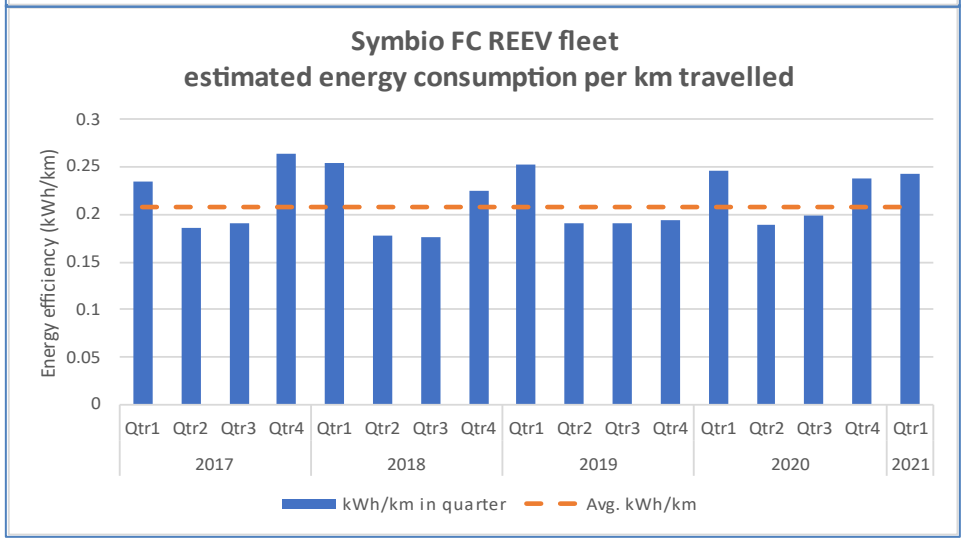
H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Fleet Energy Usage (1)



- The Symbio Kangoo ZE H2 is a FC REEV - vehicles can be fuelled by hydrogen, electricity or a combination of both.
- The top graph shows a simple comparison of hydrogen and electricity fuelled to the vehicle. Hydrogen has a higher energy content per unit (kg) than electricity (kWh).
- Comparing energy consumption at the vehicle wheel is therefore more informative. The bottom graph assumes:
  - H_2 conversion via the FC to electricity is 45% efficient (value provided by Symbio)
  - The efficiency of energy transfer from the battery & fuel cell to the wheel is 90%.
- The graph shows that the relative proportions of hydrogen and electricity used to fuel the vehicles has changed over time. During this period, more vehicles have been added to the fleet in different locations and the refuelling balance between electricity and hydrogen varies in each location.
- This is discussed further in the subsequent slides.

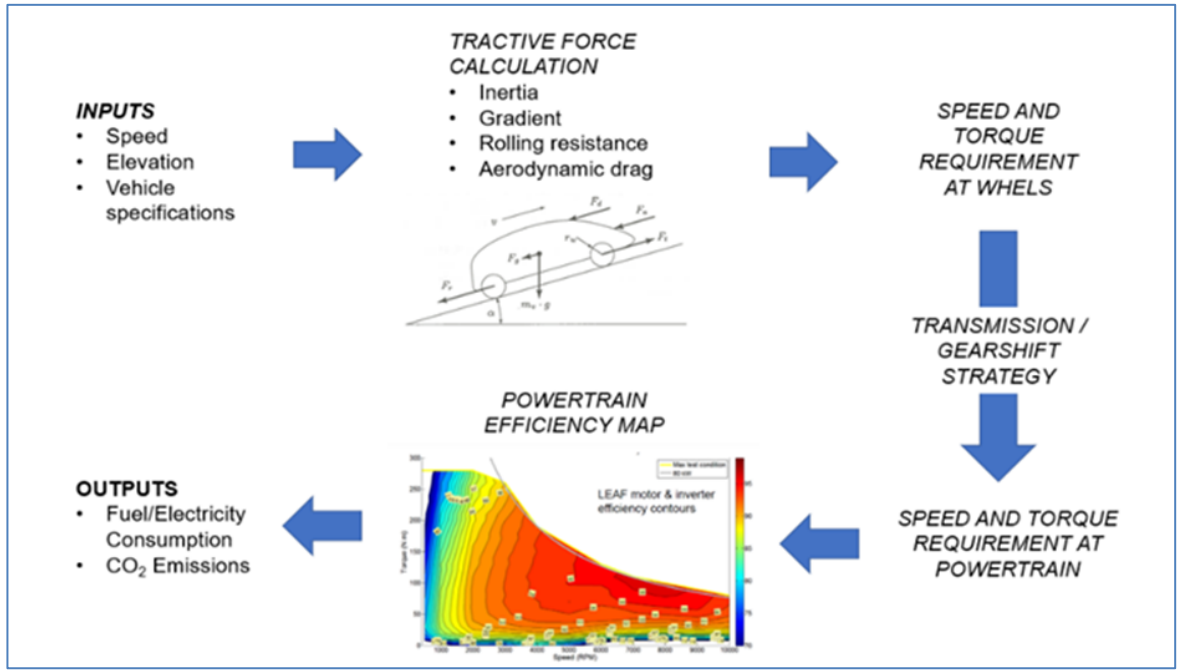
H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Fleet Energy Usage (2)





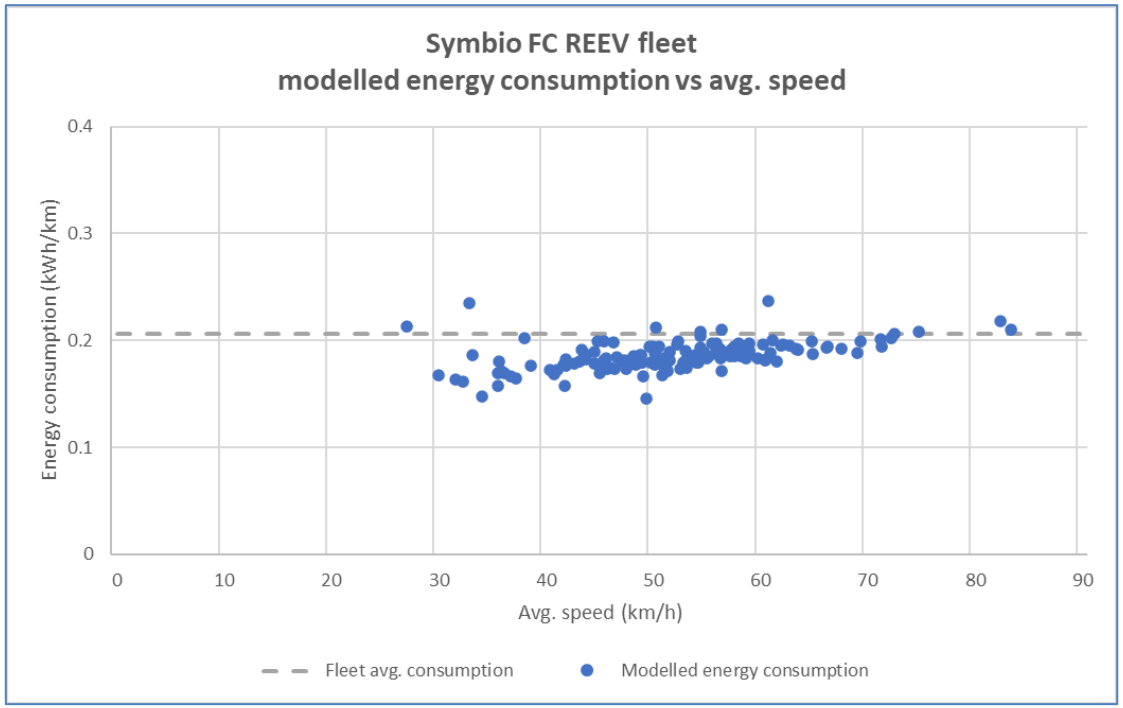
- The top graph uses the model described on the previous slide to estimate the % of the fleet's reported distance driven that has been fuelled by hydrogen and electricity.
- The top graph shows that in 2017 the split between hydrogen and electricity usage was relatively even, but by Q1 2021 this has fallen to ~ 13% H_2 (28% overall).
- The bottom graph shows the fleet energy usage per quarter over the same period.
- The figure shows that the overall vehicle energy consumption (i.e., hydrogen plus electricity) per km is approximately the same in each quarter, irrespective of the relative proportion of H_2 and electricity used, with an overall average of 0.21 kWh/km (or 4.76 km driven per kWh).
- The graph also shows seasonal variation of energy consumption (higher in winter, lower in summer) in common with all vehicles.
- In practice, this means that to the driver, the vehicle drives as an electric vehicle irrespective of whether the fuel is hydrogen, electricity, or a combination of both.

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Modelled Validation of Energy Usage (1)



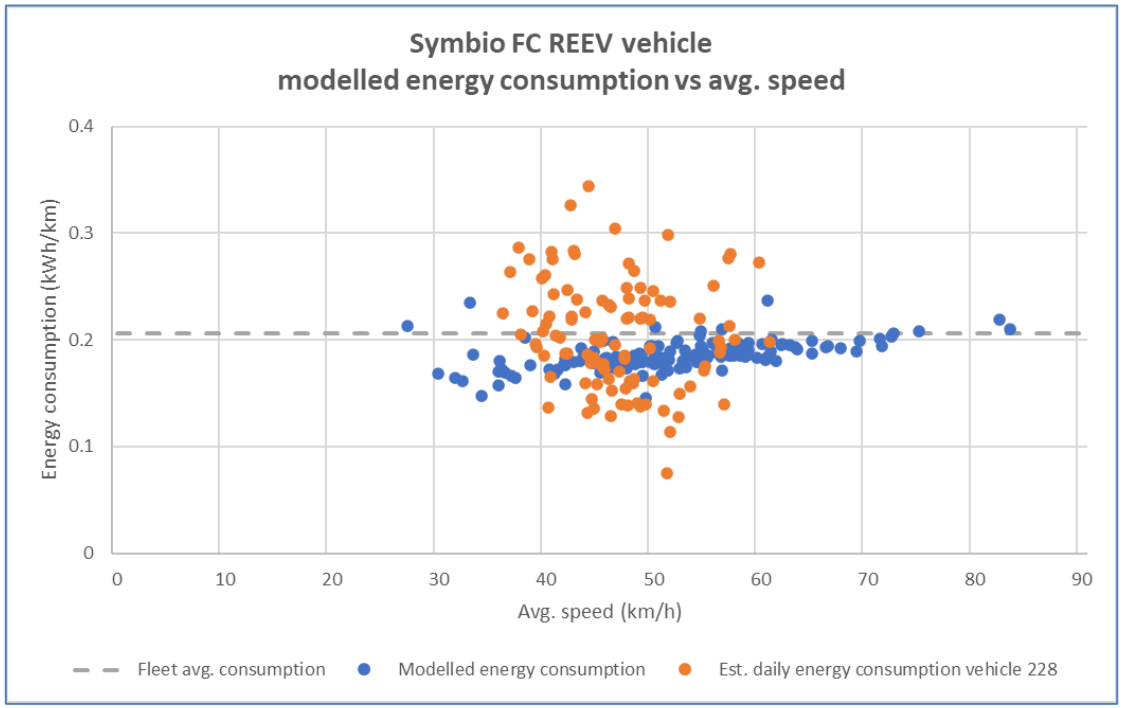
- Collection of detailed vehicle data allows validation of the findings on real-world energy usage by detailed Simulink modelling.
- Cenex has loggers installed on Symbio vehicles in the UK as part of another project. These provide more detailed data than the summary data provided by Symbio in H2ME2.
- This data is then processed to provide drive cycle and acceleration information.
- Calculation of acceleration etc. from real-world data allows us to build a *backwards-facing model* of vehicle energy usage (optimise vehicle power required to meet the drive cycle, translated to energy usage).
- This model was used to validate:
  - Overall (fleet) energy usage
  - Individual vehicle daily usage (detailed data).

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Modelled Validation of Energy Usage (2) Overall Fleet



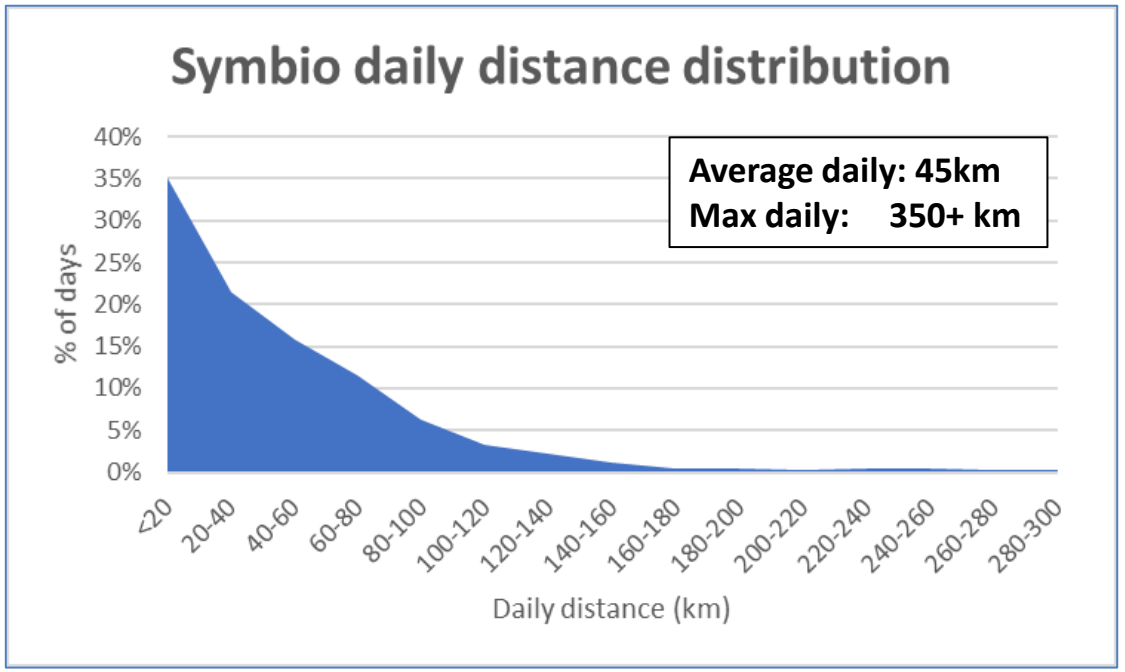
- The graph shows modelled energy consumption (50% vehicle payload assumed) over a day against average speed for a series of non-H2ME Kangoos in the UK that are fitted with Cenex logging devices.
- The modelled consumption agrees well with the real-world average value of 0.21 kWh/km found during H2ME, but also shows an expected rising trend of energy consumption with vehicle speed that is not visible in the overall fleet data.
- Scatter in the modelled consumption can be attributed to:
  - Differences in individual daily driving behaviour for similar average speeds
  - Variation in load
  - Weather conditions.
- 0.21 kWh/km gives real-world estimated ranges of:
  - 204 km total (350bar/22kWh). It is noted that journeys of 300km+ have been achieved.
  - 86 km battery-only (to 10% SOC).

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Modelled Validation of Energy Usage (3)
Individual vehicle



- The graph shows the modelled energy consumption from the previous slide compared to real-world energy consumption derived from daily Symbio data on speed, H_2 and electricity used for one vehicle operating in Paris Sud (Rungis).
- The real-world data is again clustered around the fleet average value, but shows more variation and no clear relationship to speed.
- The variation can be attributed to similar reasons as the previous slide, but also, importantly, the calculated H_2 and electricity consumption is based on refuelling data – therefore, daily calculations will either over or underestimate energy usage depending on when the fuel is used.

