ZERO EMISSION FLEET VEHICLES FOR EUROPEAN ROLLOUT

Quarterly Technical Report on Vehicle and Refuelling Station Operation

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FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Executive Summary (1)

- ZEFER (https://zefer.eu/, 2017-2022) aims to demonstrate that operating fuel cell electric vehicles (FCEVs) in urban vehicle applications can be commercially and operationally viable.
- This report, which is updated quarterly, summarises the results of the operation to the end of December 2019 of the Toyota Mirai FCEVs and hydrogen refuelling stations (HRS) that have been deployed by ZEFER:
  - **In London,** Green Tomato Cars (GTC) began operating 25 FCEVs as taxis in April 2018 and incorporated 25 more in November 2019.
  - **In London,** the Metropolitan Police Service (MPS) operates ten Toyota Mirais as general purpose police vehicles, joining the existing 11 Mirais in its fleet.
  - **In Paris,** STEP (Société du Taxi Electrique Parisien), via its Hype joint venture with Air Liquide, has deployed 53 ZEFER-supported Toyota Mirai FCEVs taxis in Paris since August 2018. Hype now operates a 100+ strong FCEV taxi fleet.
  - The vehicles in London and Paris use a network of hydrogen refuelling stations across the cities.

Executive Summary (2)

- To the end of December 2019, the ZEFER FCEVs drove **2 714 000 km*.**
- Hydrogen refuelling stations (HRS) used by ZEFER vehicles in France and the UK dispensed **32 500 kg of hydrogen in 2018 and 58 000 kg in 2019**. Not all the hydrogen was dispensed to ZEFER vehicles – much of the hydrogen in France was dispensed to STEP FCEV taxis that are supported by the H2ME2 project (https://h2me.eu/).
- FCEV taxi driving and refuelling patterns in London and Paris are similar, with vehicles driving ~ 200km between refuels and averaging just over 2 kg per hydrogen refuel (the Mirai has a 5kg tank capacity).
- Preliminary investigations of driving patterns to understand the possible influence of Clean Air Zone (CAZ) charging reveal that GTC taxis enter the current London Ultra Low Emission Zone (ULEZ) 73% of days, but 97% of days in the future 2021 ULEZ.
- The FCEVs have proven to be reliable (**> 99% availability**), with a small amount of off-road time associated with normal taxi use (minor impacts and tyre replacements). The Toyota Mirais are serviced every 10 000 km.
- There were no vehicle or HRS safety issues recorded.

* Last data received from GTC Sept 2019, last from MPS Aug 2019. No further data received at time of writing.

Abbreviations

Abbreviation	Definition
CAZ	Clean Air Zone
CCZ	London Congestion Charge Zone
FCEV	Fuel Cell Electric Vehicle
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
H_2	Hydrogen
H2ME	Hydrogen Mobility Europe
HRS	Hydrogen Refuelling Station
HyTEC	Hydrogen Transport in European Cities
LEZ	London Low Emission Zone
MPS	Metropolitan Police Service (London)
NEDC	New European Driving Cycle
NiMH	Nickel Metal Hydride
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
ULEZ	London Ultra Low Emission Zone
ZEFER	Zero-Emission Fleet vehicles for European Rollout
ZFE	Paris Zone à Faibles Émissions

Contents

Content

- **Introduction to ZEFER**
- Summary of results
- FCEV taxi operation by Green Tomato Cars in London
- FCEV operation by the Metropolitan Police Service in London
- FCEV operation by STEP/Hype in Paris
- FCEV safety and reliability
- HRS operation
- Conclusions

ZERO EMISSION FLEET VEHICLES FOR EUROPEAN ROLLOUT (2017-2022)

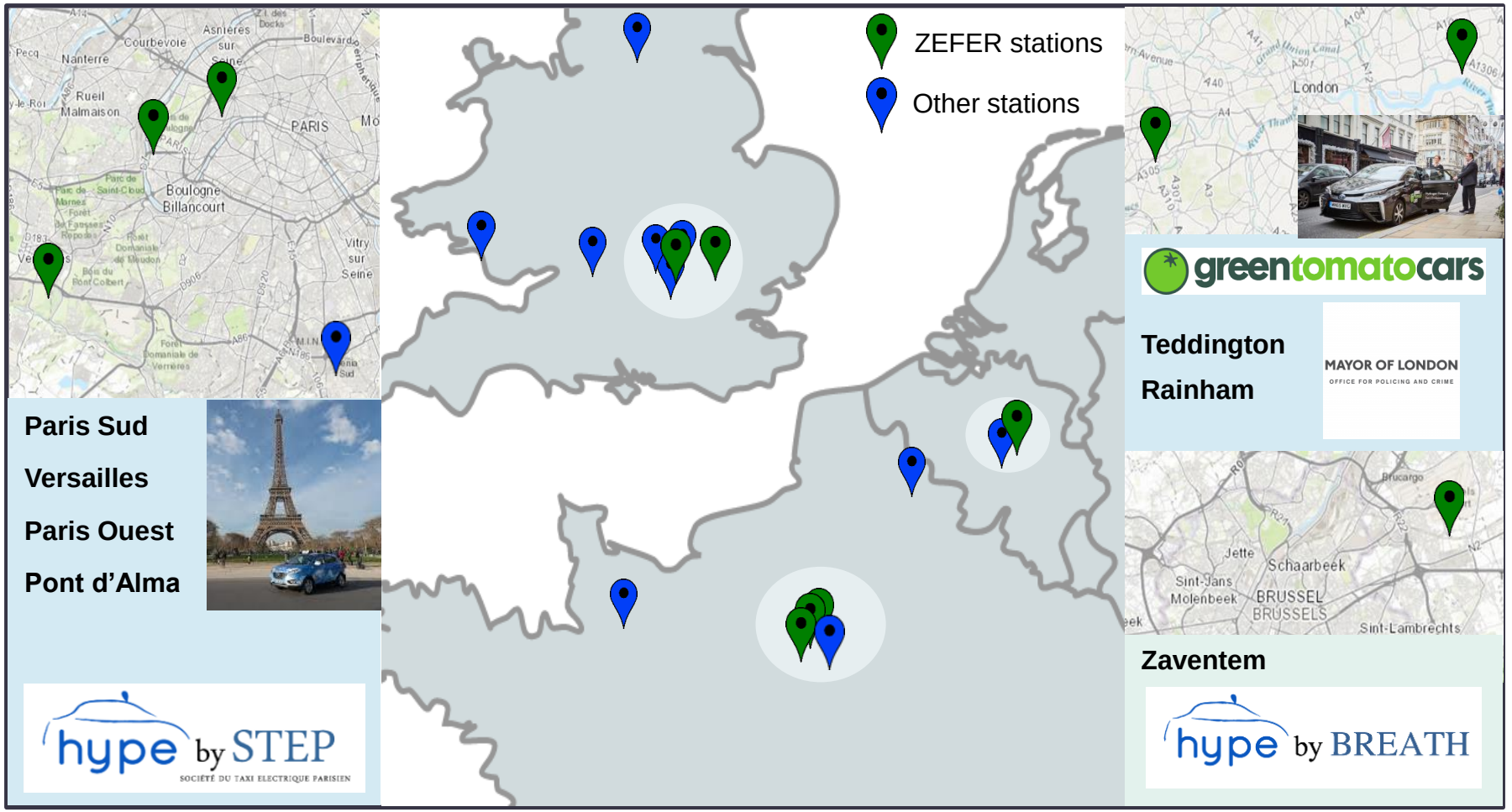
Introduction

- ZEFER (https://zefer.eu/) aims to demonstrate that operating fuel cell electric vehicles (FCEVs)* in urban vehicle applications can be commercially viable compared to diesel alternatives. The FCEV use cases that will be investigated by ZEFER are:
  - As taxis in intensive (up to 24/7) high-mileage operation, and
  - In inner-city fleets where their zero-emission characteristics are of particular value.
- ZEFER will deploy FCEVs and associated hydrogen refuelling stations (HRS) in three locations:

Location	No. of FCEV	No. of HRS**	Role of FCEV	User of FCEV
Paris	60	3	Taxi	STEP
Brussels	60	1		BREATH
London	50	2		Green Tomato Cars
London	10		Police vehicle	Metropolitan Police

* FCEVs use compressed hydrogen stored on-board to generate electricity in a fuel cell which is used to provide power. The vehicles emit only water.
** Number of HRS directly supported by the project. All locations already have additional HRS as shown overleaf.

ZEFER's FCEVs and HRSs will Complement Existing Activities in Belgium, France and the UK



Paris Sud

Versailles

Paris Ouest

Pont d'Alma

hype by STEP
SOCIÉTÉ DU TAXI ELECTRIQUE PARISIEN

greentomatocars

Teddington

Rainham

MAYOR OF LONDON
OFFICE FOR POLICING AND CRIME

Zaventem

hype by BREATH

ZEFER
Vehicles Deployed (data to December 2019)

- 71 of ZEFER's planned 180 FCEVs have reported data so far (pending data from GTC's new 25 vehicles).
- **In London:**
  - Green Tomato Cars deployed 25 Toyota Mirai FCEVs as private-hire taxis in London starting in April 2018 and added 25 more in November 2019.
  - The vehicles have joined Green Tomato Cars' existing fleet of 600 low emission taxis.
  - MPS has deployed ten Toyota Mirais as general purpose police vehicles joining the existing 11 Mirais in its fleet.
- **In Paris:**
  - STEP (Société du Taxi Electrique Parisien), via its Hype joint venture with Air Liquide, began deploying ZEFER-supported Toyota Mirai FCEVs taxis in Paris in August 2018.
  - The most recent data report (December 2019) included 107 vehicles: 47 deployed through ZEFER (all Mirais) and a further 60 supported by the H2ME2 project (mainly Hyundai ix35s).

ZEFER
Vehicle Technical Specification

	Toyota Mirai
Vehicle	
Vehicle architecture	Battery/fuel cell parallel hybrid
Top Speed	179 kph
Seats	4
Acceleration 0 → 100 km/h	9.6s
Range (NEDC)*	605 km
Stack Technology	PEM**
Stack Power Rating	113 kW
Tank Capacity	5 kg H_2
Tank Pressure	700 bar
Battery Pack Size	1.6 kWh NiMH***