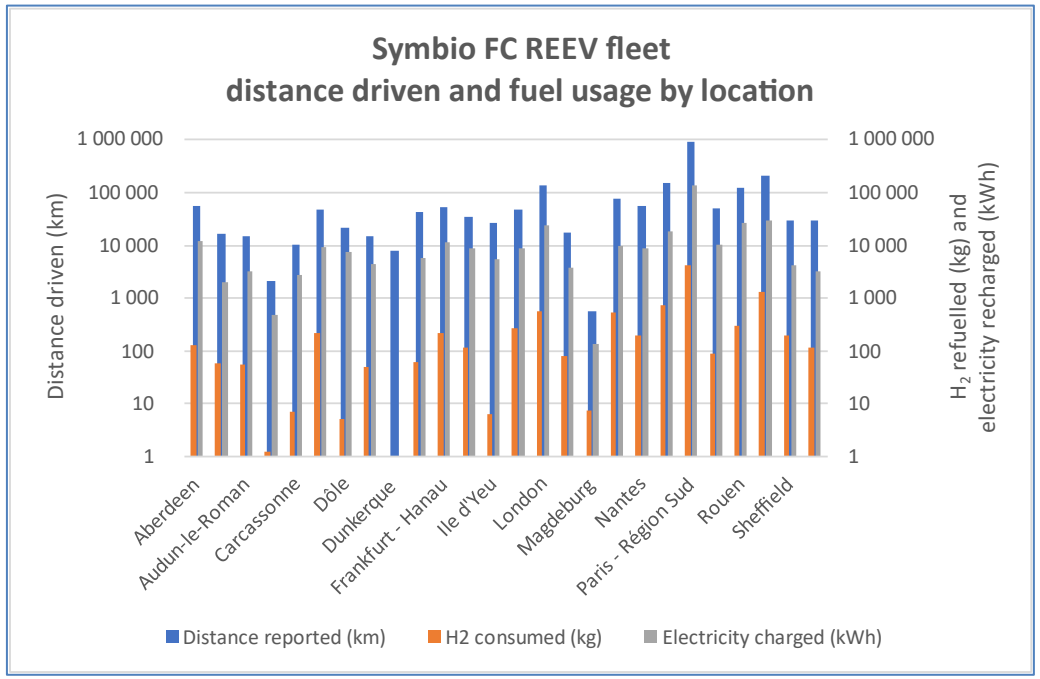
H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Fleet Daily Distance Driven



- The graph shows the daily distance distribution for all the vehicles providing detailed data to the project since 2017 (~10% of the fleet in multiple locations).
- The graph demonstrates that the Symbio vehicle is able to fulfil the duty cycle required of light vans*.

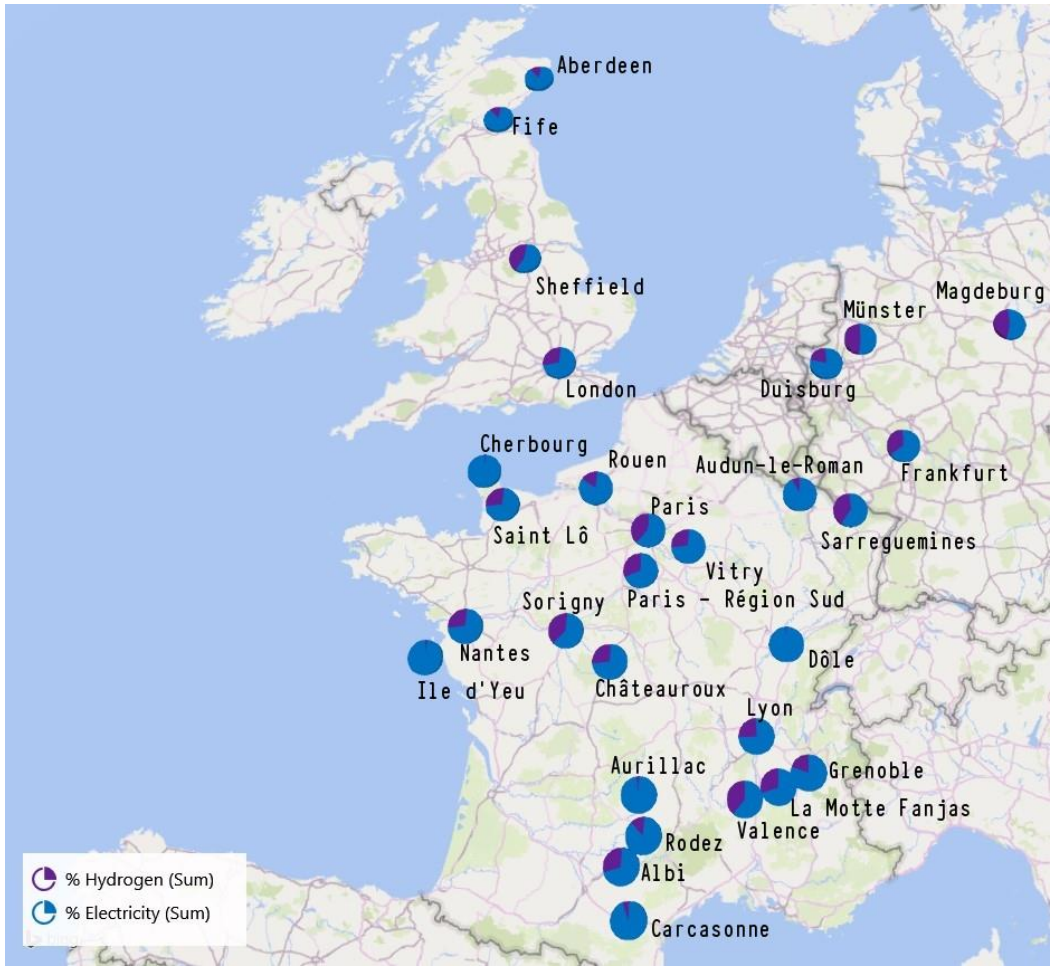
* For example, see UK van distance data in https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4550/ultra-low-emission-vans-study.pdf

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Usage Analysis by Location (1)



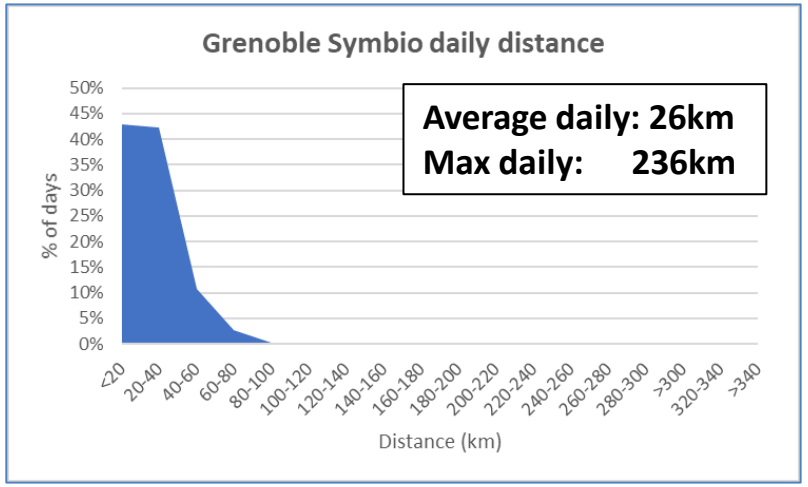
- The Symbio vehicles have been deployed in 29 different locations in France, Germany and the UK.
  - The deployments vary in scale, with the largest being the 50-strong ENGIE Cofely fleet at Rungis (Paris – Région Sud).
- The vehicles in different locations have reported significantly different amounts of kilometres driven (note the logarithmic scale), and correspondingly different amounts of hydrogen and electricity consumed.
- This is discussed further on subsequent slides.

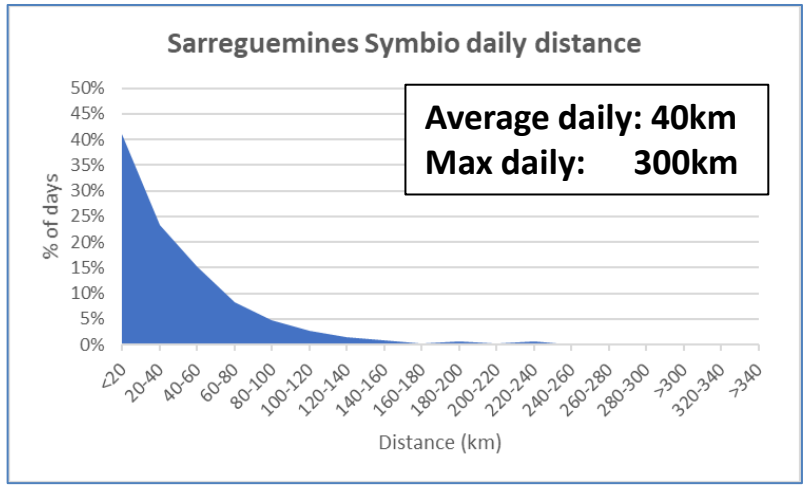
H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Usage Analysis by Location (2)

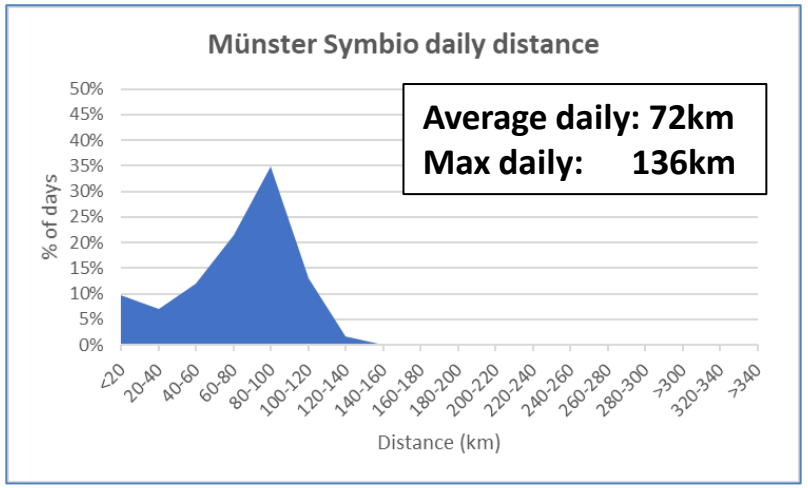


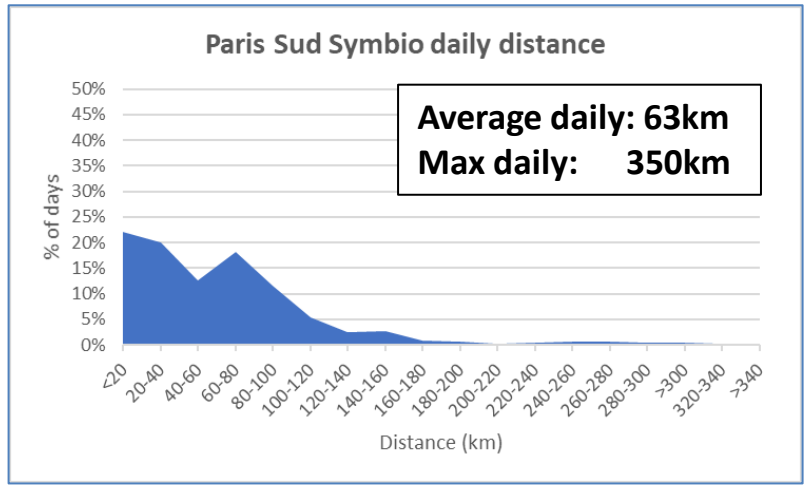
- The map shows the percentage by energy of hydrogen and electricity usage at each Symbio deployment.
- The presence/convenience of a HRS is one determining factor on the relative usage of hydrogen and electricity to propel the vehicle in a particular location:
  - For example, for much of the project's lifespan there was no HRS at Cherbourg.
- The next slides look at whether there are other factors, particularly how the vehicles are used on a daily basis, that can help understand fuel usage in a given location.
- The analysis will focus on four locations where a consistent (at least a year) set of detailed data is available for individual vehicles from 2019-2021:
  - Grenoble
  - Münster (Germany)
  - Paris – Région Sud (Rungis)
  - Sarreguemines.

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Usage Analysis by Location (3)



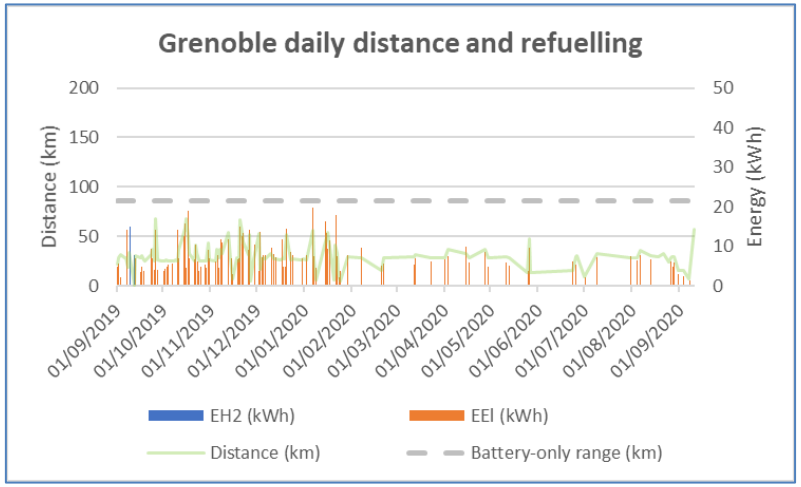


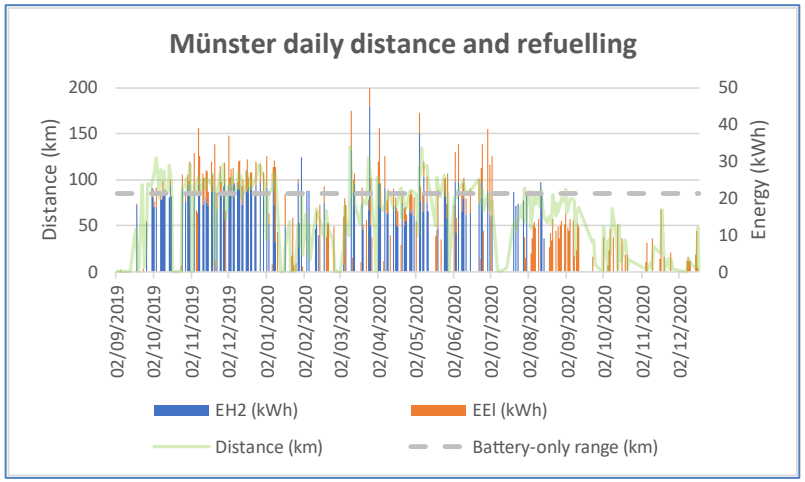




- The graphs show that the fleet-average day's driving in all locations could be covered on battery alone, based on a battery-only range of ~ 86 km at 0.21 kWh/km (to 10% SOC).
- The graphs do not show whether vehicles that need to drive further, on average and on maximum days, use more hydrogen than those that appear to have relatively short daily driving requirements.
- This question is explored further for individual vehicles on the next slides.