* New European Drive Cycle
** Proton Exchange Membrane
*** Nickel Metal Hydride

Contents

Content

- Introduction to ZEFER
- **Summary of results**
- FCEV taxi operation by Green Tomato Cars in London
- FCEV operation by the Metropolitan Police Service in London
- FCEV operation by STEP/Hype in Paris
- FCEV safety and reliability
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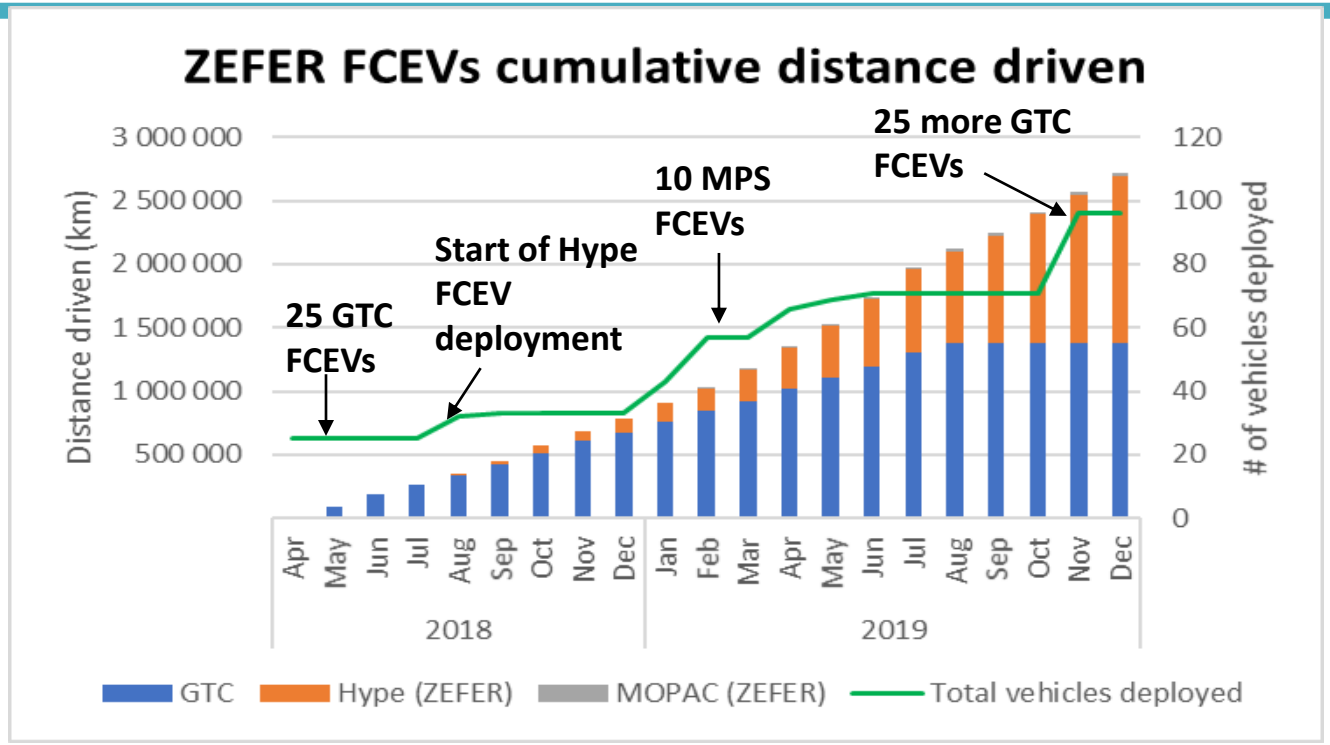
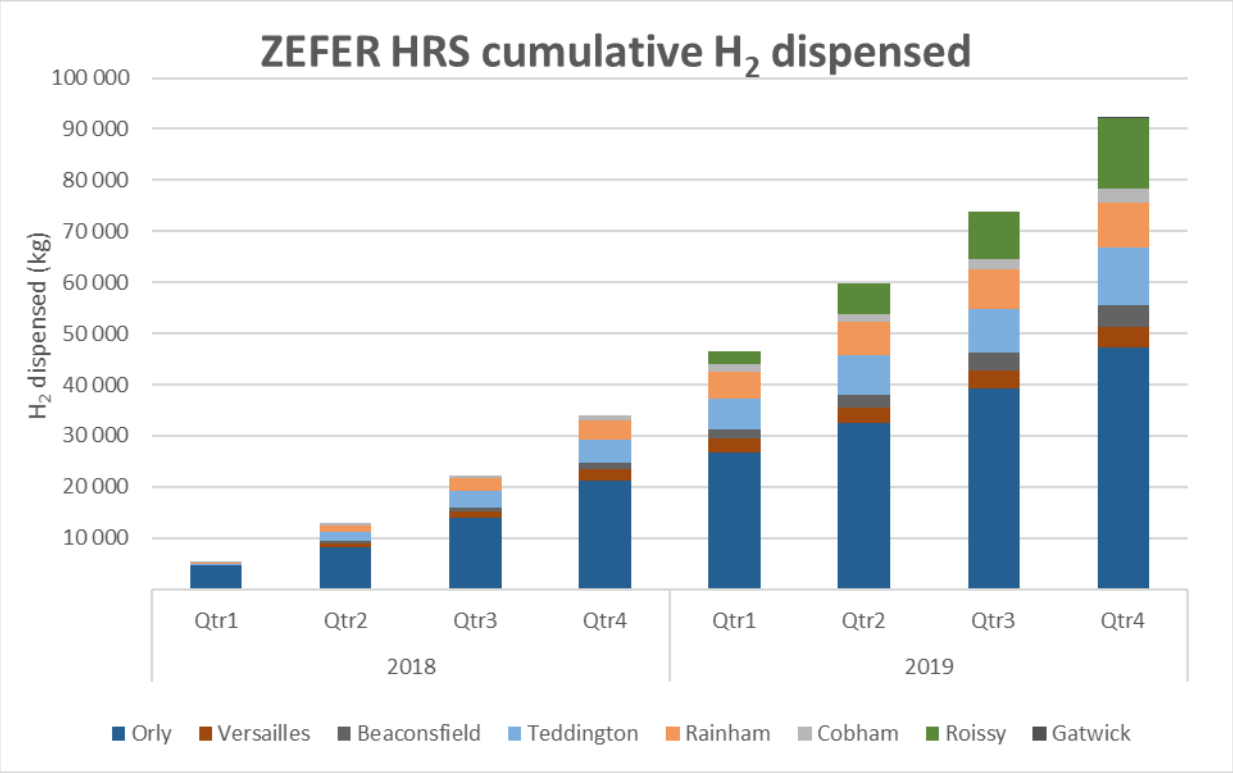
FCEVs
Cumulative Distance Driven and Vehicles Deployed



- ZEFER FCEV taxis in London and Paris, plus the MPS police vehicles in London, have reported **2 710 000 km** driven since April 2018*.
- Hype taxis deployed by H2ME2 in Paris have reported an additional 4 060 000 km driven since June 2017.
- MPS H2ME vehicles reported a further 278 000 km driven since 2017 (pending update).

* Last data received from GTC Sept 2019, last from MPS Aug 2019. No further data received at time of writing.

HRS
Cumulative Hydrogen Dispensed



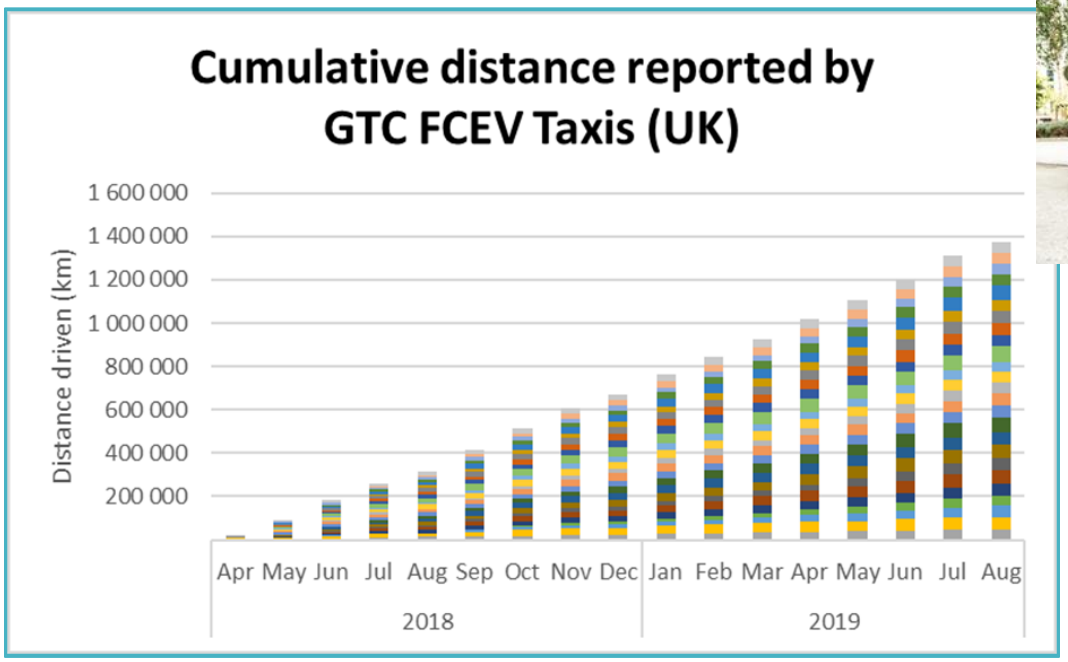
- HRS in France and the UK used by ZEFER vehicles have dispensed 92 300 kg H_2. The Orly station alone has dispensed 47 200 kg.
- Not all the hydrogen was dispensed to ZEFER vehicles – for example, much of the hydrogen in France was dispensed to STEP FCEV taxis that are supported by H2ME2.

Contents

Content

- Introduction to ZEFER
- Summary of results
- **FCEV taxi operation by Green Tomato Cars in London**
- FCEV operation by the Metropolitan Police Service in London
- FCEV operation by STEP/Hype in Paris
- FCEV safety and reliability
- HRS operation
- Conclusions

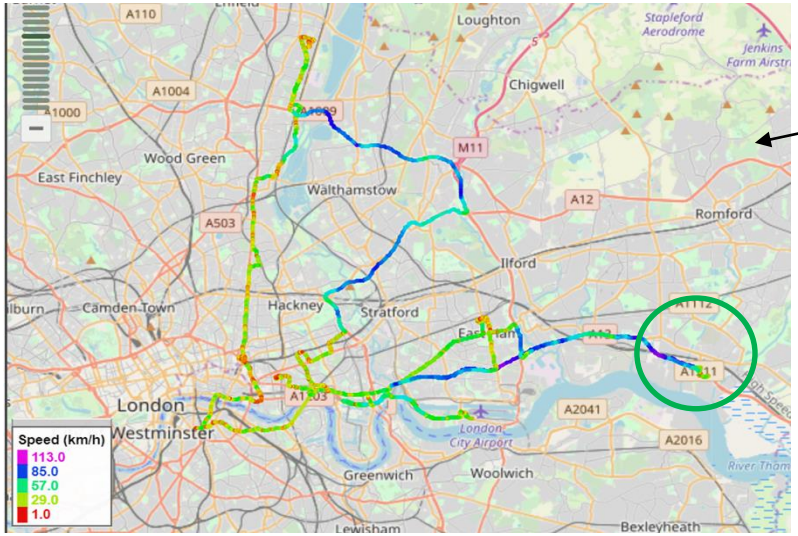
London
FCEV Taxi Operation to end of December 2019

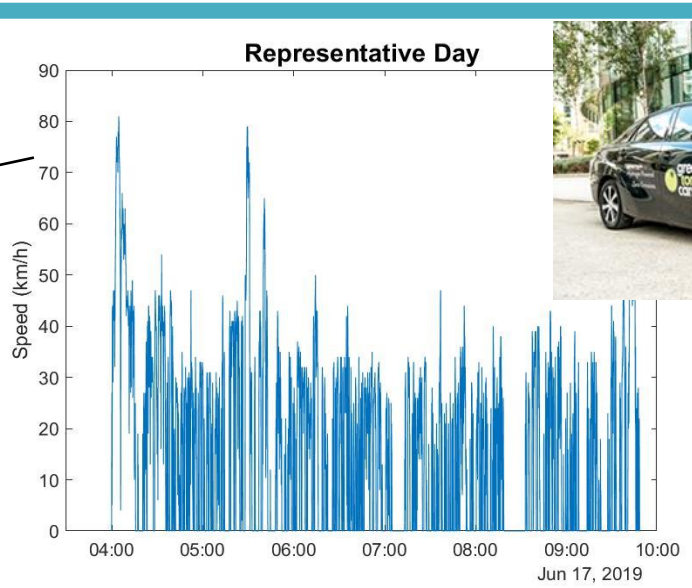


- GTC's 25 FCEV taxis have driven 1 373 000 km since April 2018* (the different-coloured bars on the graph represent the distance driven by individual vehicles).
- The average distance driven by each taxi per month is 3 500 km (~140 km/day).
- The furthest driven by one of the vehicles in a month was 8 400 km.

* Last data received from GTC Sept 2019. No further data received at time of writing.

London
How FCEV Taxis are Being Driven (1)
5 GTC Taxis With Telematics





- The FCEV taxis predominantly operate in an urban environment (i.e., London) as evidenced by their average speed and number of stops, but also drive on major roads and motorways.
- The green circle shows the Rainham HRS where the vehicle refuelled.

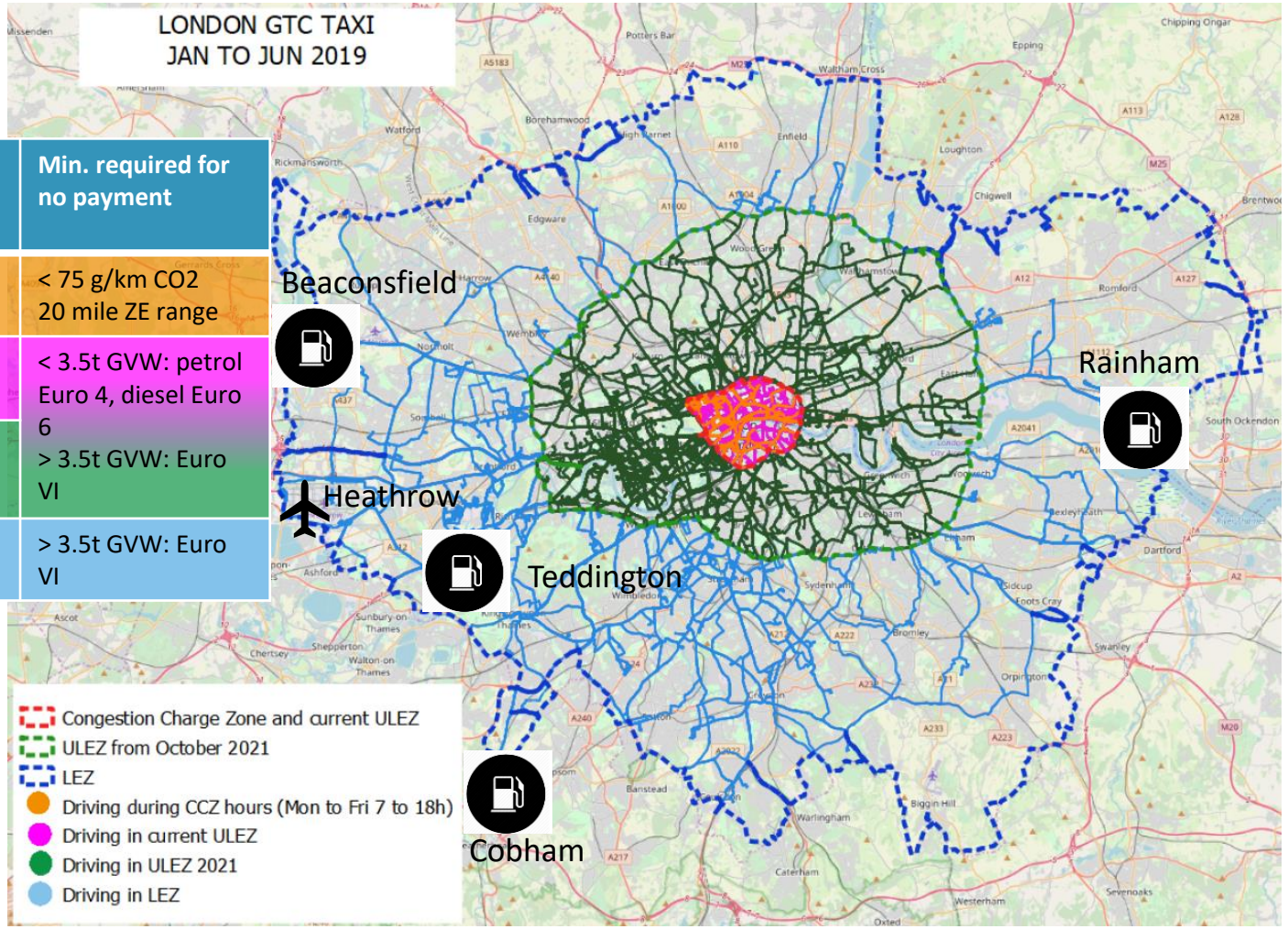
Average daily distance (km)	**110**
Max. daily distance (km)	**515**
Average journeys per day	**8**
Average days/week of usage	**5**
Average daily driving time	**3h 55min**
Average speed (km/h)	**28**
Urban driving %	**48**
Road driving %	**35**
Motorway driving %	**17**

London
How FCEV Taxis are Being Driven (2)
Clean Air Zones

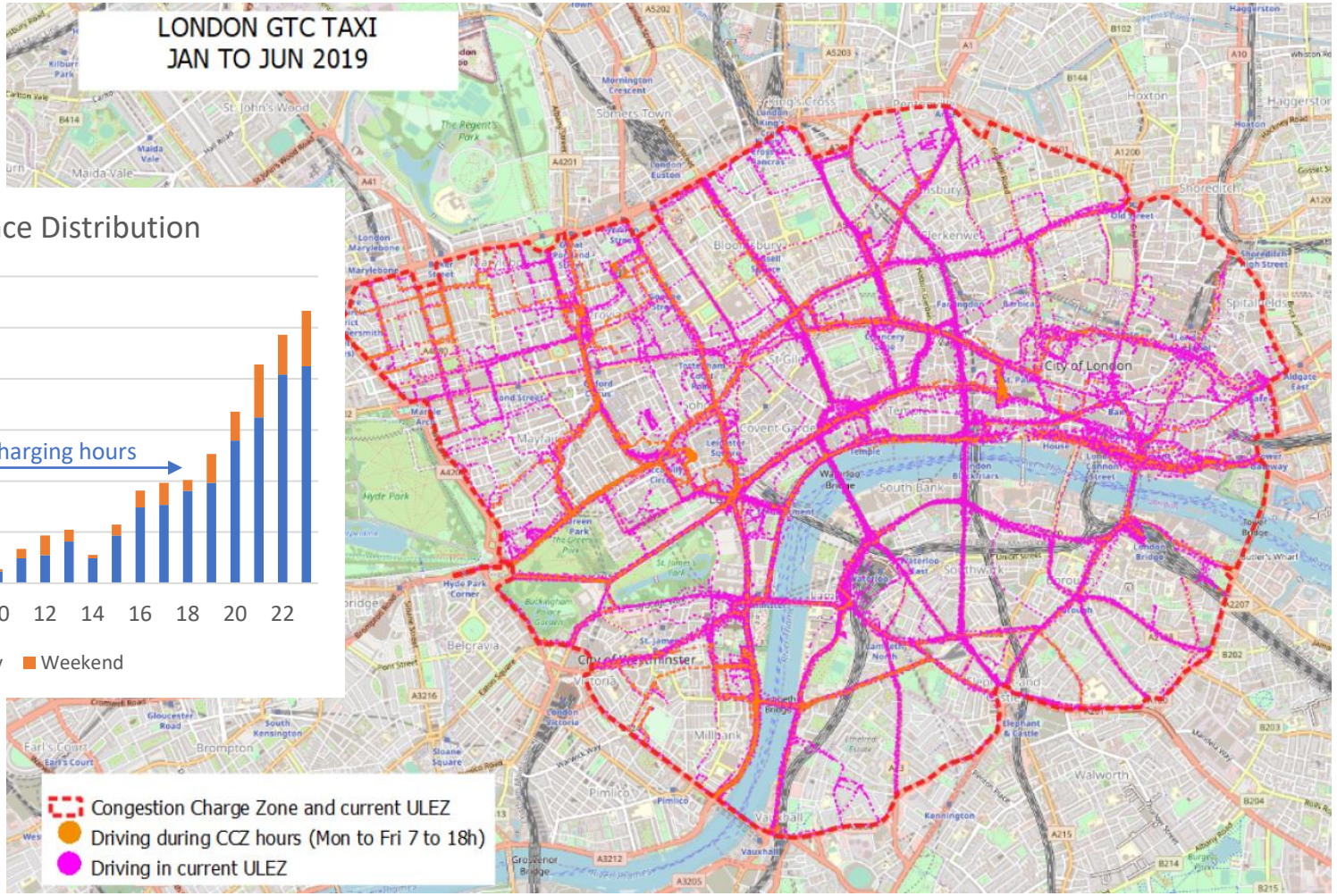
- Clean Air Zones (CAZ) are being introduced in a number of cities. CAZ charges can help reinforce the **business case for city-based FCEVs** compared to petrol/diesel vehicles
- To explore the impact of current and future CAZ charging, Cenex data screening algorithms were used to establish the boundaries of the different **London Clean Air Zones** and the amount of time that GTC's vehicles spend in them:
  - Central London Congestion Charge Zone (CCZ) and current Ultra Low Emission Zone (ULEZ): both have the same boundaries
  - Future ULEZ from October 2021: approximately London's North-South Circular Road
  - Current Low Emission Zone (LEZ): approximately up to M25
- We analysed data for the first six months of 2019 from a GTC vehicle equipped with a Cenex Clear Capture telematics device (fitted to 10% of GTC's fleet)
- Our algorithms calculated the distance and number of days entered in the different areas:
  - This vehicle enters the current ULEZ **73%** of the days
  - It would enter the 2021 ULEZ **97%** of the days

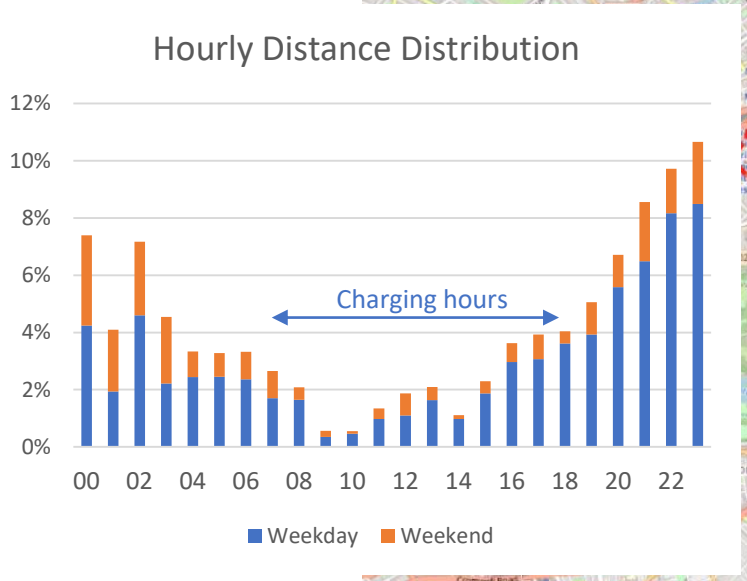
London
How FCEV Taxis are Being Driven (3)
Clean Air Zones

Zone	% days entered in zone	% distance in zone	Min. required for no payment
CCZ (Mon to Fri 7am to 6pm)	20%	1%	< 75 g/km CO2 20 mile ZE range
Current ULEZ	73%	8%	< 3.5t GVW: petrol Euro 4, diesel Euro 6 > 3.5t GVW: Euro VI
ULEZ 2021	97%	53%	
LEZ	97%	83%	> 3.5t GVW: Euro VI



London
How FCEV Taxis are Being Driven (4)
Clean Air Zones





London
How FCEV Taxis are Being Driven (5)

Once we get updated data from GTC, future analysis will include:

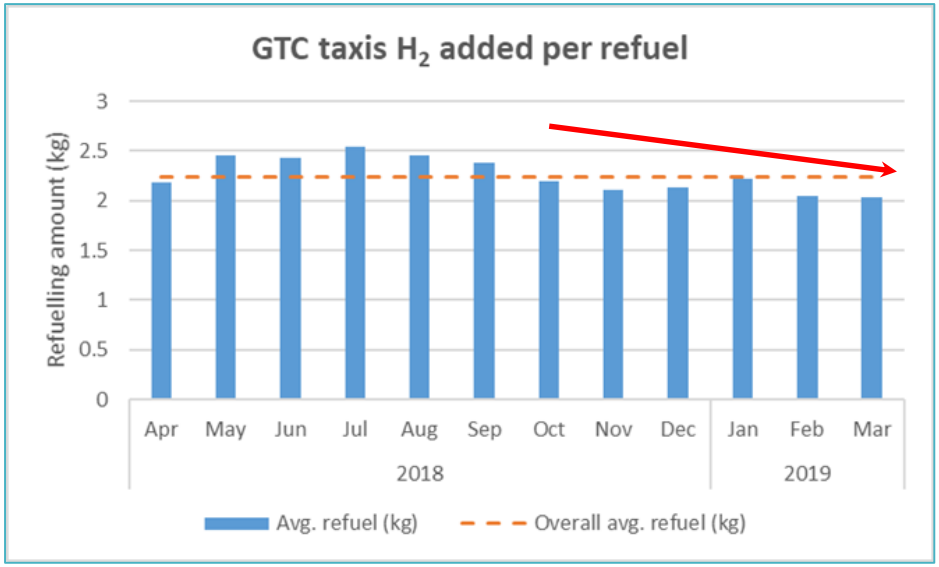
- Taxis with loggers: try to correlate fuel economy with
  - Acceleration
  - Deceleration
  - Idling time
  - Average speed
  - Max speed
  - Urban, rural and motorway driving distribution