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Usage Analysis by Location (4)



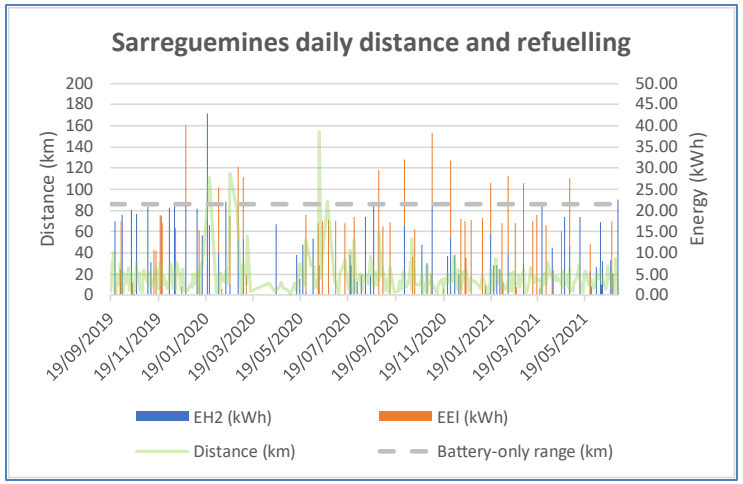


Distance driven:	**3824 km**
Average daily distance:	**30 km**
kWh H_2:	**23**
kWh electricity:	**824**
% H_2 used:	**3%**
Maximum daily distance:	**61 km**
% days over 85 km (long days):	**0%**
% H_2 used on long days:	**-**
% days H_2 refuelled	**2%**
% days recharged	**85%**

Distance driven:	**16833 km**
Average daily distance:	**60 km**
kWh H_2:	**2559**
kWh electricity:	**1408**
% H_2 used:	**62%**
Maximum daily distance:	**136 km**
% days over 85 km (long days):	**33%**
% H_2 used on long days:	**76%**
% days H_2 refuelled	**44%**
% days recharged	**74%**

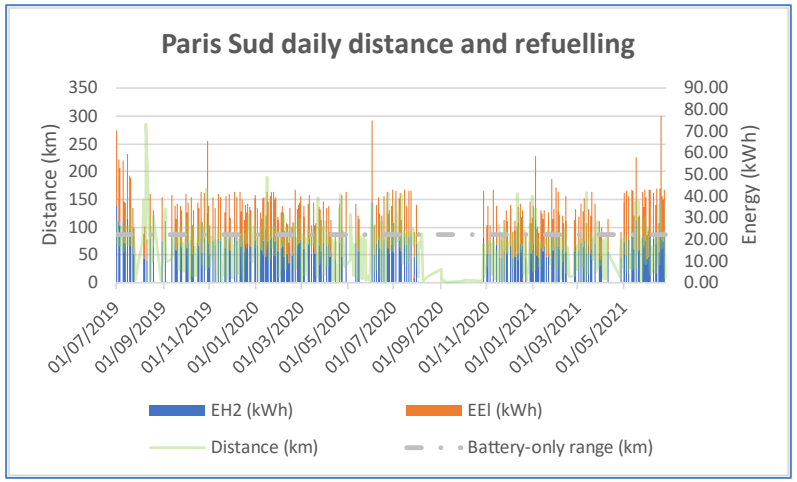
- The graphs show driving (primary y axis) and refuelling behaviour (secondary y axis) for an **individual vehicle** at each location over at least one year.
- In **Grenoble**, the vehicle habitually drives on electricity only. Its daily duty cycle does not necessitate H_2 fuelling; it recharges almost daily and very rarely fills with H_2.
- In **Münster**, the vehicle habitually fuels with H_2 and electricity. H_2 fuel provides flexibility to the driver in executing daily driving requirements on average *and* long days.

H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Usage Analysis by Location (5)



Distance driven:	**6160 km**
Average daily distance:	**17 km**
kWh H_2:	**778**
kWh electricity:	**767**
% H_2 used:	**50%**
Maximum daily distance:	**155 km**
% days over 85 km (long days):	**1%**
% H_2 used on long days:	**60%**
% days H_2 refuelled	**16%**
% days recharged	**15%**

- In **Sarreguemines** the vehicle fuels with H_2 and electricity when needed. Hydrogen fuelling provides flexibility of usage on average days and the occasional long day's driving.



Distance driven:	**35117 km**
Average daily distance:	**37 km**
kWh H_2:	**4125**
kWh electricity:	**4082**
% H_2 used:	**53%**
Maximum daily distance:	**286 km**
% days over 85 km (long days):	**23%**
% H_2 used on long days:	**53%**
% days H_2 refuelled	**44%**
% days recharged	**75%**

- In **Paris Sud (Rungis)**, the vehicle habitually fuels with electricity and H_2. The graph provides an indication that the driver(s) refuel with H_2 on the days where longer range is required which would not be achievable on the battery alone.

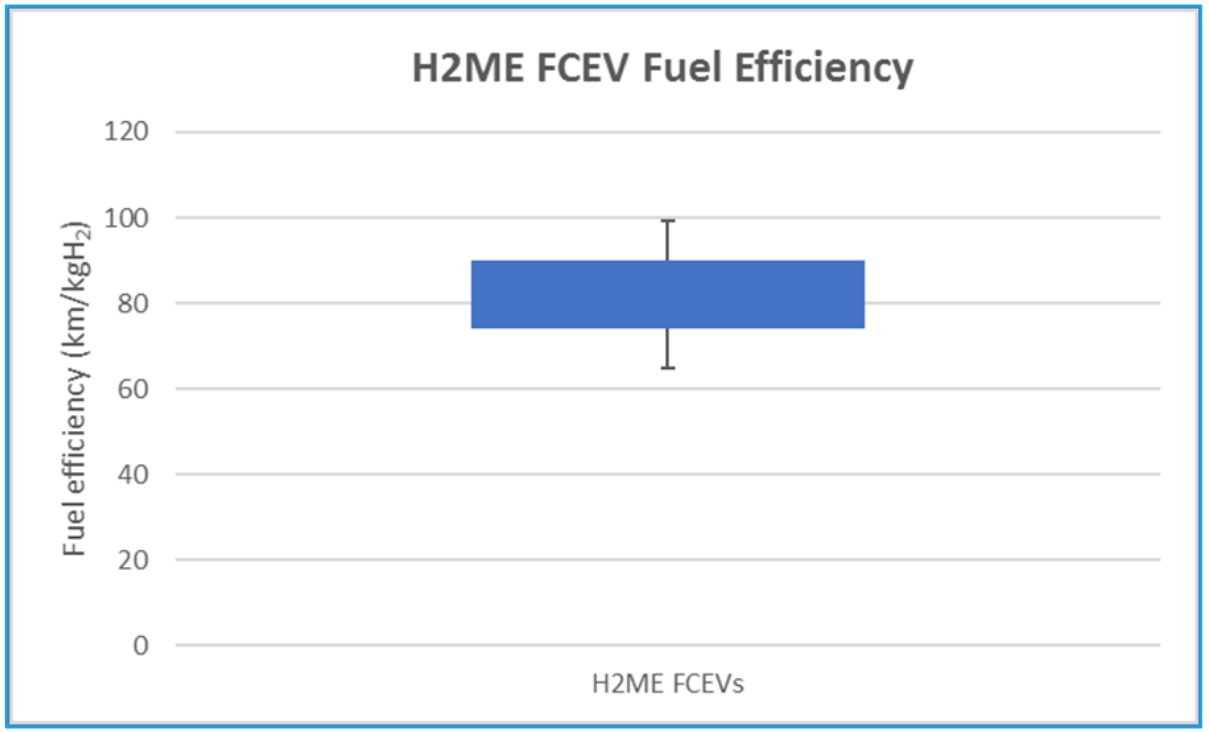
H2ME Vehicle & HRS Case Studies
Symbio Kangoo ZE H2: Summary

- Symbio Kangoo ZE H2 vehicles have reported almost two million km of data to H2ME since 2015.
- The Symbio Kangoo ZE H2 is a FC REEV - vehicles can be fuelled by hydrogen, electricity or both.
- Longitudinal analysis of fleet performance shows an average real-world energy consumption of 0.21 kWh/km, a value confirmed by detailed modelling.
- This gives the vehicles a project-average real-world range of 204 km, a 136% increase over the battery-only range of 86 km (22kWh battery to 10% battery SOC, 1.8 kg 350 bar tank).
- The range means that the vehicle is capable of fulfilling the daily needs of light duty van fleets.
- From the driver's perspective, the vehicle drives as an electric vehicle irrespective of whether the fuel is hydrogen, electricity, or a combination of both, and offers flexibility of usage.
- The relative proportion of hydrogen and electricity used to fuel the vehicle varies by location, and is dependent on factors including:
  - Local strategic priorities and fleet management to maximise hydrogen usage in a given location
  - Proximity to a HRS
  - Availability of the HRS
  - Daily average and maximum driving distance required by each vehicle's duties.

Contents

- Introduction to H2ME
- Summary of vehicle results
- Case studies of FCEV operation during H2ME-2:
  - Honda Clarity FCEVs in Denmark, France, Germany and Switzerland
  - Symbio FC REEV operation in France, Germany and the UK: electricity and hydrogen usage and refuelling
- **FCEV efficiency, safety and reliability**
- HRS performance with increasing levels of utilisation
- Summary of HRS results
- Summary results by project

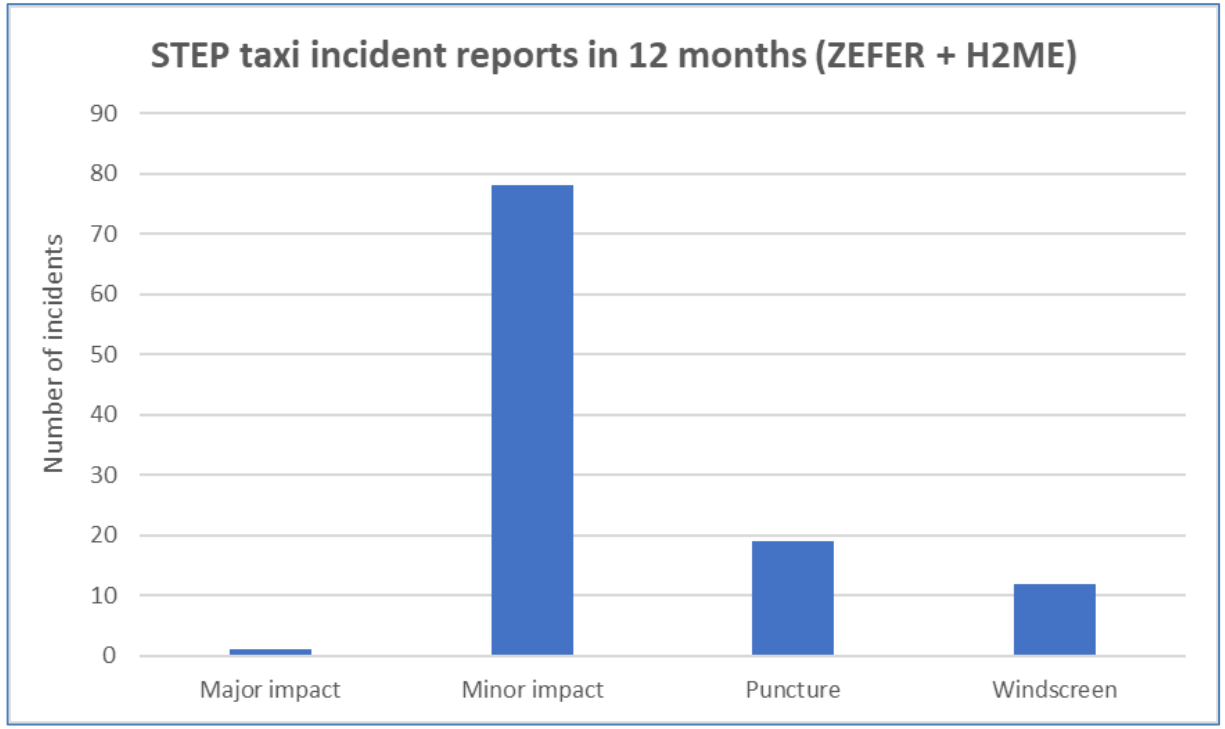
FCEV Efficiency, Safety and Reliability
Overall FCEV Fuel Efficiency



- The blue column graph shows the spread of the average efficiency of all H2ME FCEVs for which detailed monitoring data is available.
- The black bars show the most and least efficient vehicles monitored in detail during the project.
- The graph is presented as recommended by the HyLights Monitoring and Assessment Framework * – i.e., it gives minimum, maximum and average values, not individual vehicle values – to maintain anonymisation of the FCEVs from each project OEM.
- The project-average vehicle fuel efficiency is **84 km/kgH_2 (1.25 kgH_2/100 km)**.

* https://www.fch.europa.eu/sites/default/files/HyLights_D3_3_MAF-Handbook-II_Final%20%28ID%202875010%29.pdf.

FCEV Efficiency, Safety and Reliability
Safety



- As the case study shows, the FCEV taxis drive a lot. Inevitably, they are involved in incidents.
- FCEV taxis have the same frequency of incident as normal taxis (tyre replacements and minor collisions).
- The photograph shows the scale of the major impact incident shown in the graph.
- **None of the incidents involved any release of hydrogen or problems with the fuel cell system.**

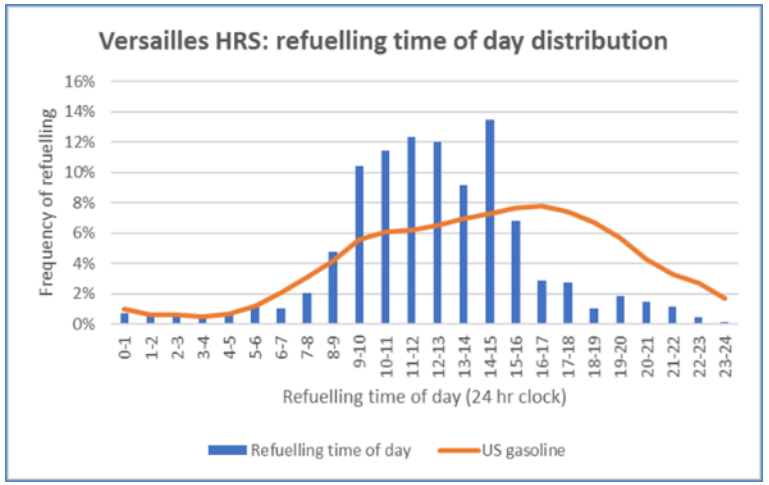
FCEV Efficiency, Safety and Reliability
Reliability

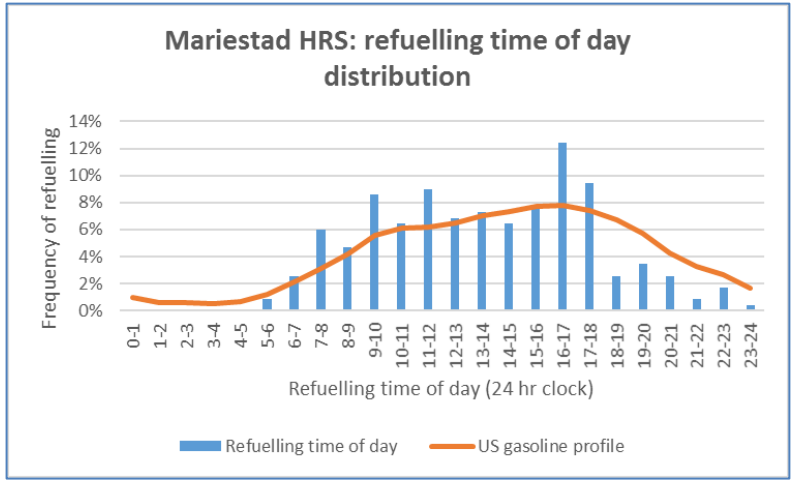
- The FCEVs have been deployed with working fleets in a variety of roles, including as taxis and police vehicles, as well as with private customers.
- In general, the FCEVs have been integrated into fleets with minimal disruption and are used in the same ways (in terms of distance travelled per day, etc.) as conventionally-fuelled vehicles.
- The FCEVs are serviced regularly; for example, in the Toyota Mirais that are used as taxis in London and Paris are serviced every 10 000 km in France, and every 10 000 miles in the UK. Key maintenance tasks involved during the service are:
  - At 10 000 km/miles there is a general check plus H_2 leak test.
  - At 30 000 km the deionising filter is changed.
  - At 100 000 km the battery and fuel cell coolant is topped up.
- The FCEVs have proven to be reliable (> 99% availability overall).

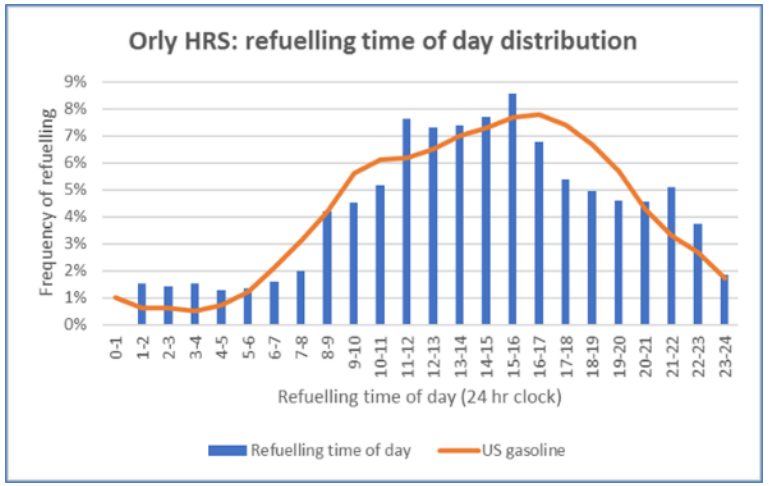
Contents

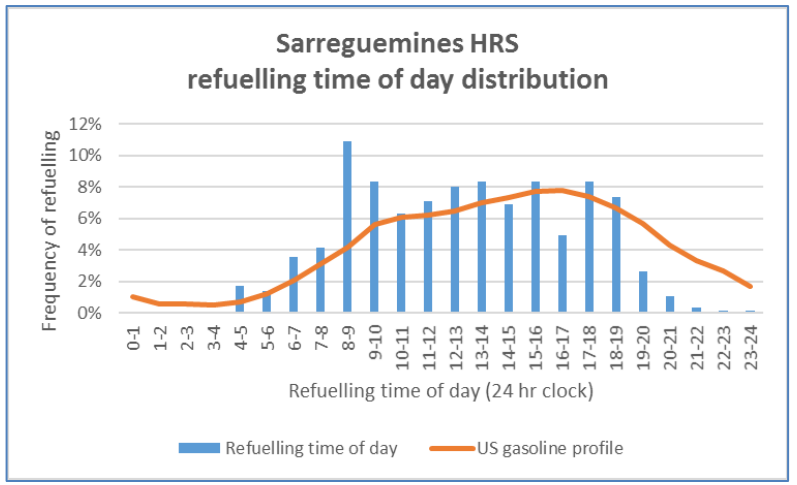
- Introduction to H2ME
- Summary of vehicle results
- Case studies of FCEV operation during H2ME-2:
  - Honda Clarity FCEVs in DenmarkGermany and Switzerland
  - Symbio FC REEV operation in France, Germany and the UK: electricity and hydrogen usage and refuelling
- FCEV efficiency, safety and reliability
- **HRS performance with increasing levels of utilisation**
- Summary of HRS results
- Summary results by project

H2ME Vehicle & HRS Case Studies
All Project HRS: When do Vehicles Refuel?





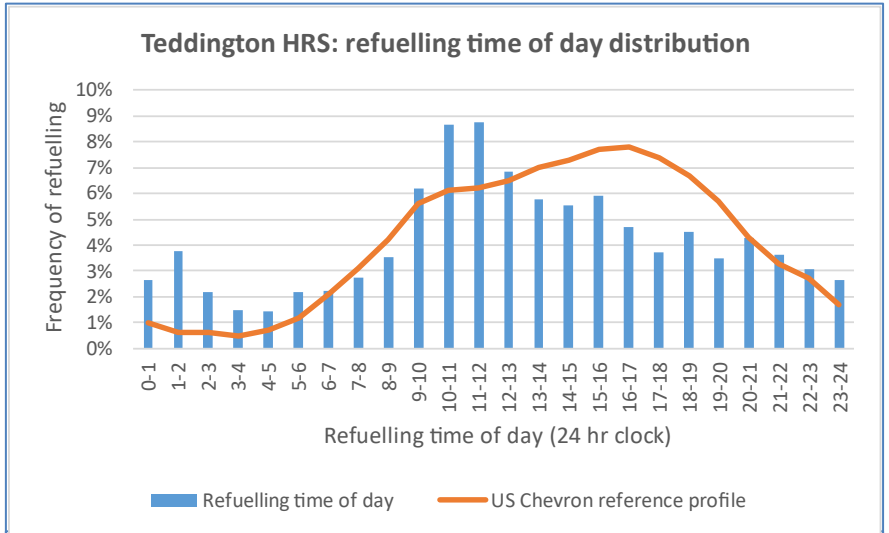


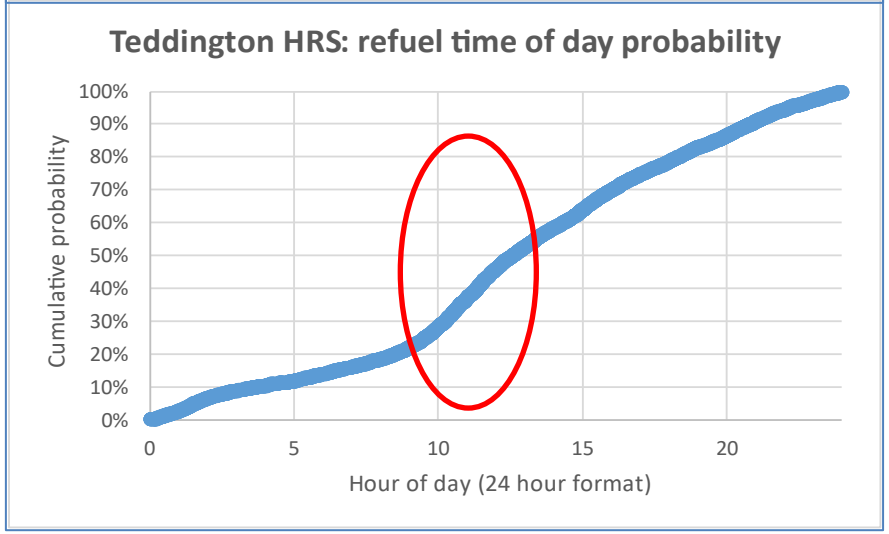


- The graphs show the refuelling time of day distribution a number of project HRS compared to a standard gasoline station refuelling profile.*
- Most H2ME HRS are relatively lightly used (<10% load, as measured by the average daily refuelling amount divided by its rated daily capacity).
- The HRS in Orly (Paris) is the most highly used project HRS. The usage of the Orly station reflects the deployment of STEP taxis in Paris since 2017.
- Pre-COVID, the Orly station load was over 40% (80 kg/day, based on a 200kg/day rated capacity).
- Compared to other H2ME stations, the Orly station usage profile most closely resembles that of a conventional gasoline station (orange line in graphs).

* The graphs each show a typical US gasoline station refuelling profile (the Chevron Demand Profile) which is used by the US NREL to benchmark the operation of HRS that it monitors against conventional stations. For example, see https://www.nrel.gov/docs/fy15osti/64107.pdf

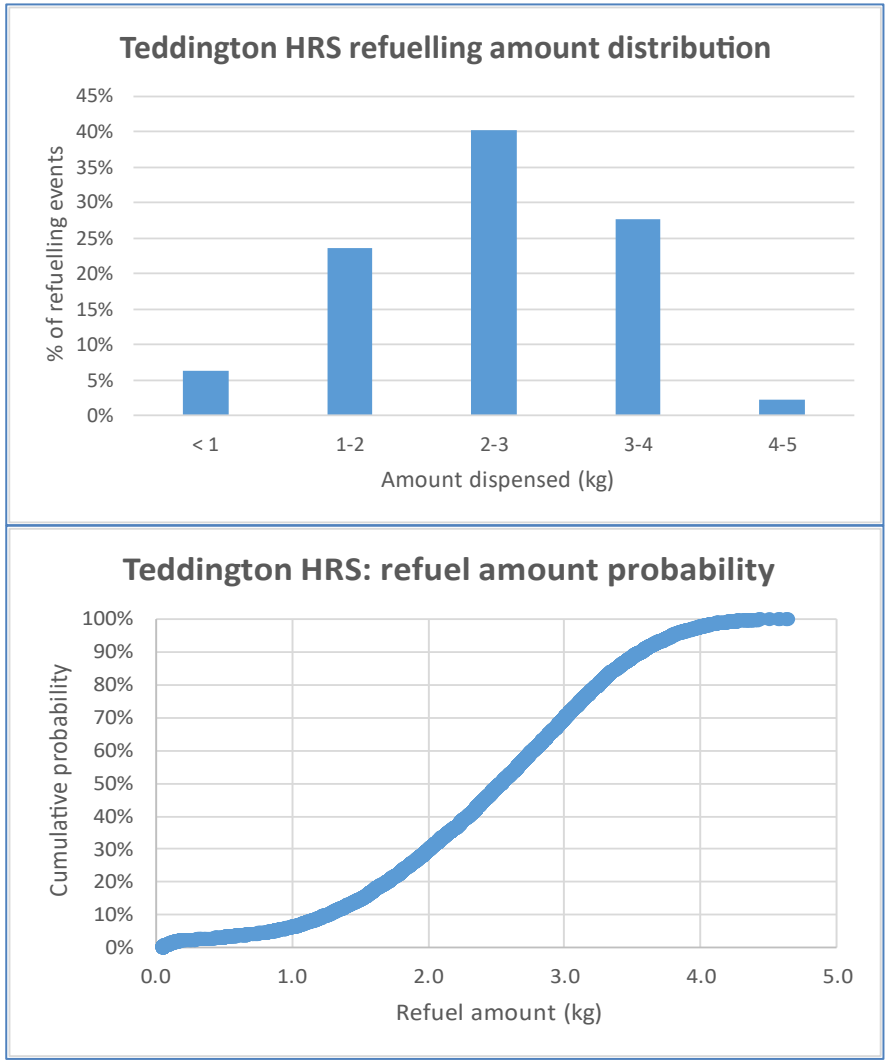
H2ME Vehicle & HRS Case Studies
Teddington HRS: Time of Day Usage





- The top graph shows the refuelling profile for 700 bar refuelling at the Teddington HRS which:
  - Like Orly has a relatively high usage – in this case from Toyota Mirai taxis and police vehicles.
- The graph shows that the daily refuelling profile is similar to Orly, with perhaps more usage in the early hours due to police refuelling.
- The bottom graph shows how this refuelling profile translates to a refuelling probability across the day.
- The inflection highlighted in the graph shows the relatively higher probability of refuellings between 9-13:00.
- The Teddington HRS will be used in the remainder of this section as a model of a relatively highly used HRS.

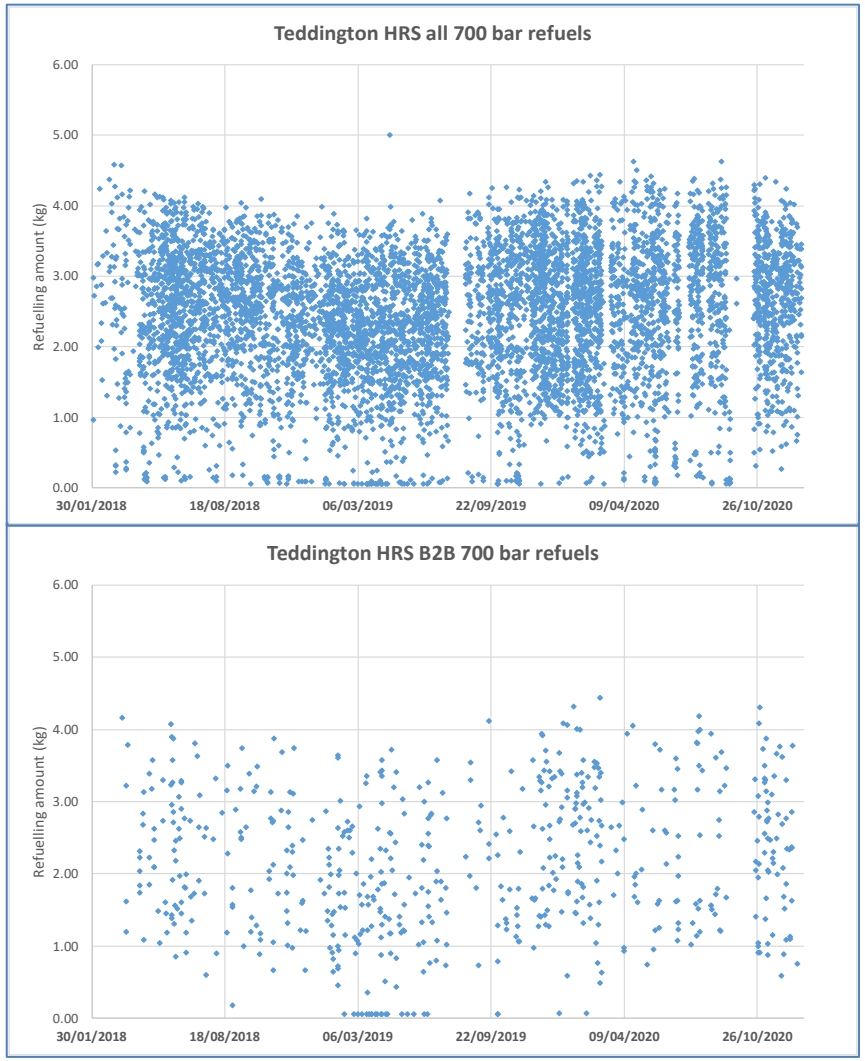
H2ME Vehicle & HRS Case Studies
Teddington HRS: Refuelling Amount Distribution



- The top graph shows the distribution of amount per refuel for 700 bar refuelling at the Teddington HRS.
  - The modal (most popular) refuel amount is 2-3 kg.
  - This reflects the fact that the vast majority of FCEVs using the HRS in this period were Toyota Mirais with a 5 kg tank capacity.*
- The bottom graph shows the same data presented as a cumulative refuelling amount probability.
- The graph reflects the average 50% of tank capacity refuelling of 2.5 kg reported previously for the Toyota Mirai fleet in H2ME.*

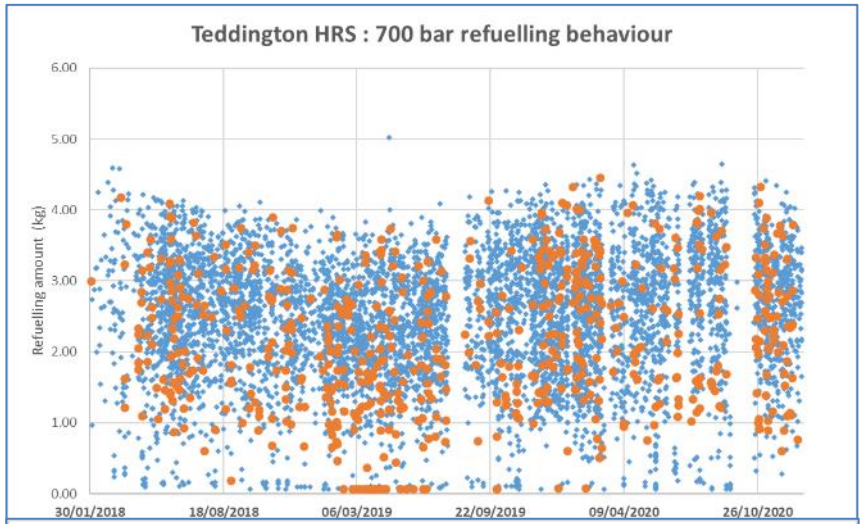
* As reported in *H2ME-1 Vehicle and Infrastructure Performance Report 5 (2015-2020)*

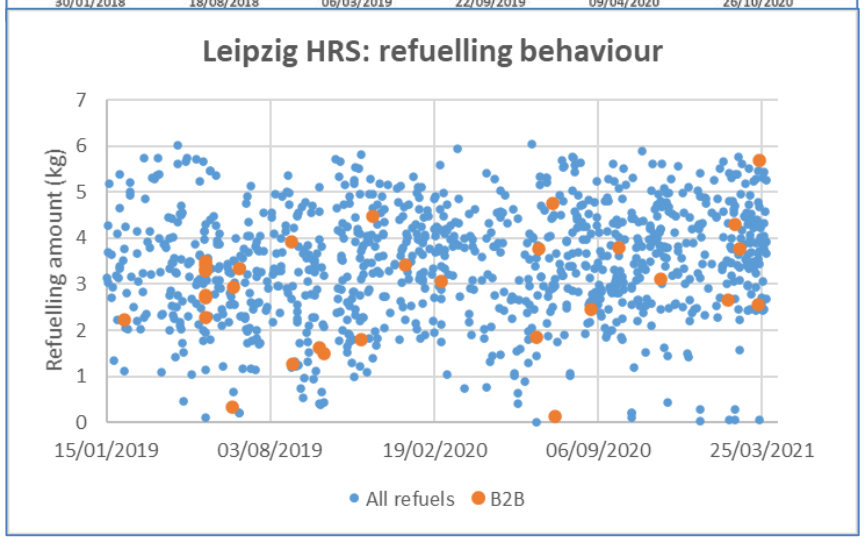
H2ME Vehicle & HRS Case Studies
Teddington HRS: B2B Refuelling



- The top graph shows all 700 bar refuelling events at Teddington from 2018-2020, showing:
  - 16 400 kg H_2 dispensed:
  - 6 700 refuels
  - An average of 2.45 kg per refuel
  - Avg/max dispensed per day (2019-2020): 21/65kg
  - Avg/max refuels per day (2019-2020): 9/34
- In line with other HRS operators, we define back-to-back (**B2B**) refuelling as a refuelling event that occurs within ***ten minutes*** of a previous event.
- The bottom graph shows refuelling events that started within ten minutes of a previous refuel ***and*** ended with a tank pressure of over 650 bar (to remove misfuelling which do not end with a full tank).
- By this criterion, **9%** of refuels at Teddington are B2B.