- All taxis: seasonal variance of fuel economy

London
Where GTC FCEVs are Refuelling

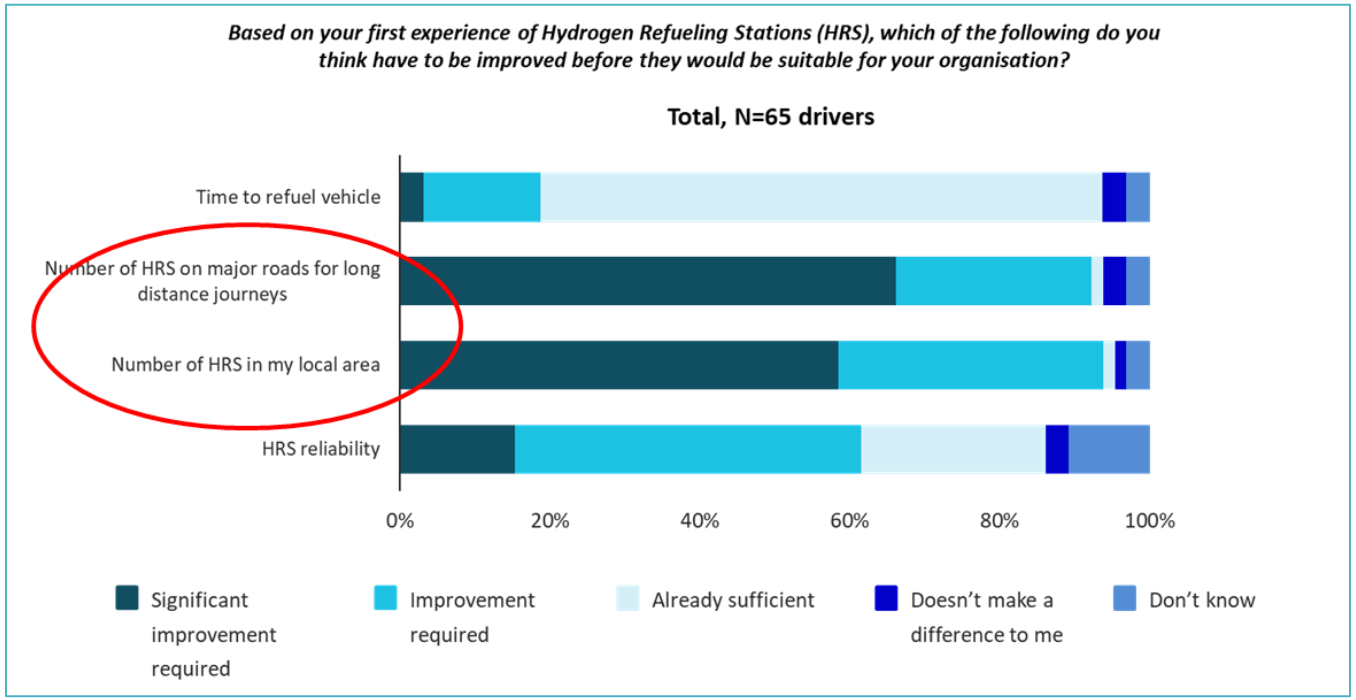
- The figure shows the location of ITM Power HRS around London and the number of kg of hydrogen dispensed to GTC FCEVs between Apr 18 and Dec 19.
- The FCEVs use all the ITM London HRS, but the two most popular stations are the more centrally-located ZEFER stations: 75% of the total fleet hydrogen is dispensed by the Rainham and Teddington HRS.

London
How GTC FCEVs are Being Refuelled (1)



- Overall average refuelling amount is 2.2 kg (44% of tank capacity of 5 kg).
- HRS data above shows that drivers in late 2018/early 2019 were refuelling more frequently than previously: average refuelling amount and distance between refuelling events (not shown) were down.
- Unnecessary trips to refuel reduce the economic efficiency of the drivers (when drivers are travelling to refuel they are generally not carrying passengers and therefore not earning money for the company).

London
How GTC FCEVs are Being Refuelled (2)



- Results from driver surveys carried out during H2ME and ZEFER by Element Energy prior to May 2019 showed driver concerns about the number of HRS in cities where the taxis operate.
- This is thought to be one of the contributing factors towards the refuelling behaviour in late 2018/early 2019 shown on the previous slide.

London
How GTC FCEVs are Being Refuelled (3)

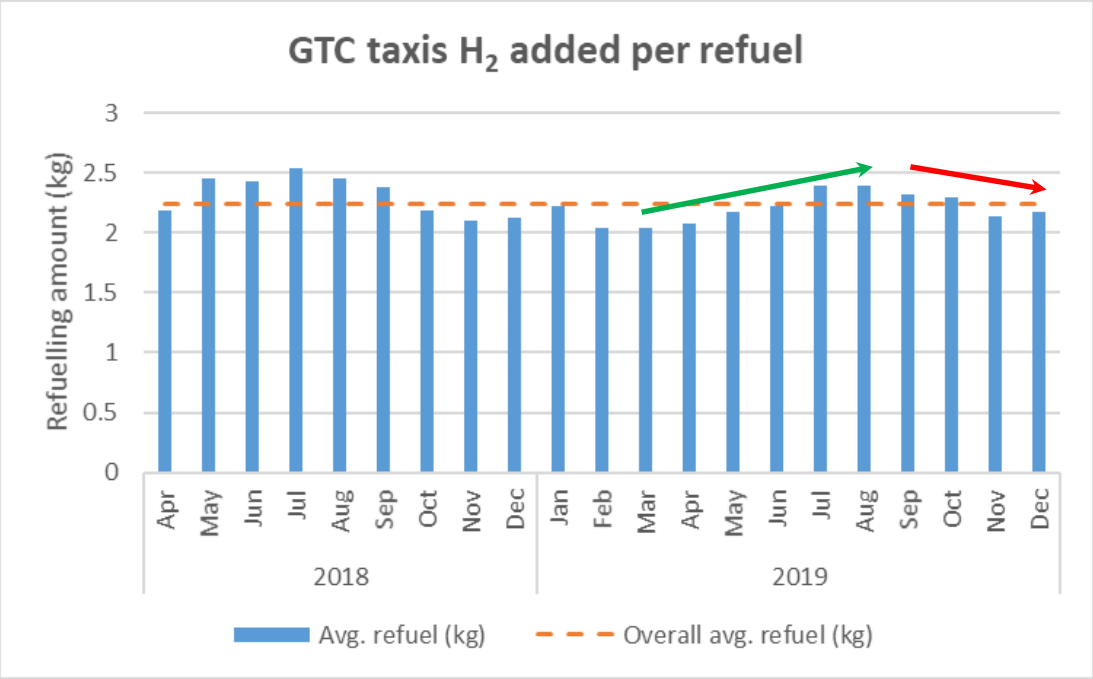
- GTC and London refuelling-station operator ITM Power have worked together to address driver refuelling behaviour by a combination of measures:

1. ITM Power has provided information to the drivers on the availability of the stations in the refuelling network. This showed for example that when some stations were out of action temporarily others in the network were available and could have been used by the drivers.

2. ITM Power developed and released an app used by the drivers which shows live data on the status of each refuelling station.

3. GTC has changed the FCEV drivers from contracted to self-employed which incentivises them to increase hourly productivity and minimise unnecessary trips to refuel.

London
How GTC FCEVs are being Refuelled (4)



- Evidence since the changes introduced by GTC and ITM Power in early 2019 indicates that drivers improved refuelling efficiency (i.e., refuelling less frequently as shown by the green arrow in the graph) and therefore productivity.
- However, refuelling efficiency has dropped again from September 2019. 25 new vehicles were introduced to the fleet in October: new drivers with no experience in refuelling FCEVs were recruited who are still in the process of being trained and growing accustomed to the vehicles, which can explain this drop.
- If the data is available, future versions of this report will compare the distance between refuels for both FCEVs and comparator vehicles (petrol/hybrid).

Contents

Content

- Introduction to ZEFER
- Summary of results
- FCEV taxi operation by Green Tomato Cars in London
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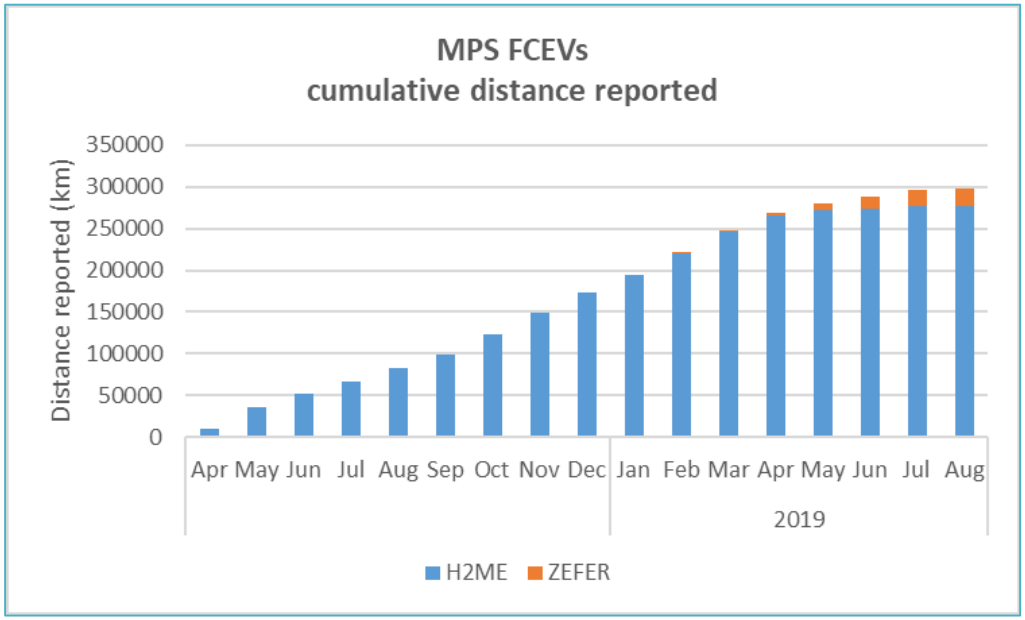
- FCEV operation by STEP/Hype in Paris
- FCEV safety and reliability
- HRS operation
- Conclusions

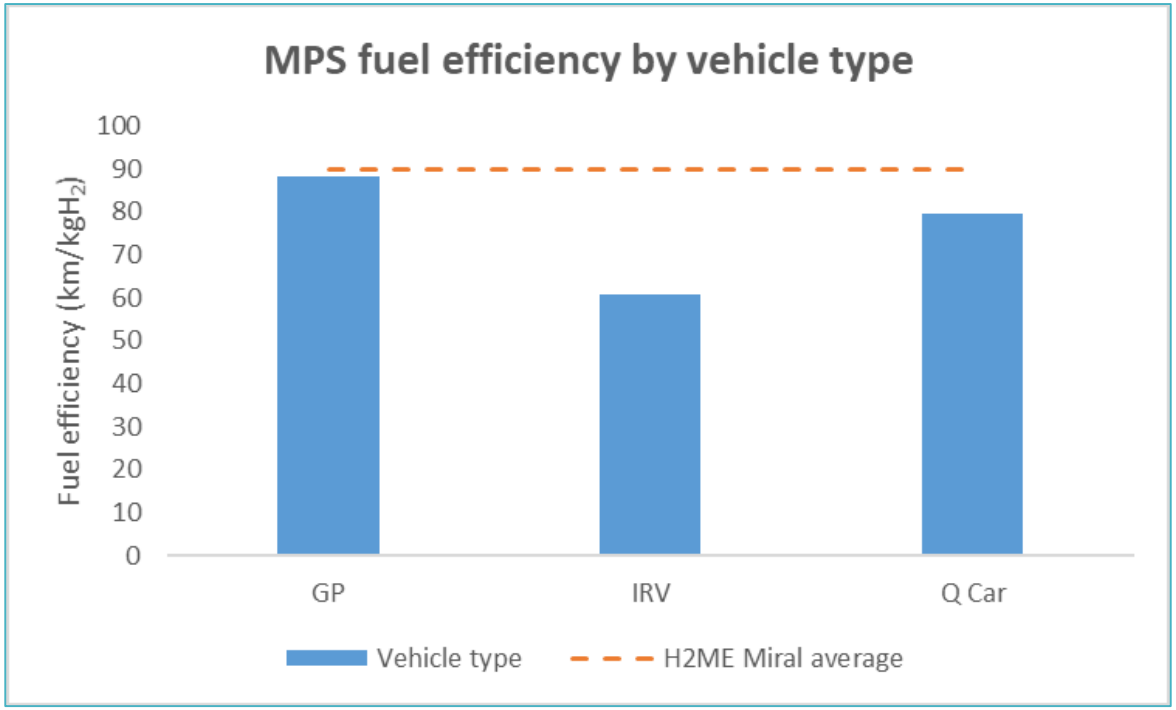
London
MPS FCEV Operation to end of December 2019



- MPS has deployed 21 FCEVs under H2ME and ZEFER.
- The vehicles have reported a total of 300 000 km driven (21 000 km for ZEFER)*.
- The cars operate in three roles:
  - ZEFER: ten *General Purpose Vehicles* (GP) used for general duties.
  - H2ME: *six Incident Response Vehicles* (IRV), which are marked police cars used to answer urgent calls.
  - H2ME: five Q Cars, which are essentially unmarked IRVs.