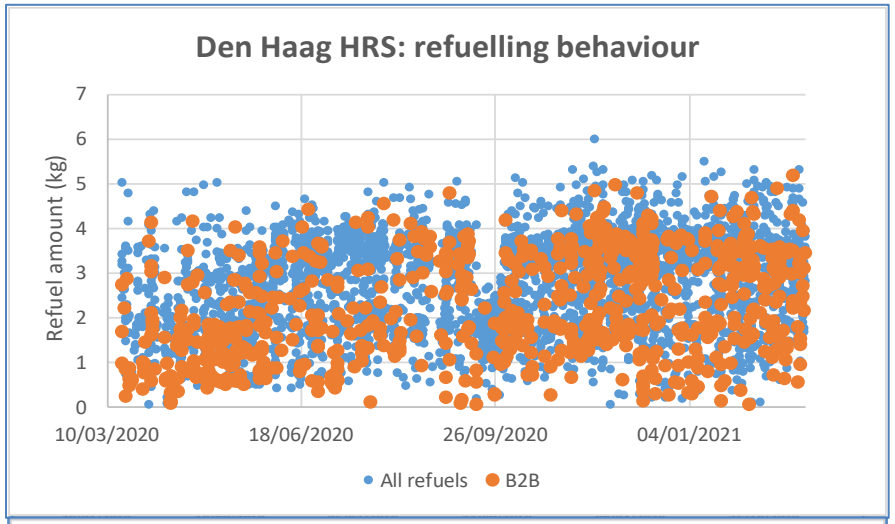
H2ME Vehicle & HRS Case Studies
All HRS: Effect of Load on B2B Refuelling (1)

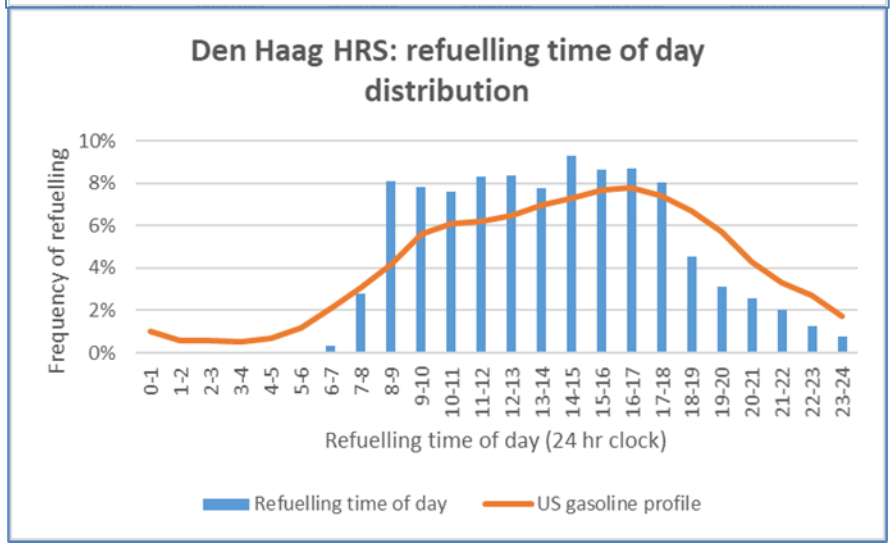




- The top graph shows all 700 bar refuelling events at Teddington from 2018-2020 (as in the previous slide). During that time:
  - 16 400 kg H_2 dispensed in 6 700 refuels
  - Average/maximum dispensed per day: 21/65kg
  - Avg/max refuels per day: 9/34
  - B2B refuelling probability: **9%**.
- The bottom graph compares the Leipzig HRS in Germany (2019-). During that time:
  - 3 675 kg H_2 dispensed in 1 100 refuels
  - Avg/max dispensed per day: 11/34kg
  - Avg/max refuels per day: 3/10
  - B2B refuelling probability: **2.8%**.
- As expected, the lower the station load, the lower the B2B refuelling probability.

H2ME Vehicle & HRS Case Studies
All HRS: Effect of Load on B2B Refuelling (2)





- The bottom graph shows the Den Haag HRS (2020-), which supports the refuelling of ~ 40 Mirais and 40 Nexos (mainly taxis):
  - 13 700 kg H_2 dispensed in 1 100 refuels
  - Avg./max. dispensed per day: 33/88 kg
  - Avg./max. refuels per day: 13/32
  - B2B refuelling probability: **19%** (based on payment system timestamp. No removal of low end pressure fills possible as no pressure data is available).
- The bottom graph shows the refuelling time of day distribution for Den Haag. The HRS is not open between midnight and 5am, so the refuellings are compressed into a smaller timeframe and the peak is longer than Teddington (9am-5pm). Therefore there is an increased chance of B2B refuelling.

H2ME Vehicle & HRS Case Studies
All HRS: B2B Refuelling Questions

- HRS B2B refuelling capability as the number of vehicles deployed and the station load increases was one of the key learning aims of H2ME2.
- If B2B refuelling capability is exceeded regularly, it is likely that issues such a lack of sufficient hydrogen availability at the HRS for immediate refuelling, and therefore increased waiting time for vehicles to refuel, will being to emerge.*
- Given the relatively low levels of usage at H2ME2 HRS at present, we have simulated increasing HRS usage to understand the usage point at which HRS operational issues may become problematic.**
- **Questions for the B2B refuelling simulation to address**

1. How does B2B refuelling change as HRS usage increases?
2. If most HRS claim that they are capable of at least two B2B refuellings, at what level of increased usage would three or more B2B become significant (here considered as 10% of refuels), thereby creating issues?
3. What effect does increased load have on the daily dispensing limit (kg) of the station?
4. How would different vehicle use cases affect this?

* Work to optimise the user hydrogen refuelling experience is the subject of another series of H2ME2 reports. For example, see https://h2me.eu/wp-content/uploads/2020/11/H2ME2-D6.07-Public-FV-Commercial-advancements-in-the-%E2%80%A6.pdf

** Much of analysis in the remainder of this section is based on work initially carried out by Dr. Ben Becker of H2Mobility on usage and B2B refuelling in the H2Mobility HRS network. Cenex is very grateful to Ben and to H2Mobility for sharing his work and for helpful and insightful conversations about implementing simulation methodology in this analysis.

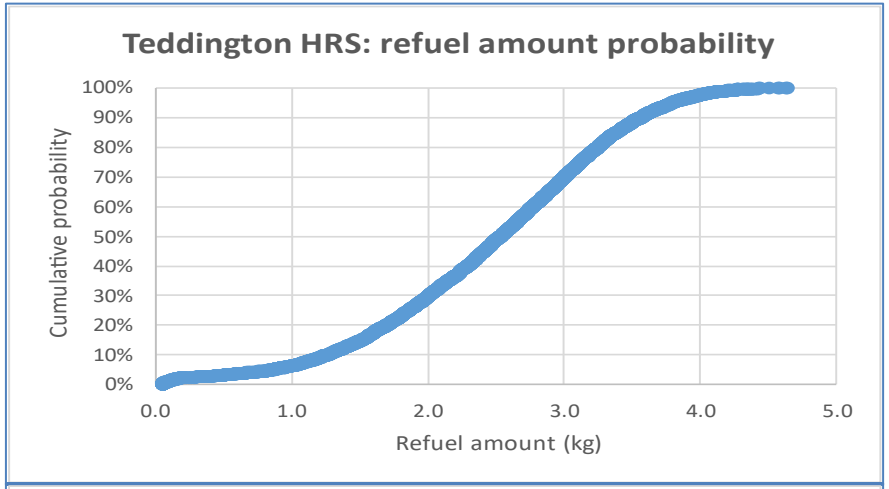
All HRS: Monte Carlo Simulation of Increased HRS Load

- **Monte Carlo (MC)** simulation recreates a chance process, runs it many times, and observes the results.
- **Procedure**

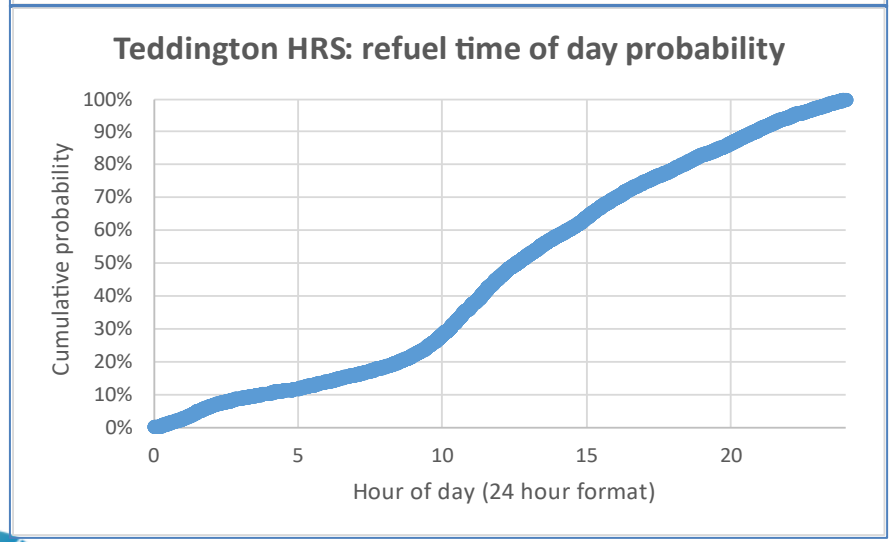
1. Generate weighted inputs (scenarios) according to the distribution of refuellings observed in H2ME. For these refuelling simulations, there are three input variables:
   I. Day of week
   II. Time of Day
   III. Amount of hydrogen refuelled
2. Simulate a week's refuelling based on the inputs.
3. Run the simulation multiple times to ensure statistical validity.

H2ME Vehicle & HRS Case Studies
All HRS: Monte Carlo Simulation of Increased HRS Load. Inputs

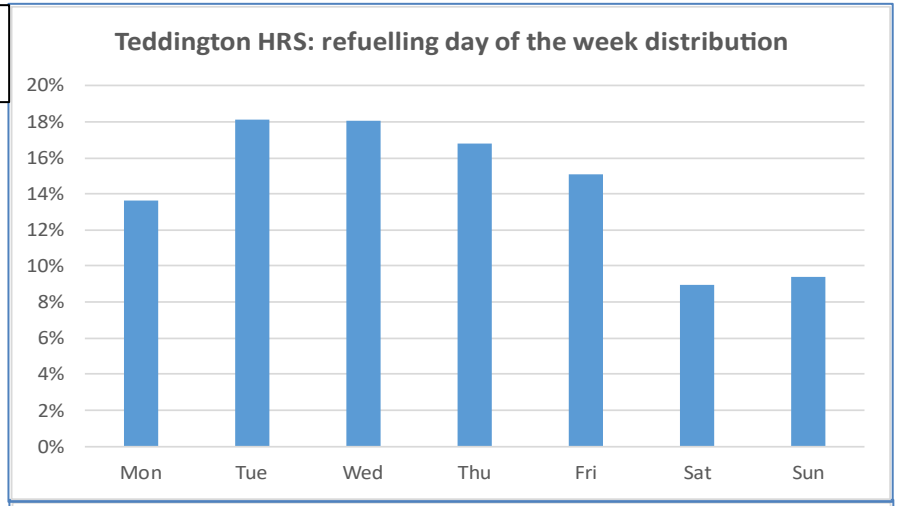
Input



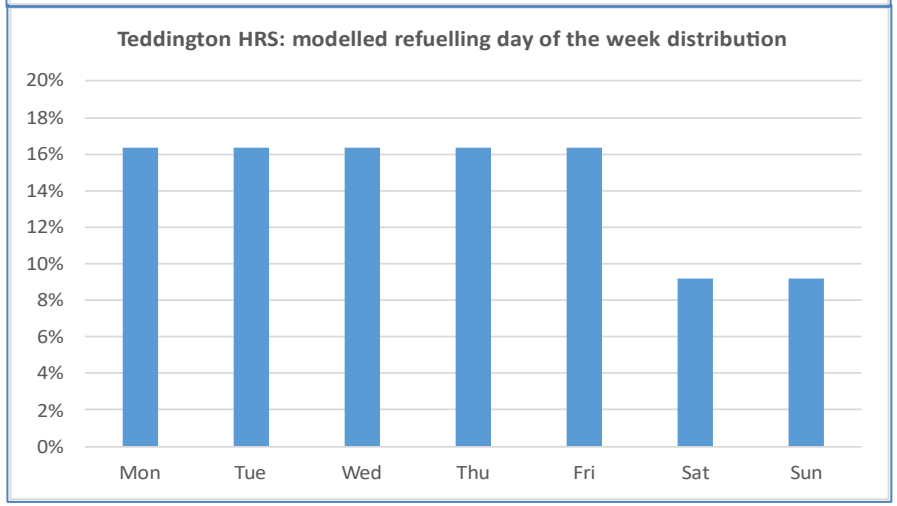
Input



Real-world data

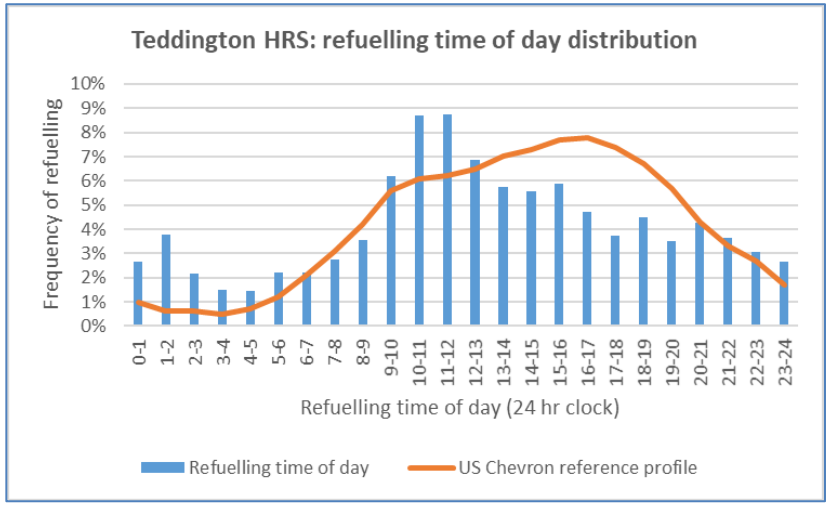


Input

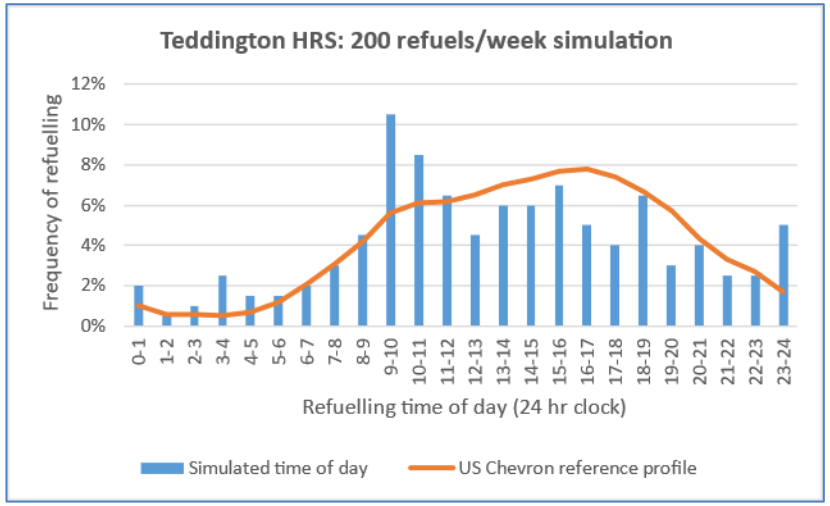


H2ME Vehicle & HRS Case Studies
All HRS: Monte Carlo Simulation of Increased HRS Load. Inputs and Outputs

Real-world data

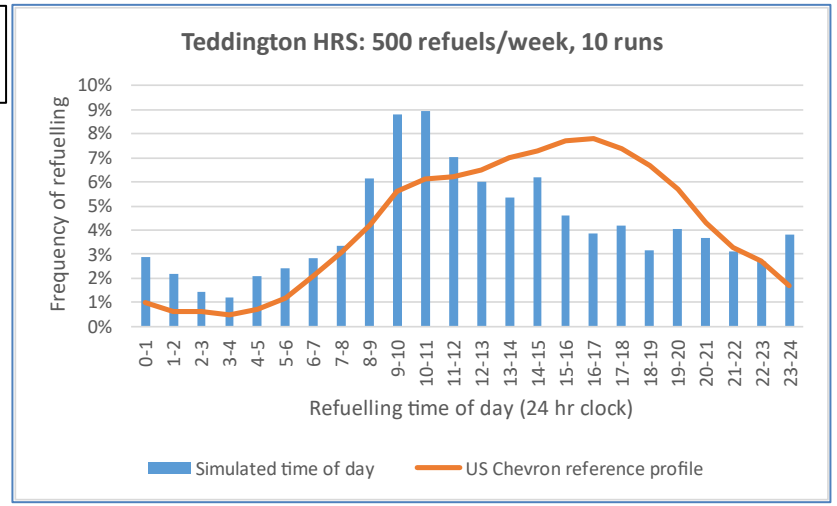


Simulated output

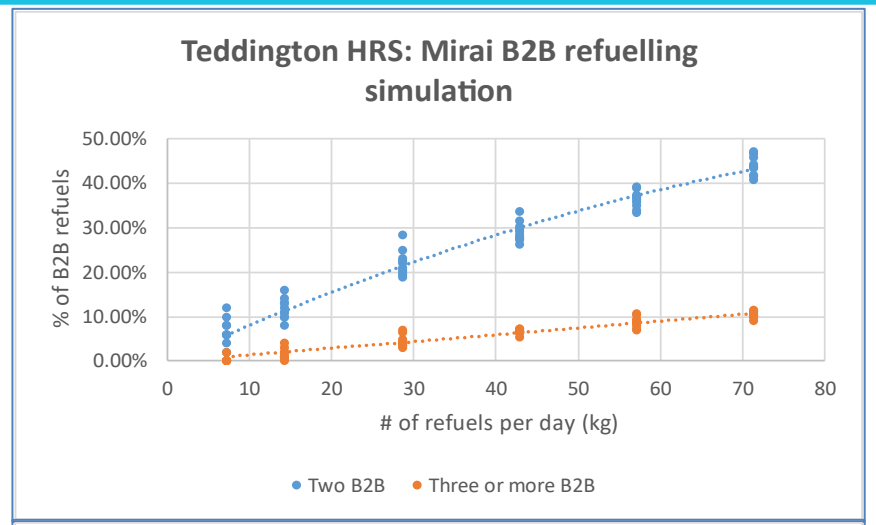


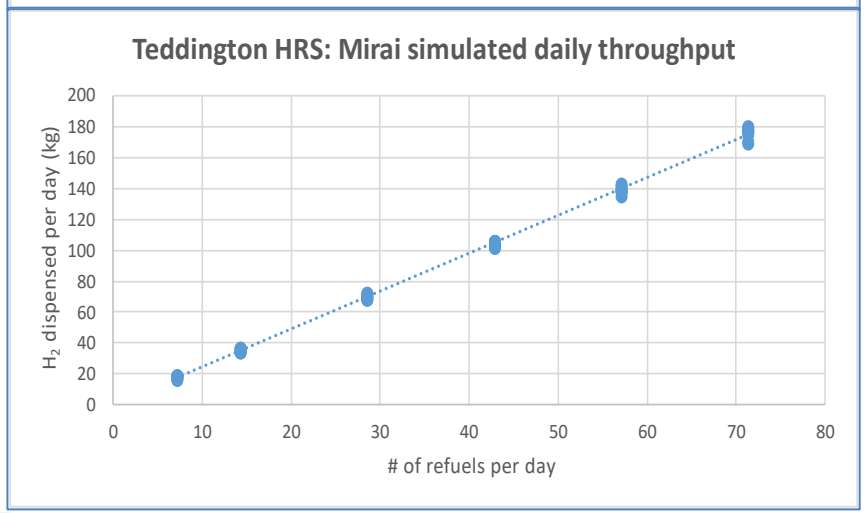
- As expected, the more times the simulation is run, the closer the simulated output reflects the real-world data.

Simulated output



H2ME Vehicle & HRS Case Studies
All HRS: Simulation of Effect of Usage on B2B Refuelling





- The top graph shows a limited run (10 weeks) simulation of Mirai B2B refuelling behaviour for varying number of refuels, showing:
  - Proportion of 2 B2B refuels
  - Proportion of 3 or more B2B refuels
- As the usage reaches ~ 70 refuellings per day:
  - The chance of **B2B** refuelling exceeds **40%**
  - The chance of **3 or more B2B** approaches **10%**
  - The HRS average daily load approaches 180kg, near the 200 kg/day limit of many H2ME2 HRS.
- To note:

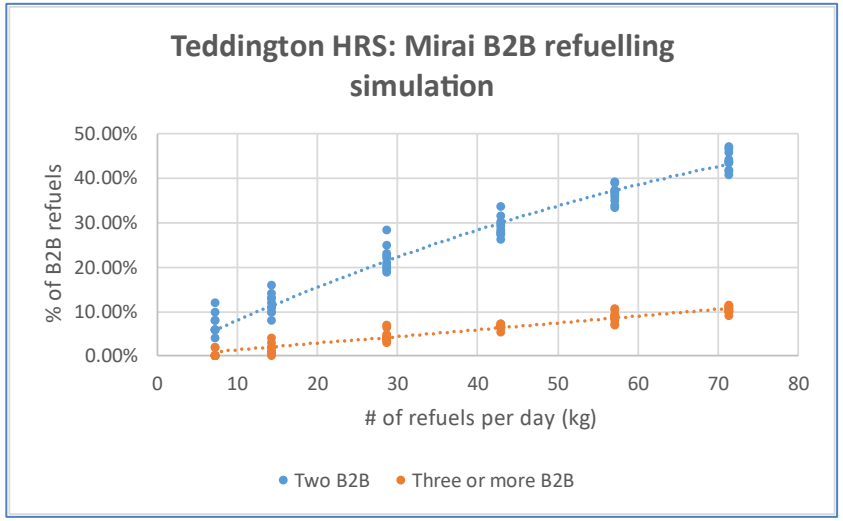
1. The B2B percentages from the simulation appear higher than the values for Teddington shown in previous slides, showing that the requirement for a >650 bar end pressure may underestimate the true B2B value.

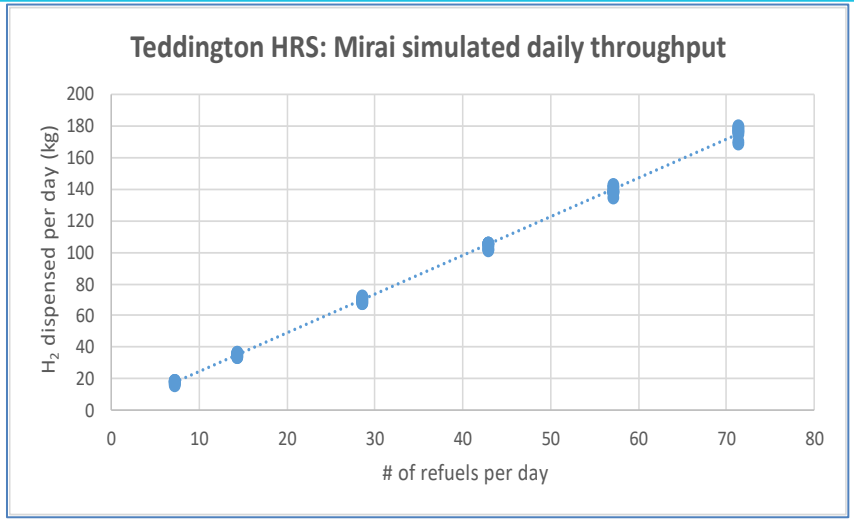
H2ME Vehicle & HRS Case Studies
All HRS: H2ME Vehicle Test Use Cases

Mirai use cases	Km/year	Km/kgH_2	Modelled fleet size	Avg. # of fleet refuels per day	Avg. H_2 required per day (kg)
Taxi UK (ZEFER)	45 000	95	100	58	144
Taxi FR (H2ME2 & ZEFER)	45 000	85	100	64	161
MPS UK (H2ME2 & ZEFER)	32 000	60	100	65	162
H2ME2 Target	15 000	95	100	19	48

- The H2ME2 and ZEFER real-world Toyota Mirai use cases (in terms of km driven per year and fuel efficiency) shown above were used as inputs (in terms of number of refuels and H_2 required per day) to the simulation to show the effect of different levels of vehicle usage on HRS load.
- These use cases are used in the simulation to examine two key questions:
  - At what level of daily usage does the chance of **3 or more B2B** approach **10%?**
  - At what level of daily usage does the usage approach the 200kg/day limit of many H2ME2 HRS?

H2ME Vehicle & HRS Case Studies
All HRS: H2ME Vehicle Test Use Cases and HRS Load (1)

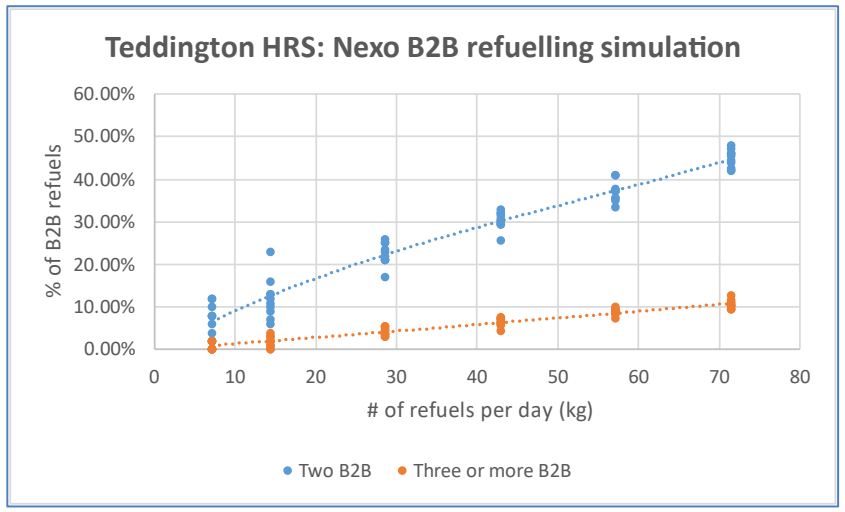


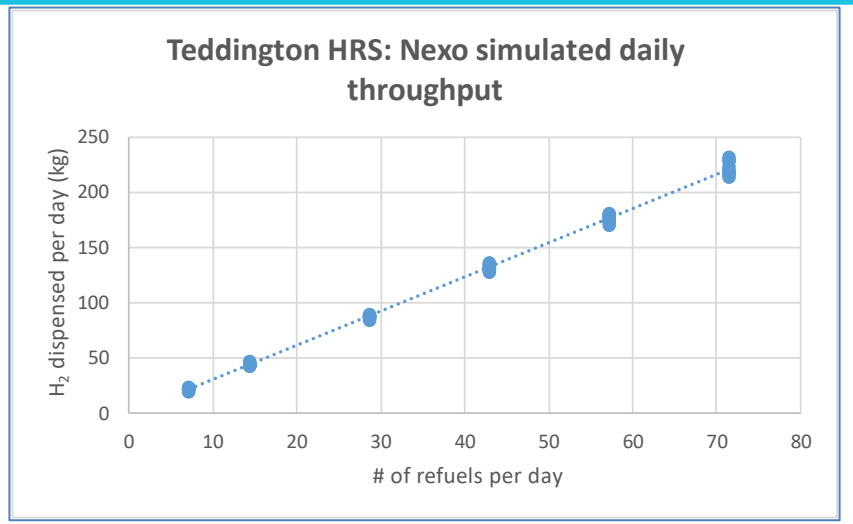


Mirai use cases	Km/year	Km/kgH_2	Fleet size	Avg. fleet refuels per day	H_2 required per day (kg)
Taxi UK (ZEFER)	45 000	95	100	58	144
Taxi FR (H2ME2 & ZEFER)	45 000	85	100	64	161
MPS UK (H2ME2 & ZEFER)	32 000	60	100	65	162
H2ME2 Target	15 000	95	100	19	48

- For modelled 100 Mirai high usage (taxi, police vehicle) applications, the H2ME2 HRS limit on daily throughput (~ 200 kg) is reached at ~same time as 3xB2B refuelling becomes a concern (~10% of refuels).
- For 'normal' passenger car applications (i.e., the H2ME-2 target), this level of usage would not be reached until ~ 300 vehicles used the HRS.