* Last data received from MPS Aug 2019. No further data received at time of writing.

London
MPS FCEV Fuel Efficiency (1)



- The different types of vehicles have different real-world efficiencies:
  - The ZEFER GP vehicles (caveat – only relatively limited data so far) appear to be operating at the same level of efficiency (~90 km/kgH_2) found for Mirais in H2ME.
  - The IRVs are significantly less efficient than the H2ME average.
- This is discussed further in the next two slides.

London
MPS FCEV Fuel Efficiency (2)

- Issues to note in terms of fuel consumption of the Mirai include:

  - 1. In common with all vehicles (conventional as well as electric) high speed, aggressive driving will consume much more fuel than lower speed, non-aggressive driving.

  - 2. All auxiliaries (e.g., police computers, etc) and air conditioning/heating run off the fuel cell via the 12v battery → fuel cell vehicles can idle.

  - 3. The vehicle has regenerative braking which is always operative and cannot be disengaged by the driver.

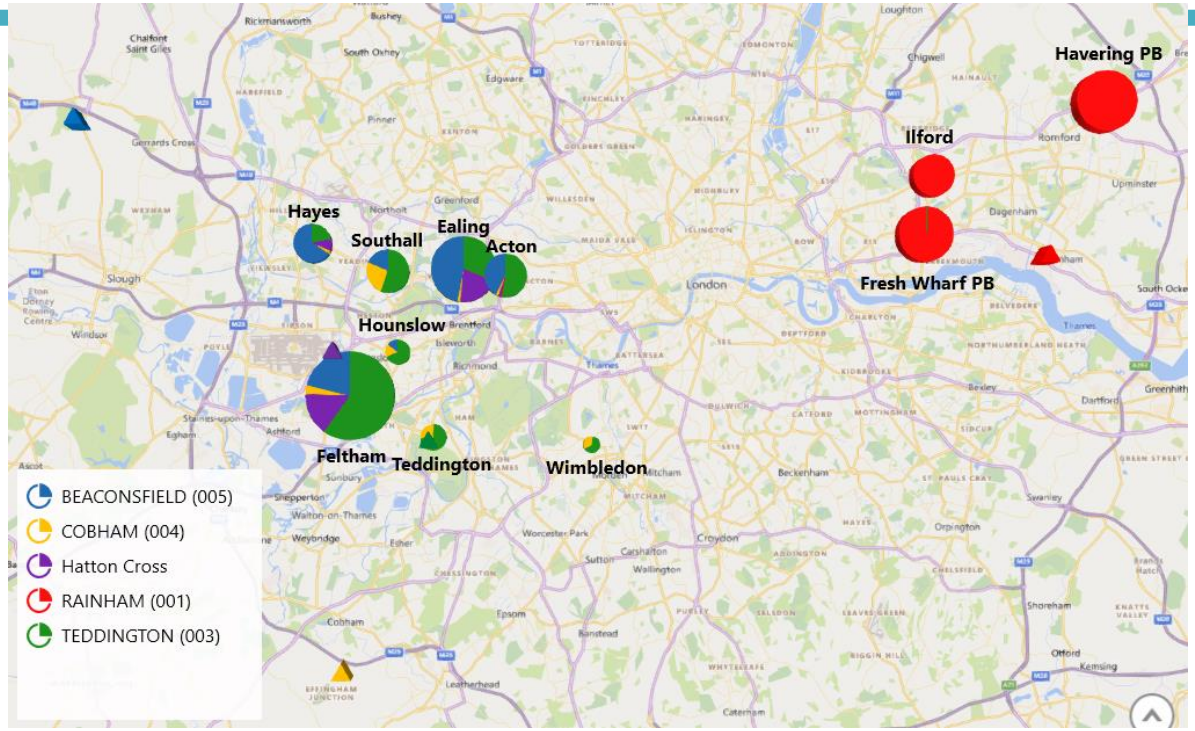
London
MPS FCEV Fuel Efficiency (3)

Vehicle Id	H2ME1	H2ME6	H2ME8
Country			
Vehicle role	Taxi	Private customer	Police IRV
Fuel efficiency (km/kg H2)	112	89	54
Max speed (km/h)	127	122	177
Avg speed (km/h)	21	35	20
Idling time (%)	30	12	44
Avg. distance/trip (km)	17	10	7
Ignition on/100km	6	11	15
Comments	Eco driving		Aggressive driving
	High idling (taxi)	Less idling	Lots of idling
	Longer trips		Short trips
	Fewer start-ups		Multiple start-ups

- The table gives a qualitative comparison of the efficiency of Mirais in different roles :
  - CleverShuttle drivers in Germany (vehicle H2ME1) are incentivised for eco driving, meaning lower maximum speeds and less harsh driving.
  - IRVs in London (vehicle H2ME8) have to respond quickly to incidents as they occur as so are inevitably driven relatively harshly, but also spent a lot of time idling* waiting for dispatch.

*Thanks to Toyota Motors Europe for providing idling data

London
Where MPS FCEVs are Refuelling



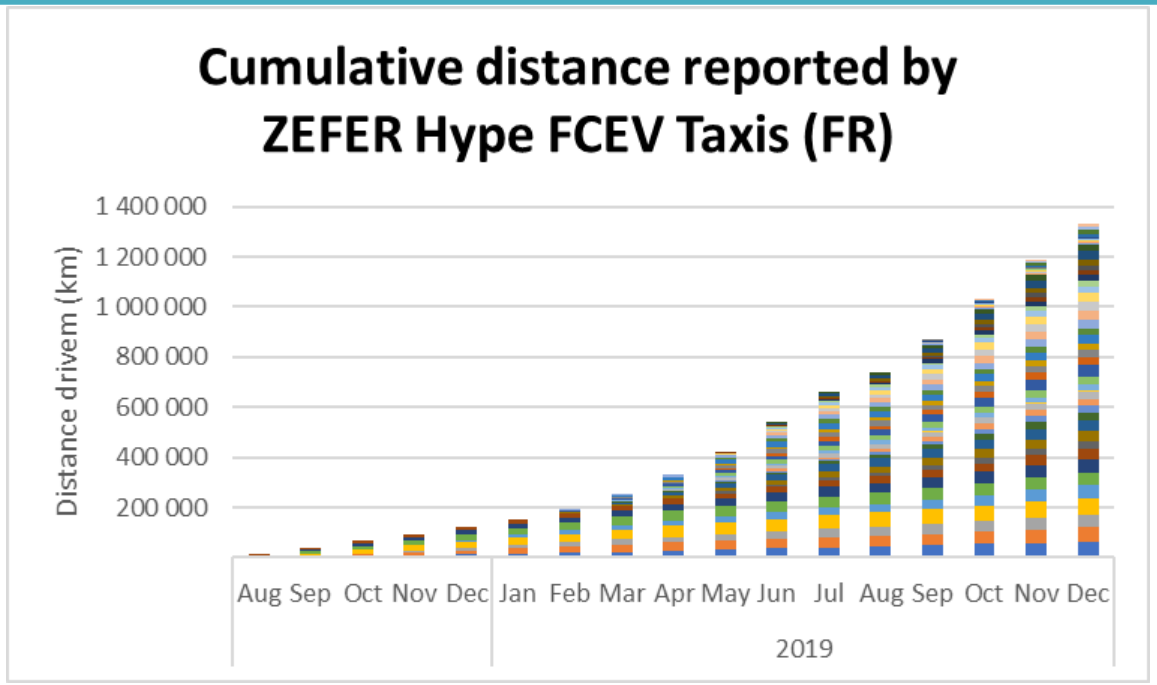
- The figure shows where H2ME and ZEFER MPS vehicles refuel.
  - In West London, vehicles use multiple refuelling stations
  - in East London the vehicles use the local Rainham station exclusively
- An additional refuelling station is proposed for Barking in East London which will provide an additional local option for vehicles in the area.

Contents

Content

- Introduction to ZEFER
- Summary of results
- FCEV taxi operation by Green Tomato Cars in London
- FCEV operation by the Metropolitan Police Service in London
- **FCEV operation by STEP/Hype in Paris**
- FCEV safety and reliability
- HRS operation
- Conclusions

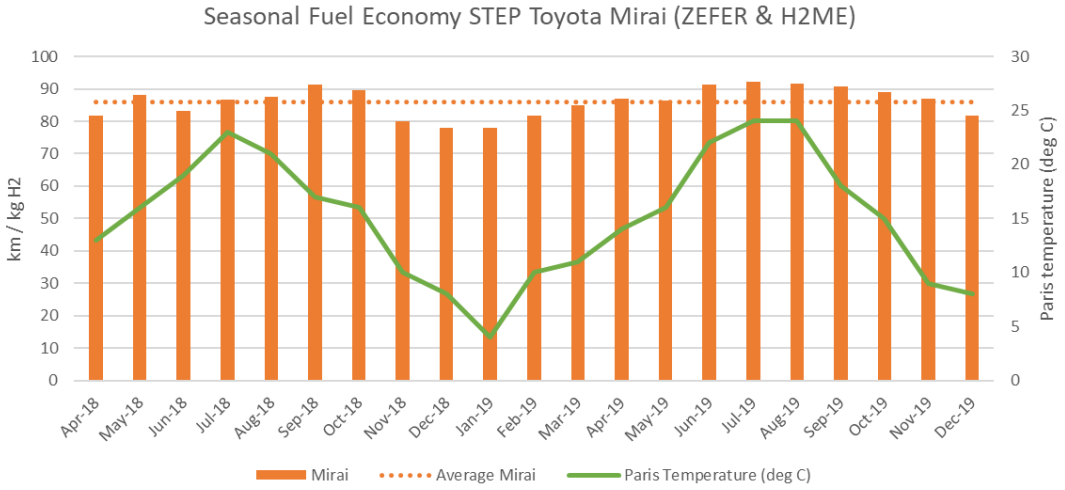
Paris
FCEV Taxi Operation to end of December 2019

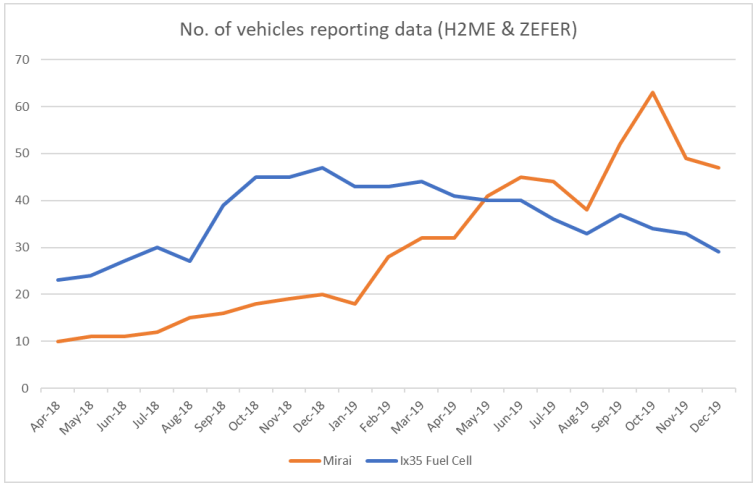


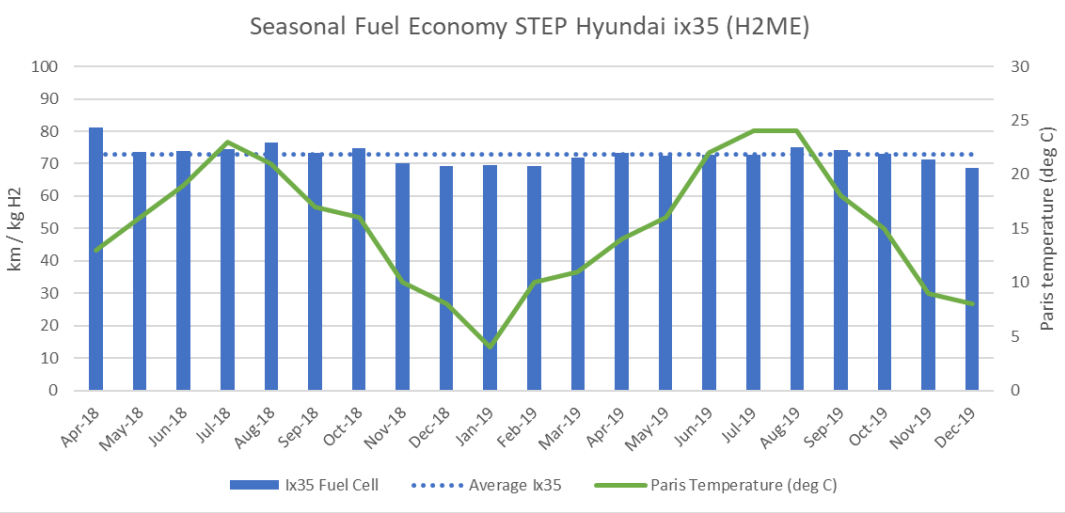
- The ZEFER Hype/STEP FCEVs have reported a total of 1 331 600 km driven (FCEV taxis supported by H2ME2 have accumulated an additional 4.06m km since June 2017).
- The ZEFER taxis drive an average of 3 670 km per month (153 km per day).
- The furthest driven by one of the vehicles in a month was 6 460 km.
- During the period, the ZEFER taxis refuelled 14 135 kg of hydrogen.