H2ME Vehicle & HRS Case Studies
All HRS: H2ME Vehicle Test Use Cases and HRS Load (2)





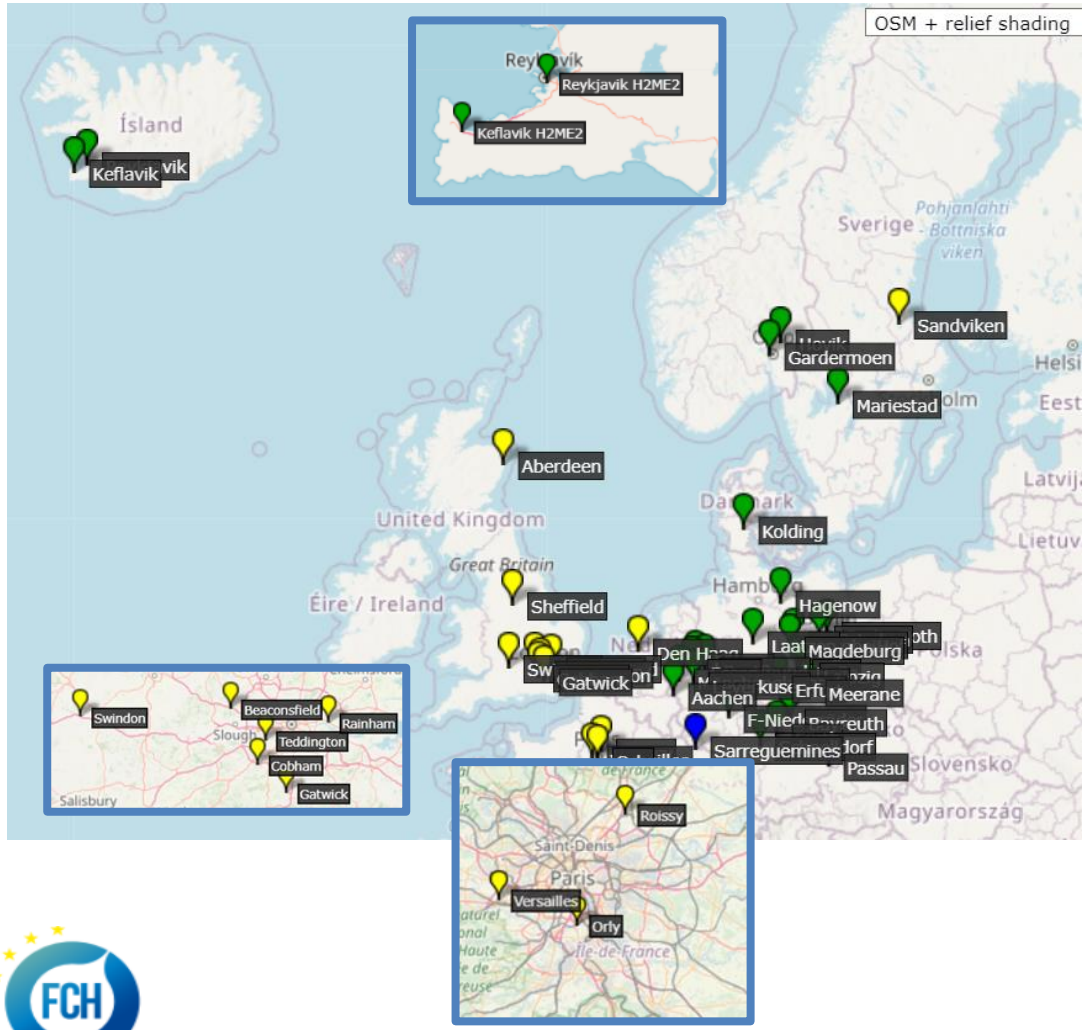
Replace Mirai with Nexo	Km/year	Km/kgH_2	Fleet size	Avg. fleet refuels per day	H_2 required per day (kg)
Taxi UK (ZEFER)	45 000	95	100	45	144
Taxi FR (H2ME2 & ZEFER)	45 000	85	100	50	161
MPS UK (H2ME2 & ZEFER)	32 000	60	100	51	162
H2ME2 Target	15 000	95	100	15	48

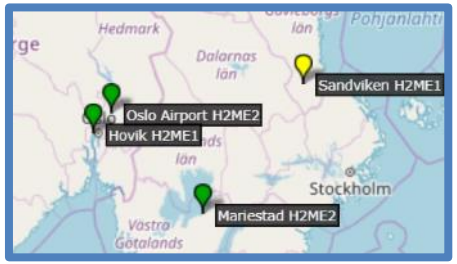
- Replacing Mirais with Nexos in the simulation (but assuming the same relative refuelling behaviour as the Mirai), means fewer refuels per day, reducing the 3xB2B probability and increasing the likelihood that daily HRS capacity would be the performance limiting factor rather than B2B capability.

Contents

- Introduction to H2ME
- Summary of vehicle results
- Case studies of FCEV operation during H2ME-2:
  - Honda Clarity FCEVs in Denmark, Germany and Switzerland
  - Symbio FC REEV operation in France, Germany and the UK: electricity and hydrogen usage and refuelling
- FCEV efficiency, safety and reliability
- HRS performance with increasing levels of utilisation
- **Summary of HRS results**
- Summary results by project

H2ME HRS Overview
HRS Reporting Data

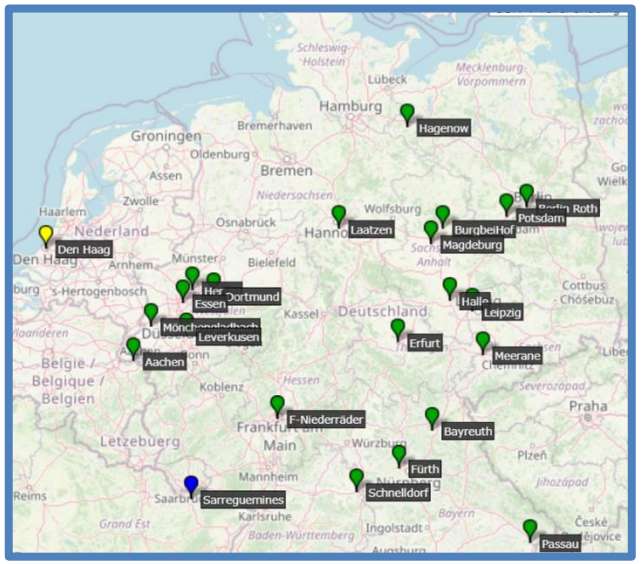




700 bar station

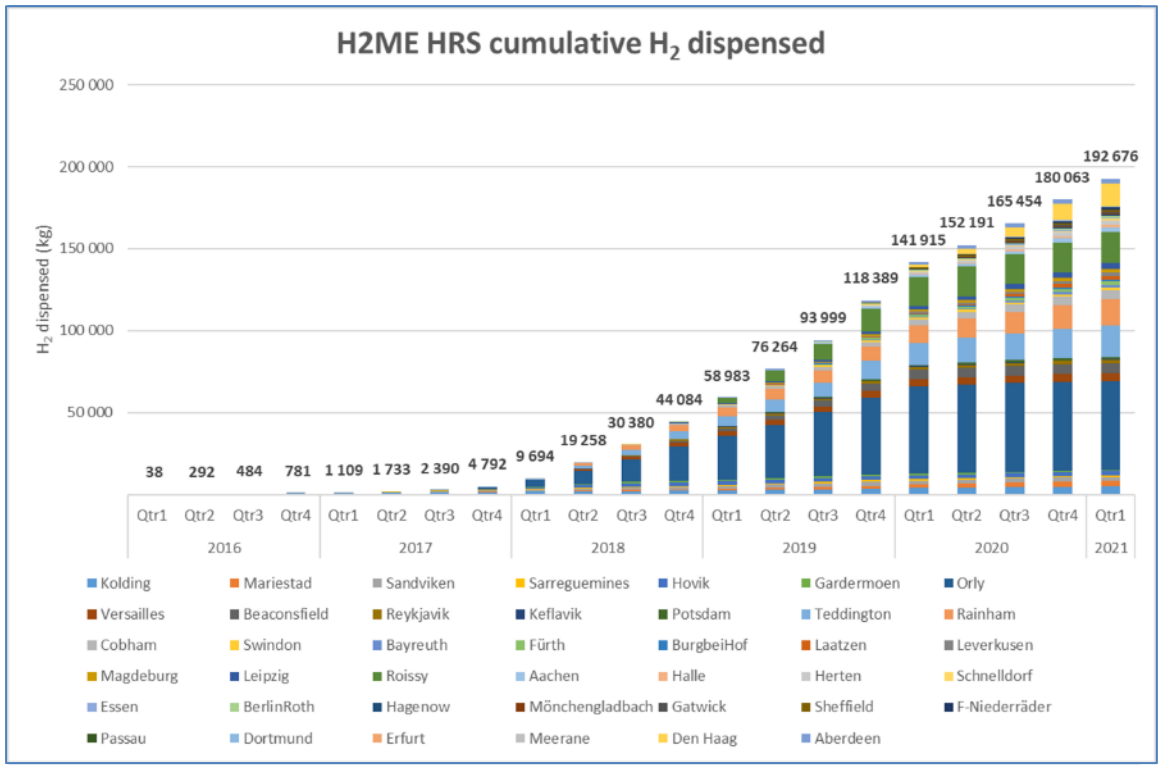
700 & 350 bar station

350 bar station



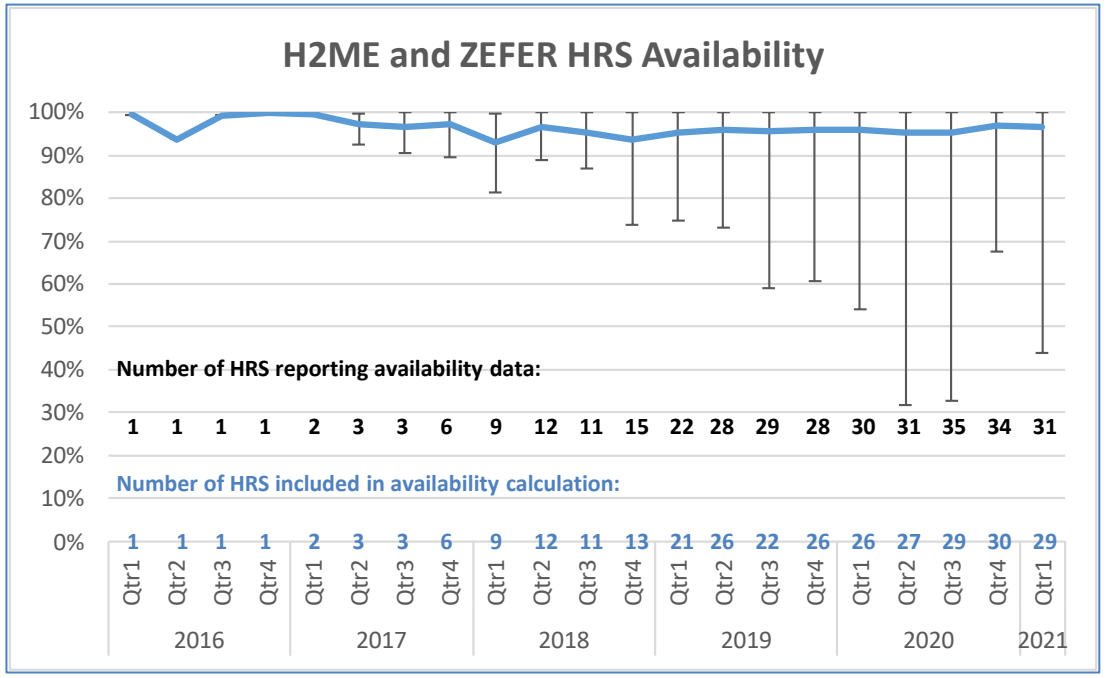
- 39 HRS in eight countries currently report data to H2ME

H2ME HRS Overview
Hydrogen Dispensed



- 39 stations which report data to H2ME have dispensed **192 700 kg** of hydrogen in **84 866** refuelling events since March 2016.
- The growth in H_2 dispensed slowed in 2020 due to the impact of COVID-19 on some vehicle usage.
- Five stations have dispensed over 5 000 kg and together account for ~2/3 of the HRS H_2 reported by the project.
- These stations are in locations where FCEV taxis are deployed, demonstrating the importance of high-use fleet vehicles in promoting the HRS business case:
  - Orly (Paris, FR) 54 000 kg
  - Roissy (Paris, FR) 18 600 kg
  - Rainham (London, UK) 15 900 kg
  - Teddington (London, UK) 19 390 kg
  - Den Haag (NL) 13 700 kg.

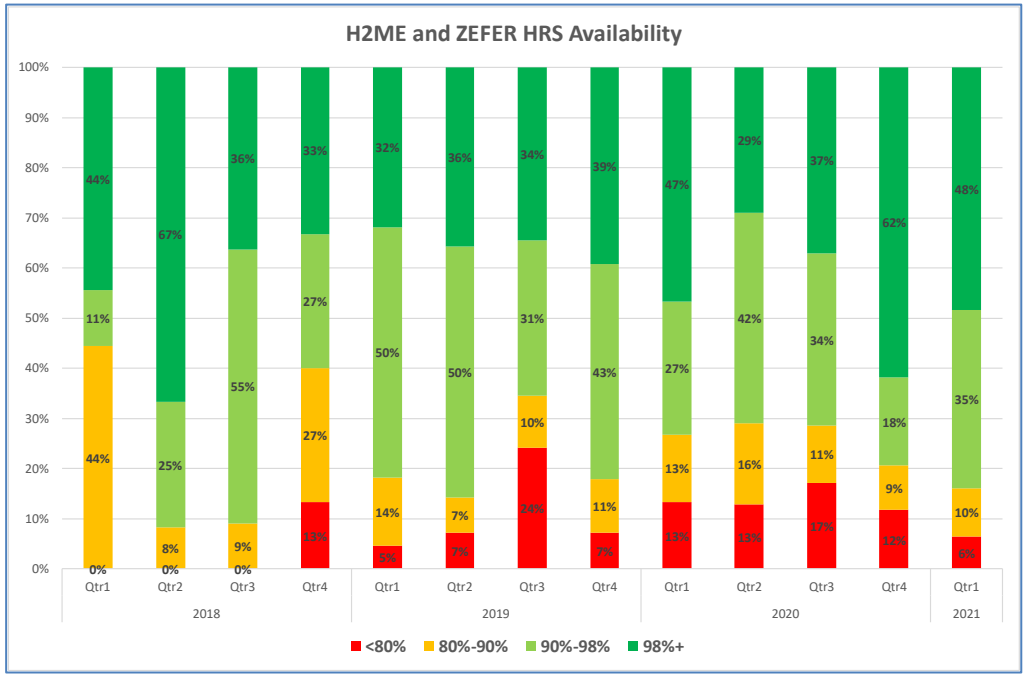
H2ME HRS Overview
Station Availability



- The definition of HRS availability is focused on the user (i.e. – can the station dispense H_2?), but excludes maintenance.
- The graph is presented as recommended by the HyLights Monitoring and Assessment Framework * – i.e., minimum-maximum/average – to maintain anonymisation of the HRS from individual project OEMs (Level 4 as per the DoA).
- The black bars show the lowest and highest HRS availability in the quarter.
- The project-average station availability is currently **96.5%** (blue line).
- The reported average excludes HRS which have exhibited unusually-low availability in a given quarter (less than 80%) as these are generally down to one-off issues or, more recently, COVID-19 related problems (e.g., lack of parts and available maintenance staff).

* https://www.fch.europa.eu/sites/default/files/HyLights_D3_3_MAF-Handbook-II_Final%20%28ID%202875010%29.pdf.

H2ME HRS Overview
Station Availability: Non-HyLights Presentation



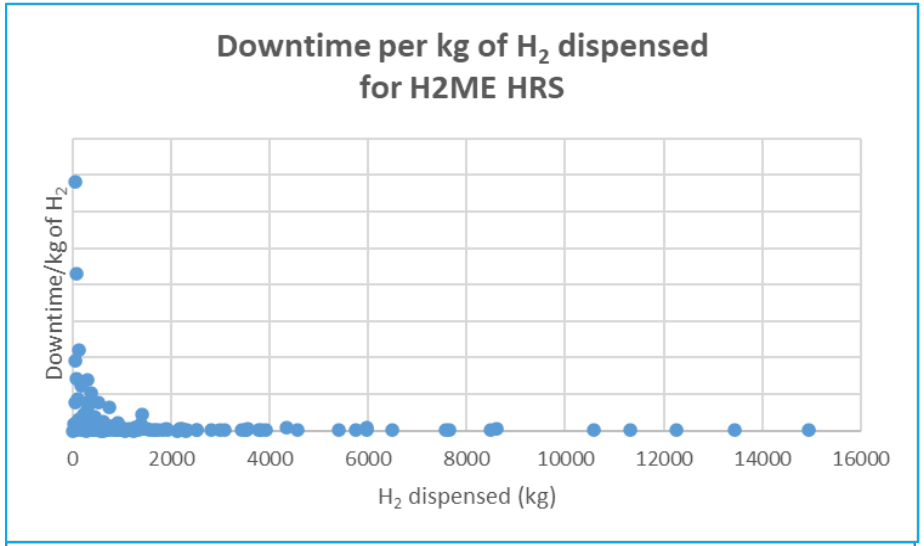
Number of HRS reporting availability data:

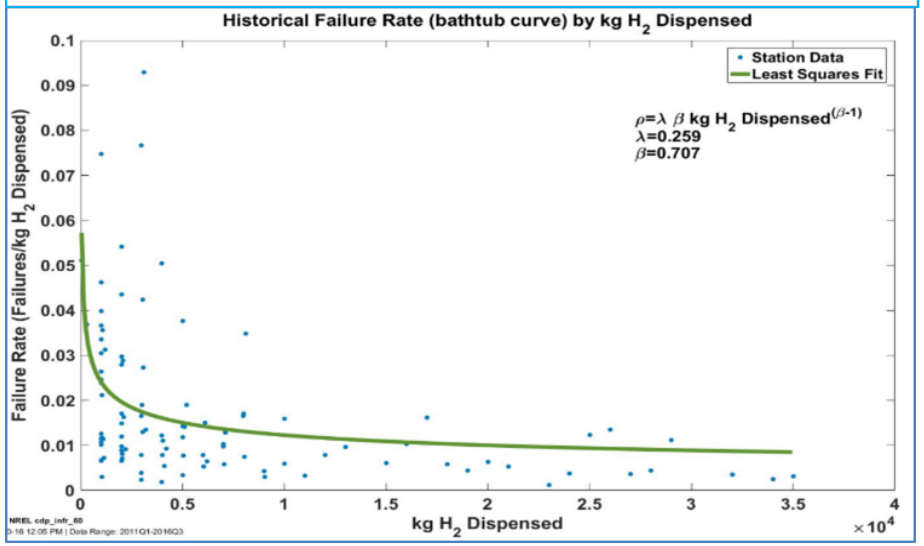
9	12	11	15	22	28	29	28	30	31	35	34	31

- The definition of HRS availability is focused on the user (i.e. – can the station dispense H_2?), but excludes maintenance.
- This stacked graph shows the availability of all HRS from 2018 using the same presentation as that used by H2MDE in the last GA.
- The graph shows that half of the project HRS exceeded 98% availability in 2021 Q1.
- The graph also shows the impact on availability of the introduction of increasing numbers of new HRS from late 2018 onwards as shown by the increase in the proportion of HRS exhibiting low (<80%) availability in each quarter as new HRS are introduced.
- As stated in the previous slide, the project-average station availability of all HRS excluding those reporting under 80% availability is currently **96.5%.**

* https://www.fch.europa.eu/sites/default/files/HyLights_D3_3_MAF-Handbook-II_Final%20%28ID%202875010%29.pdf.

H2ME HRS Overview
Station Reliability: the Effect of Adding New HRS

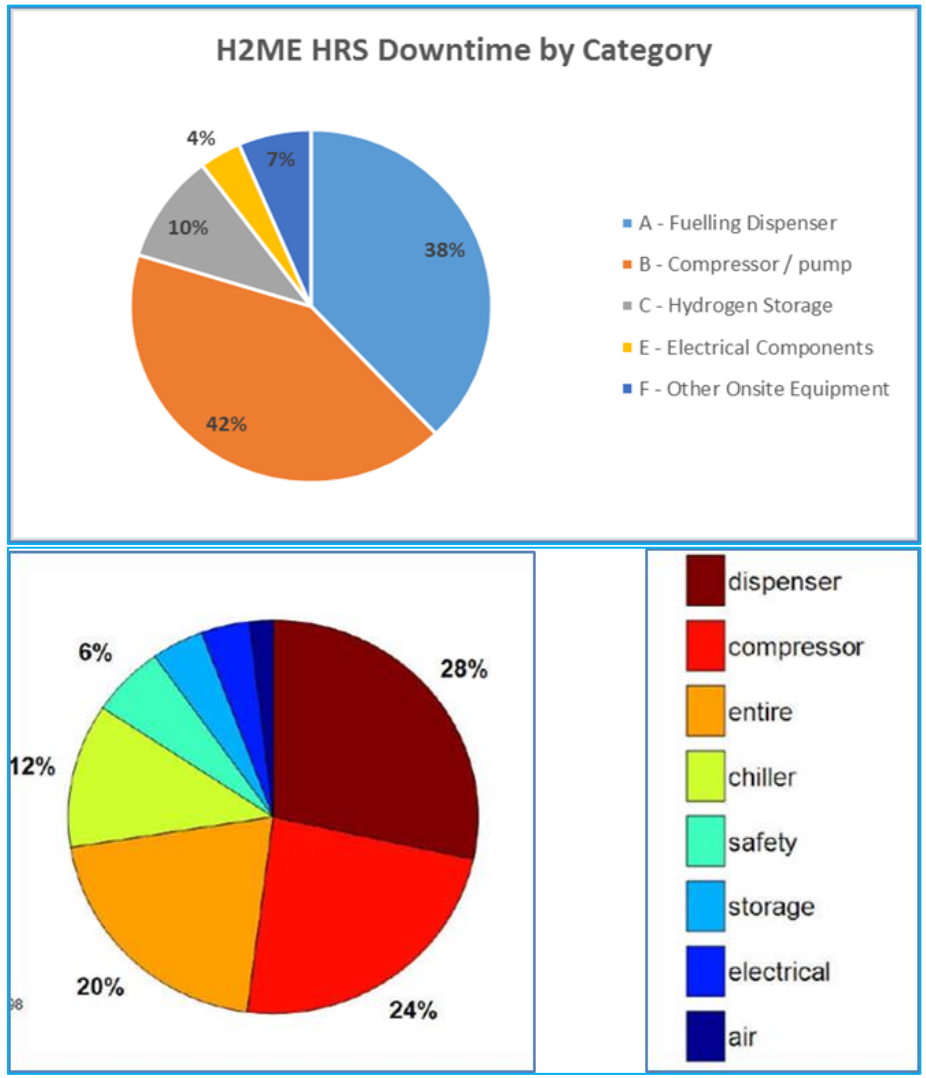




- The top graph shows that the reliability of H2ME HRS typically improves after initial issues.
- This is a well-known phenomenon in reliability engineering called the *bathtub curve,* which consists of three phases:
  - The first phase consists of initial teething problems as defective components are identified.
  - During the second, main, phase of HRS lifetime the failure rate is lower and relatively constant as increasing usage irons out early problems.
  - Eventually as the station ages, it is anticipated that the failure rate will rise again (hence bathtub curve) as components wear out.
- The bottom graph demonstrates that the US DOE Fuel Cell Technologies Office Learning Demonstration stations show a similar reliability improvement as more hydrogen is dispensed*.

* https://www.hydrogen.energy.gov/pdfs/progress16/vii_b_1_sprik_2016.pdf, CDP-INFR-59, May 2018

H2ME HRS Overview
Station Availability: Causes of Downtime

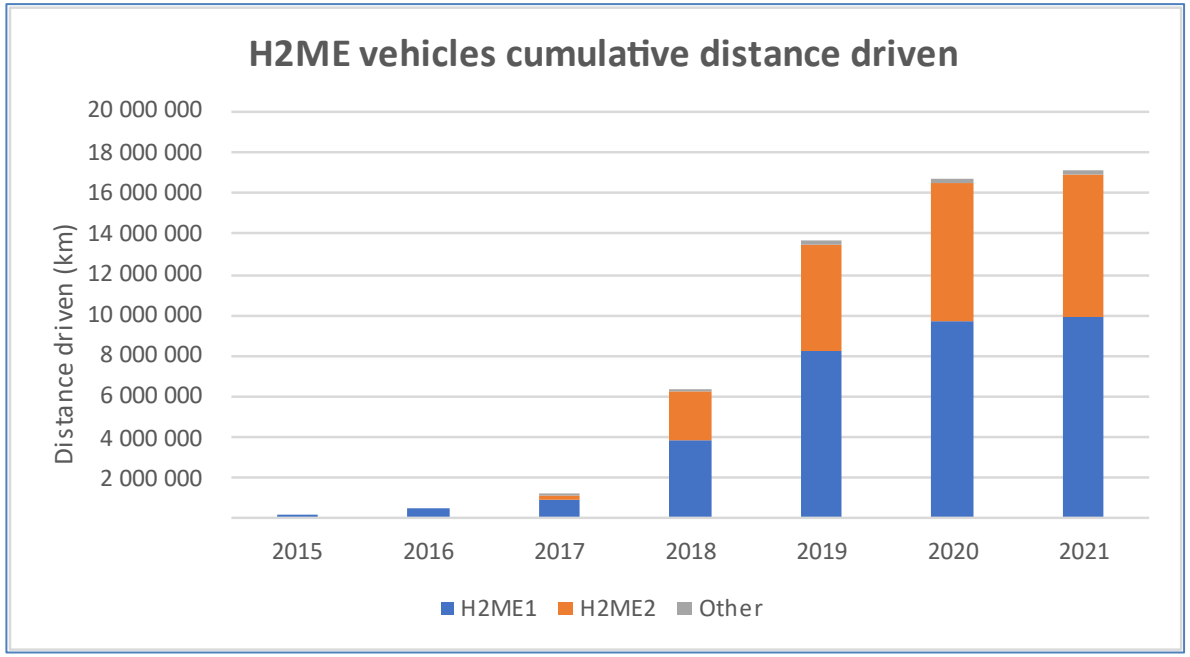


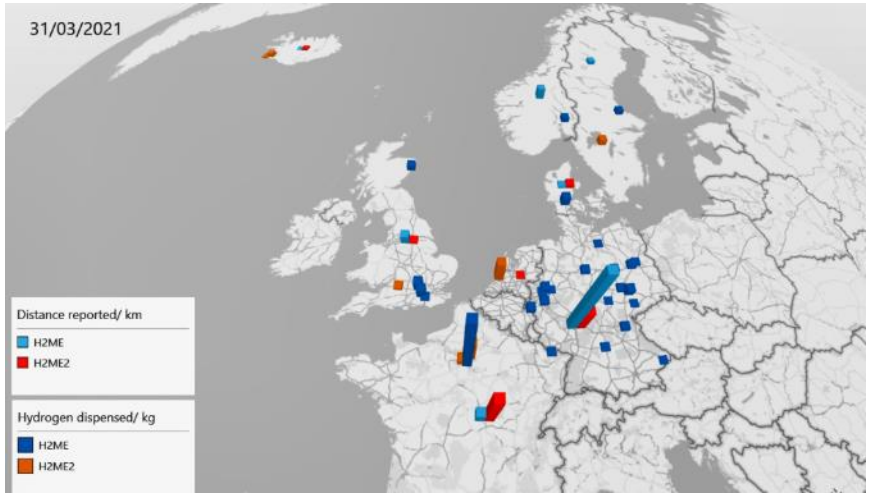
- The top pie chart shows that issues with fuelling dispensers, chillers and compressors dominate H2ME HRS downtime.
- Electrolyser downtime for stations with electrolysers is not included to maintain HRS OEM anonymisation and to allow comparison across all stations.
- Dispenser, compressor and chiller issues were also seen to be the main single causes of station downtime in the US DOE Fuel Cell Technologies Office Learning Demonstration stations (bottom pie chart), although not all categories in the two pie charts are directly comparable*.
- For example, H2ME did not, in the past, report chiller outages as these were not considered by HyLights[+], which was published in 2011. Since that time, chillers have become a key component of HRS as precooling is an integral part of the SAE J2601 protocol.[x]

* https://www.nrel.gov/hydrogen/infrastructure-cdps-retail.html CDP-INFR-21, May 2018
[+] https://www.fch.europa.eu/sites/default/files/HyLights_D3_3_MAF-Handbook-II_Final%20%28ID%202875010%29.pdf
[x] https://www.sae.org/standards/content/j2601_202005/ for details.

Contents

H2ME Vehicle Overview
Distance Reported

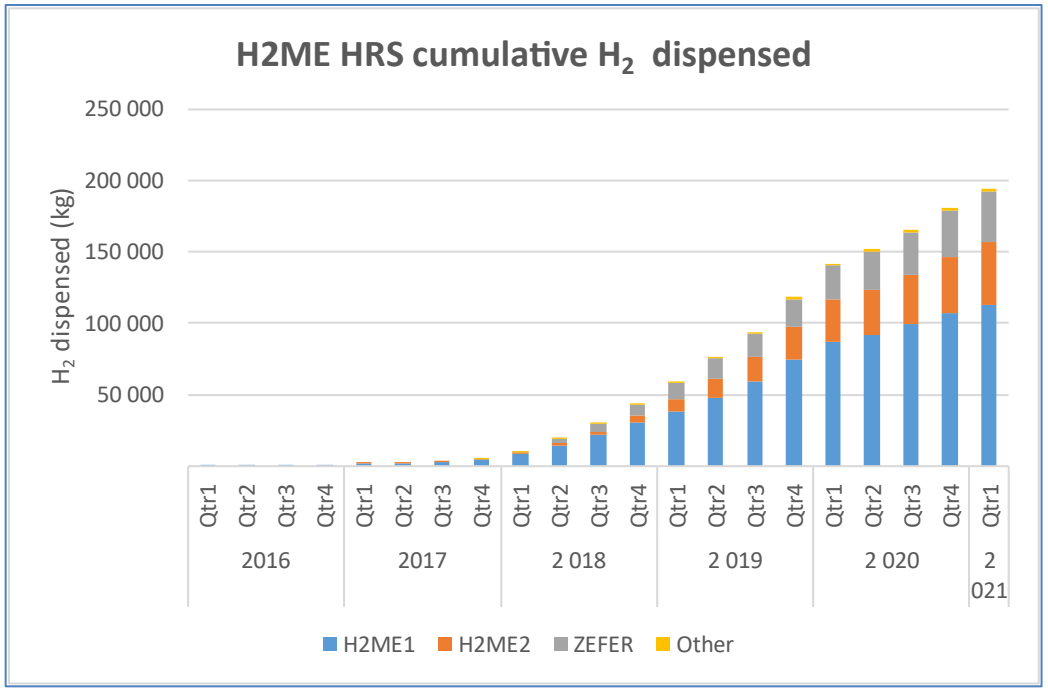


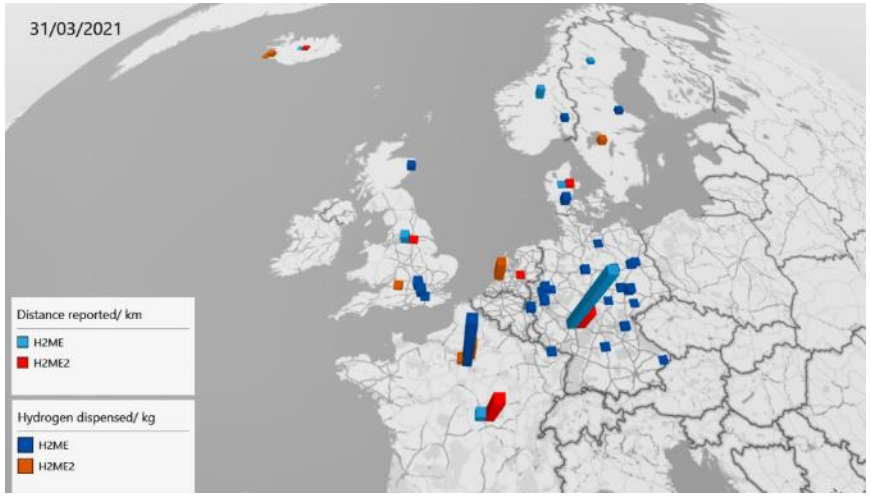


Project	Distance reported
H2ME1	9 872 000
H2ME2	7 068 000
Other	218 000*

* Non-H2ME Symbio vehicles providing data to the project

H2ME HRS Overview
Hydrogen Dispensed





Project	H_2 dispensed (kg)	# of refuels	# of HRS
H2ME1	112 996	49 051	29*
H2ME2	44 510	20 136	7
ZEFER⁺	35 178	14 864	2
Other⁺	1 900	1 246	1*

* 2 HRS in Norway (1 H2ME1, one other) no longer report data to the project
⁺ Non-project stations reporting data to H2ME as per the DoA

Acknowledgements

The authors thank the H2ME project partners for providing data and constructive input.
This project has received funding from the **Fuel Cells and Hydrogen 2 Joint Undertaking** under grant agreement No 671438 and No 700350. This Joint Undertaking receives support from the **European Union**'s Horizon 2020 research and innovation programme, the New European Research Grouping on Fuel Cells and Hydrogen ("**N.ERGH**Y") and **Hydrogen Europe**.