Paris
How FCEV Taxis are Being Driven (1)

- Fuel economy in Hyundai ix35 less affected by seasons compared to Toyota Mirai
- Toyota Mirai: 18% difference between Dec-18 (min) and Jul-19 (max)
- Hyundai ix35: 18% difference between Dec-19 (min) Apr-18 and (max)
- Mirai fuel economy better than ix35: average of 86 vs 73 km/kg



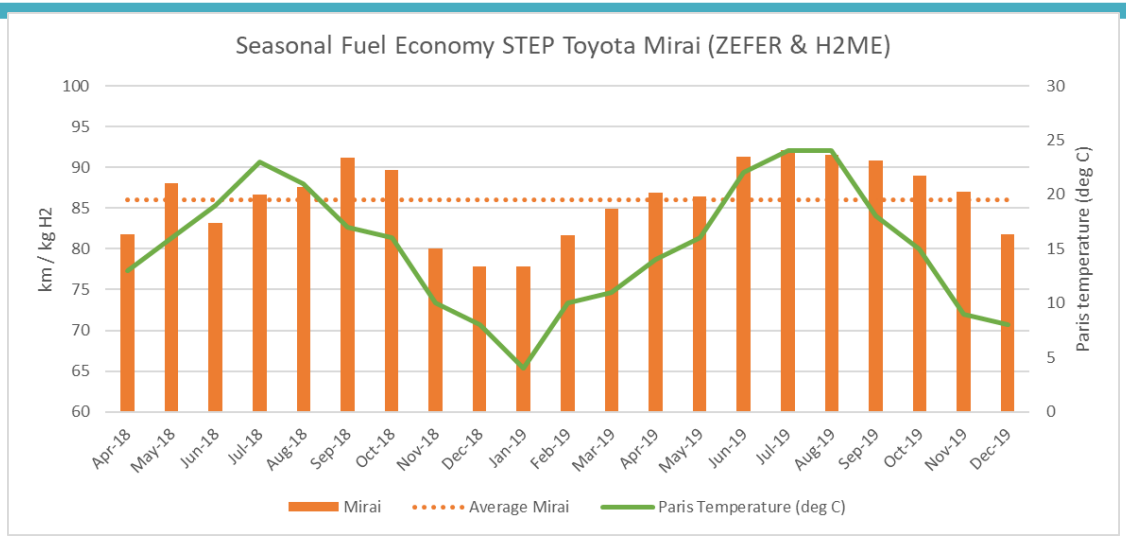




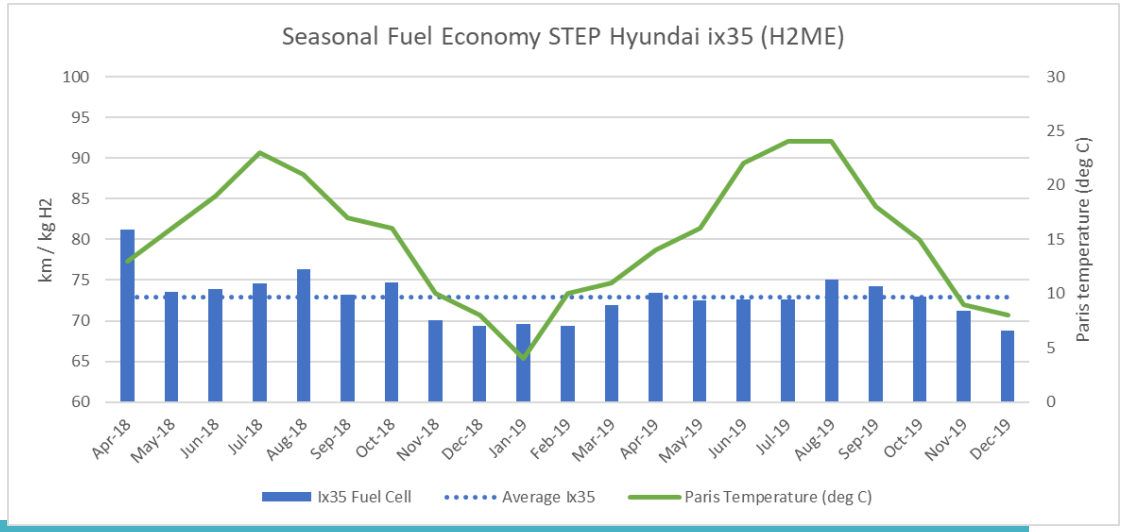
Paris
How FCEV Taxis are Being Driven (2)

- Generally, temperature has a negative correlation with vehicle energy consumption (i.e., fuel efficiency is lower in winter) due to factors including:
  - reduced battery and mechanical efficiency.
  - greater use of cabin heating during the winter.
  - increased rolling & wind resistance.
- If the data is available, future versions of this report will include an analysis of seasonal variance for comparator vehicles (battery electric and petrol/hybrid vehicles).

zoom

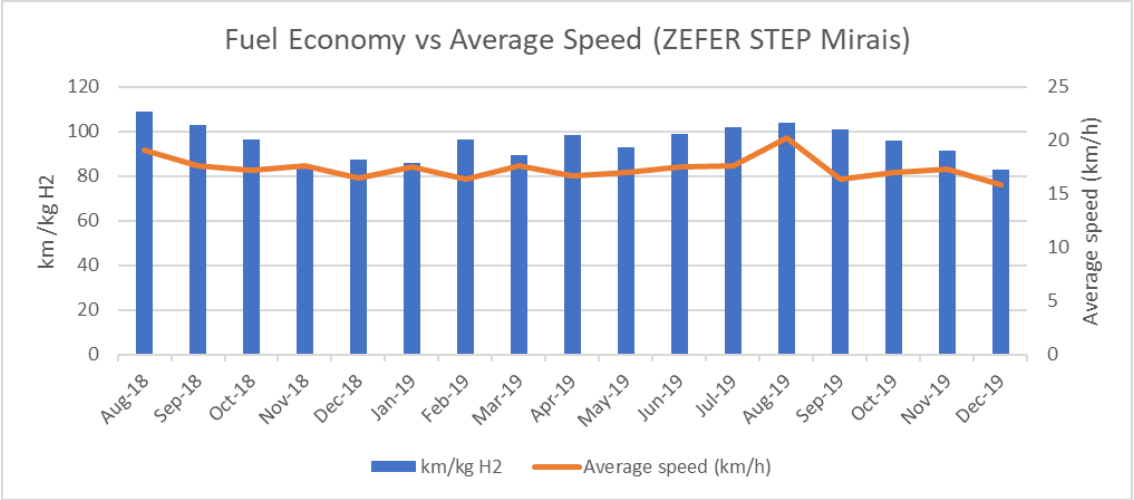


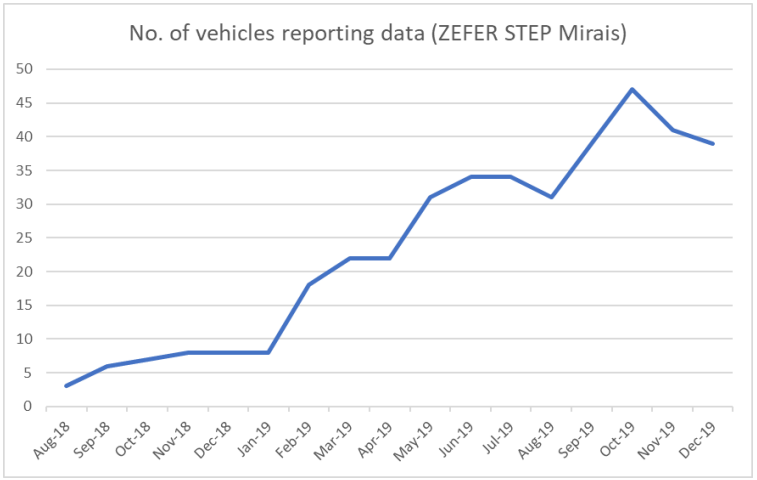
zoom

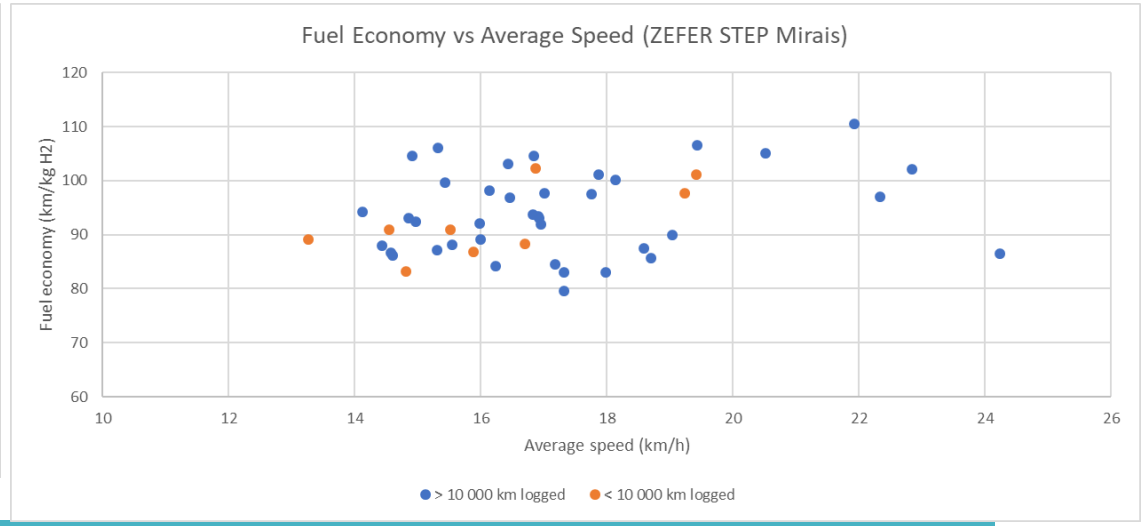


Paris
How FCEV Taxis are Being Driven (3)

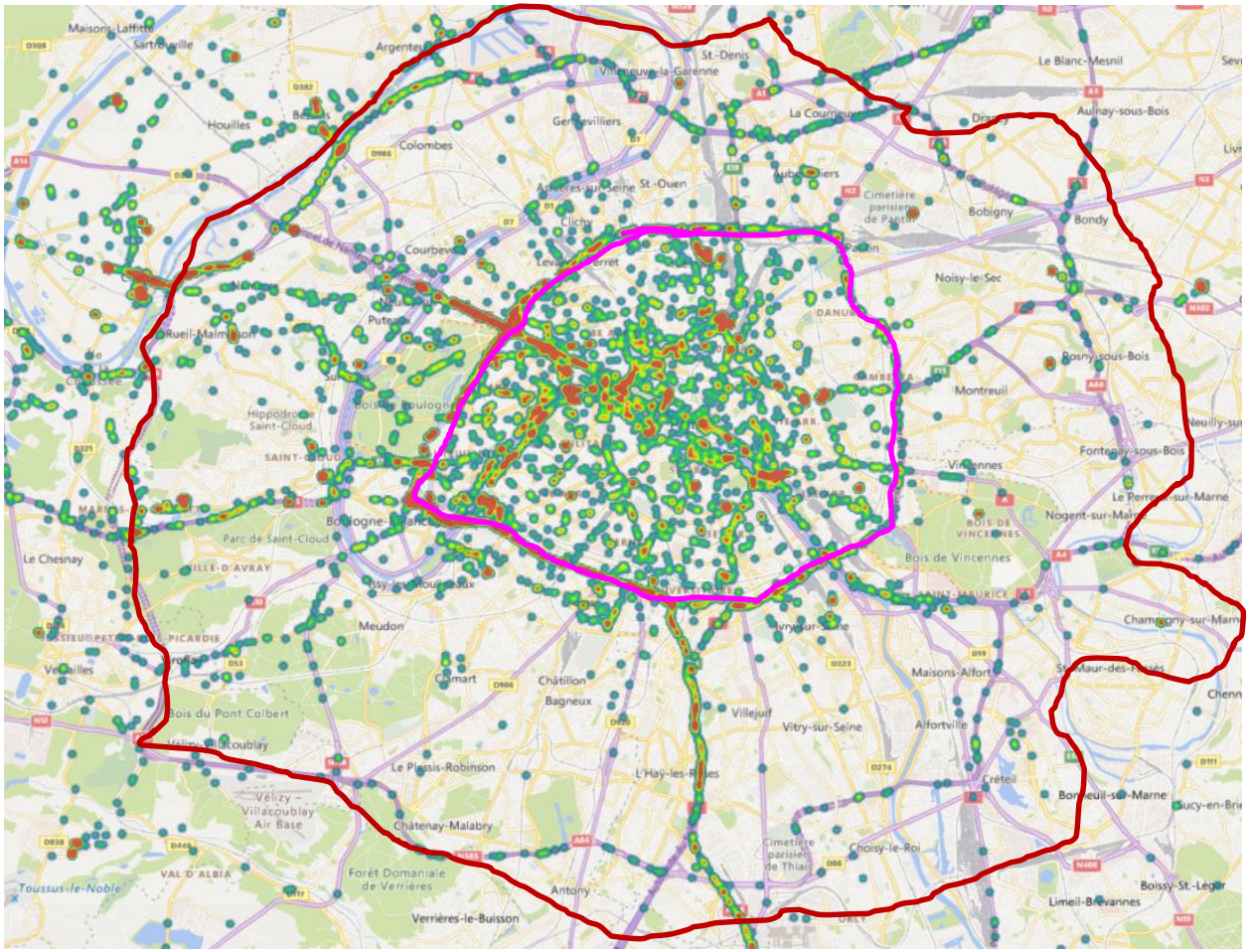
- No clear trend correlating average speed with fuel economy.
- More insight could be drawn from acceleration rates and idling time, but these are unavailable as raw data frequency is one point every 10 minutes
- Slight increase in average speed in months of August due to holiday season and therefore less traffic.







Paris
How FCEV Taxis are Being Driven (4)
Crit'Air Pollution Control Zones

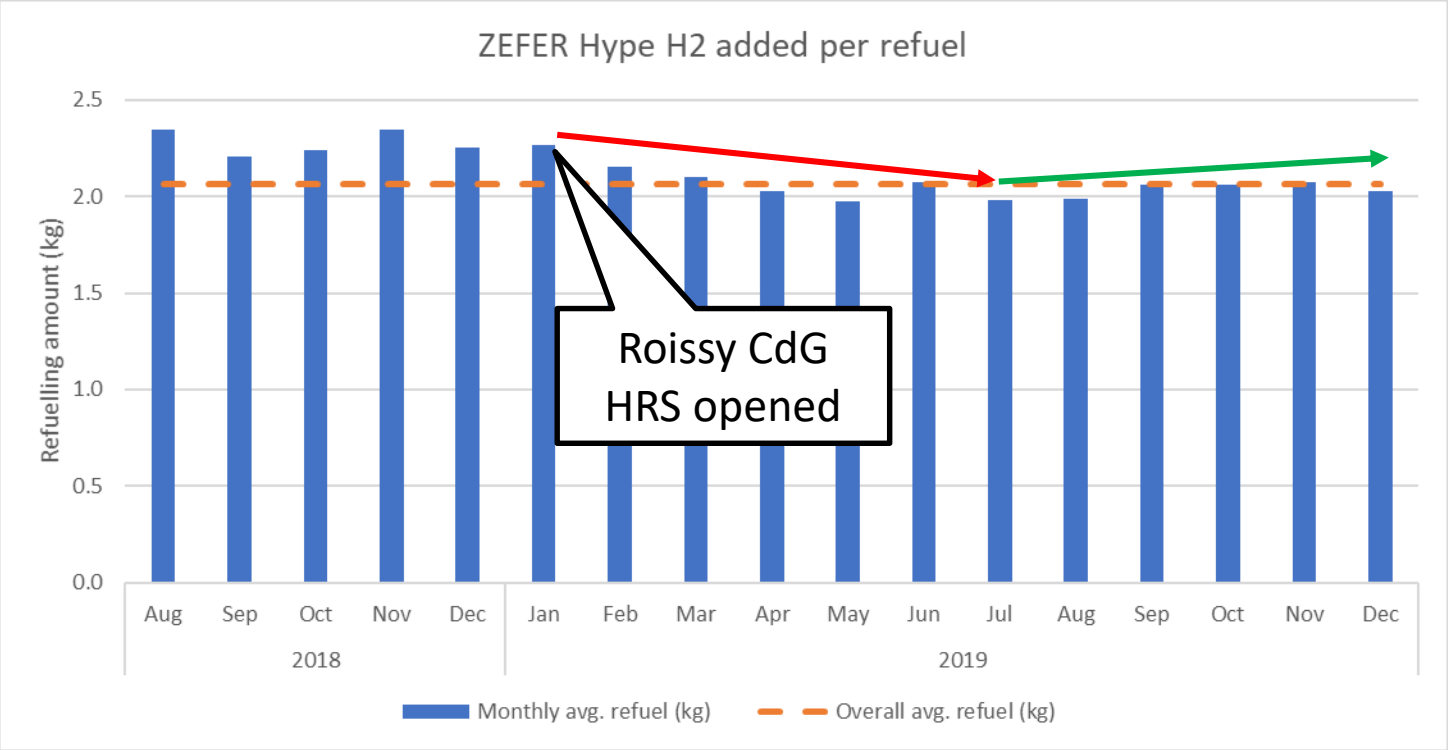


- Random ZEFER vehicle data for 6 months
- Zones that forbid circulation 8am to 8pm (Mon to Fri for <3.5t and everyday for >3.5t):

Legend		
Zone name	**'Paris' (city walls)**	**ZFE = Zone à Faibles Émissions**
Vehicles forbidden now	>= Crit'Air 4 (<= Euro 3)	Crit'Air 5 (<= Euro 2)
Vehicles forbidden from Jan 2021	>= Crit'Air 3 (<= Euro 4)	>= Crit'Air 4 (<= Euro 3)

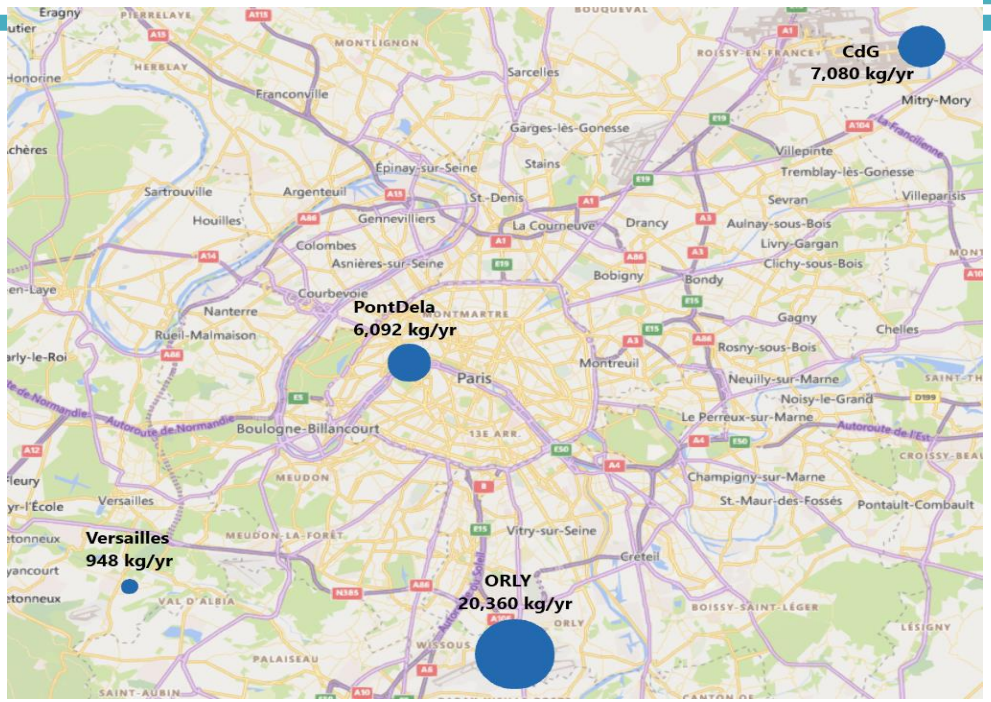
https://www.zonefaiblesemissionsmetropolitaine.fr/

Paris
How FCEVs are being refuelled



- The overall average refuelling amount is 2.1 kg (42% of the tank capacity of 5kg).
- Amount of H_2 per refuel has decreased since the opening of the Roissy/CdG HRS, likely due to drivers accessing an additional HRS in their airport jobs.

Paris
Where FCEVs are Refuelling

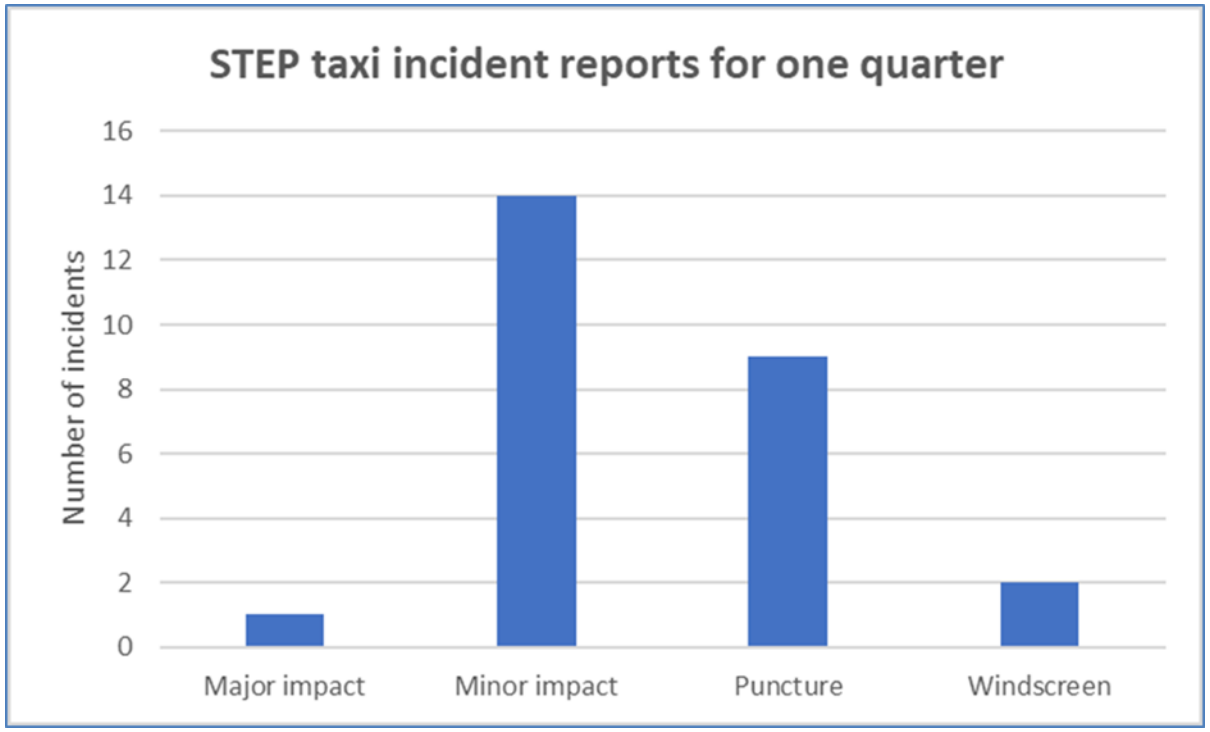


- The figure shows the location of Air Liquide HRS around Paris and the number of kg of H_2 per year dispensed to H2ME2 and ZEFER Hype FCEVs.
- The FCEVs use all the Paris HRS, but the most popular station is Orly.
- The CdG/Roissy station has been open since December 2018 and already shows relatively heavy usage (2nd most popular HRS).
- The mean distance between refuels for the ZEFER STEP taxi fleet is 197 km.

Contents

Content

- Introduction to ZEFER
- Summary of results
- FCEV taxi operation by Green Tomato Cars in London
- FCEV operation by the Metropolitan Police Service in London
- FCEV operation by STEP/Hype in Paris
- **Vehicle safety and reliability**
- HRS operation
- Conclusions



- The STEP taxis drive a lot. Inevitably, they are involved in incidents.
- The taxis have the same types of incident as normal taxis (data shown for H2ME2 vehicles).
- The photograph shows the scale of the major impact incident shown in the graph.
- **None of the incidents involved release of hydrogen or problems with the fuel cell system.**

FCEVs
Reliability

- Toyota Mirais are serviced every 10 000 km (or 10 000 miles in the UK):
  - 10 000 km/mile service comprises general check plus H_2 leak test.
  - Deionising filter changed every 30 000 km/miles.
  - Battery and fuel cell coolant is topped up at 100 000 km*.
- Vehicles have in practice proven to be very reliable (> 99% availability).

*Source: Toyota UK

Content

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- FCEV safety and reliability
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HRS Operational Monitoring – Teddington, UK

HRS Specification

Parameter	Value
Station Supplier	ITM Power
Station Type	Standalone
Accessibility	Public
Hydrogen Dispensing Pressure	35 & 70 Mpa
Capacity	80 kg/day
On-site generating capacity	80kg/day (to be expanded to 270 kg/day)
Back to Back capacity	2 vehicles (5 kg capacity)

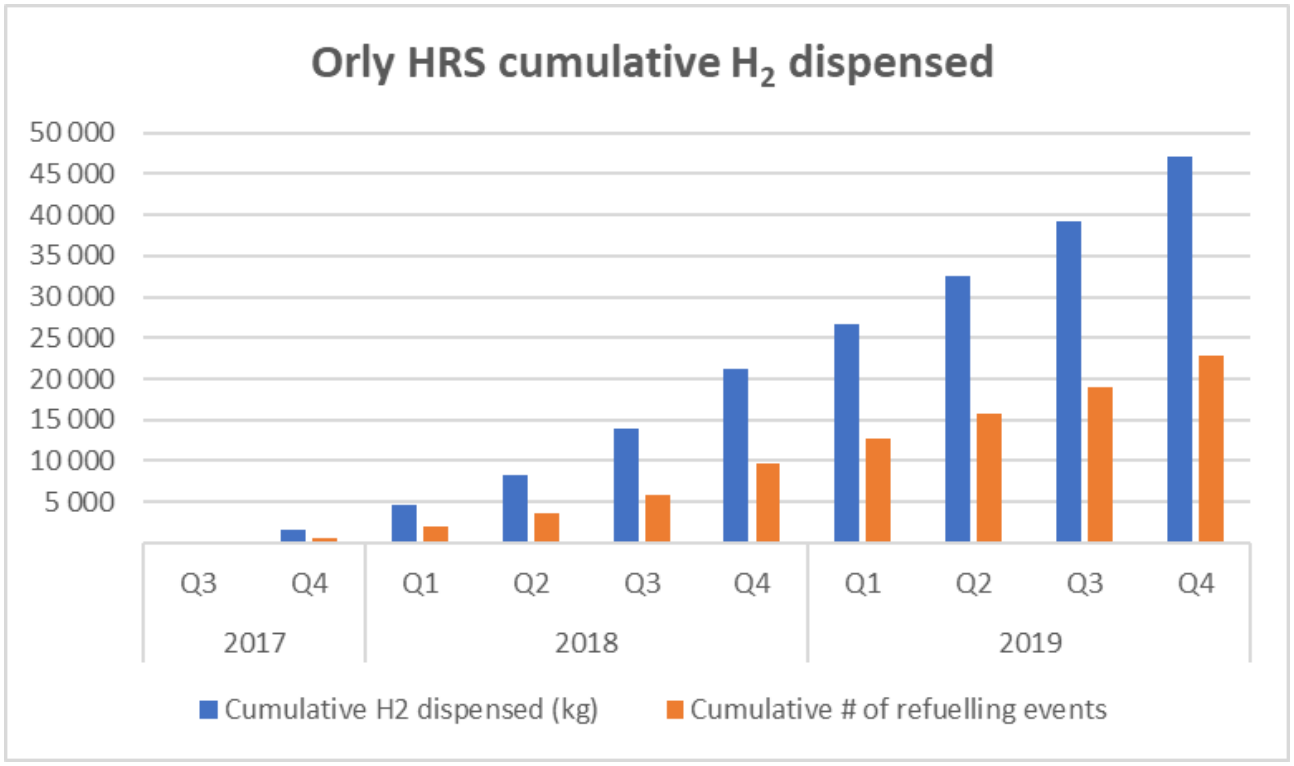
HRS Operational Monitoring – Orly, Paris

HRS Specification

Parameter	Value
Station Supplier	Air Liquide
Station Type	Standalone
Accessibility	Public
Hydrogen Dispensing Pressure	35 & 70 Mpa
Capacity	200 kg/d

HRS Operational Monitoring – Orly

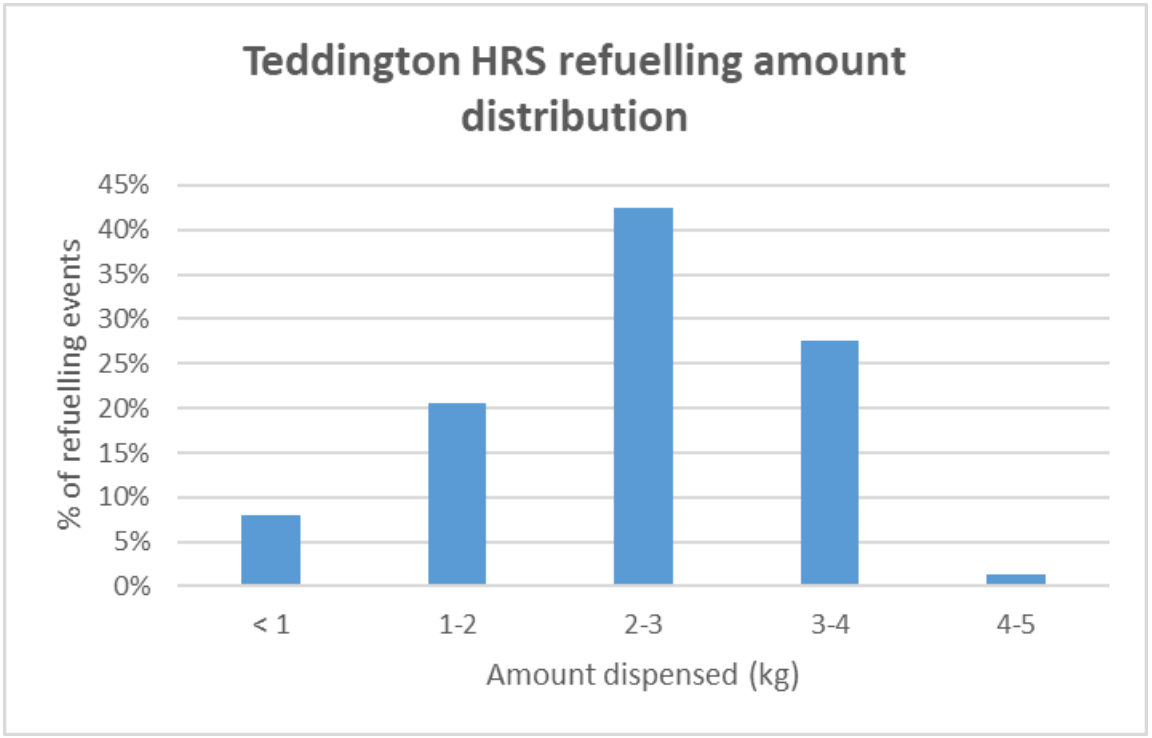
Refuelling amount



- The Orly station has dispensed 47 000 kg of hydrogen since September 2017.
- 94.4% of the near-23 000 refuellings were at 700 bar due to usage by STEP taxis in H2ME2 and ZEFER.

HRS Operational Monitoring – Teddington

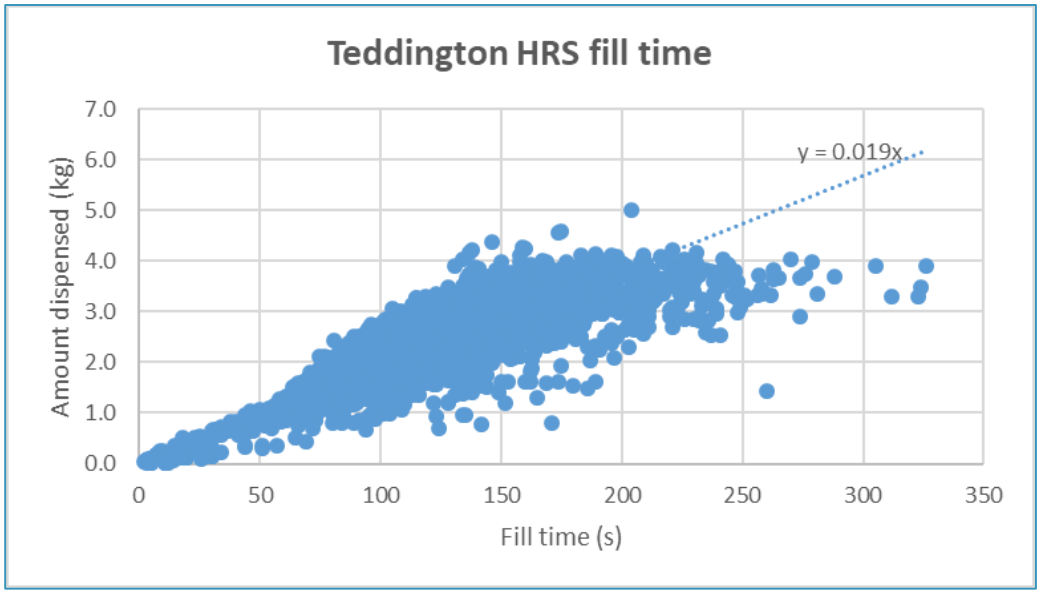
Amount dispensed per refuel



- The modal (most popular) refuelling amount (over 40% of refuellings) is 2-3 kg (considering 700 bar refuels only).
- The refuelling data includes non-ZEFER vehicles (e.g., MPS vehicles supported by H2ME.

HRS Operational Monitoring – Teddington

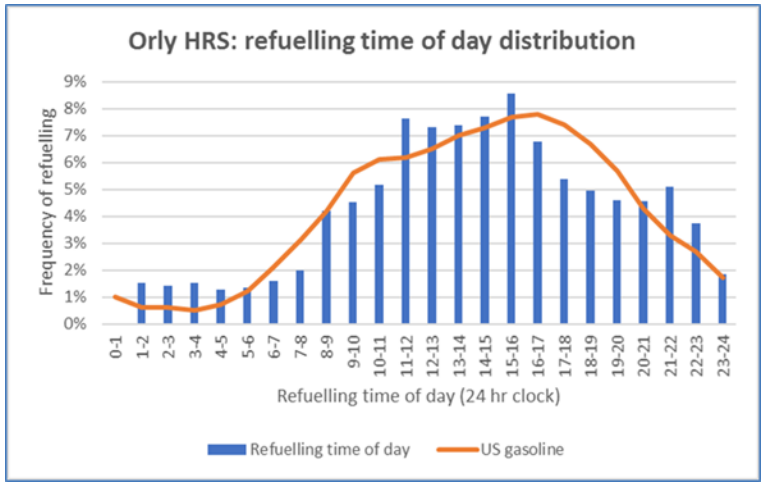
Refuelling rate

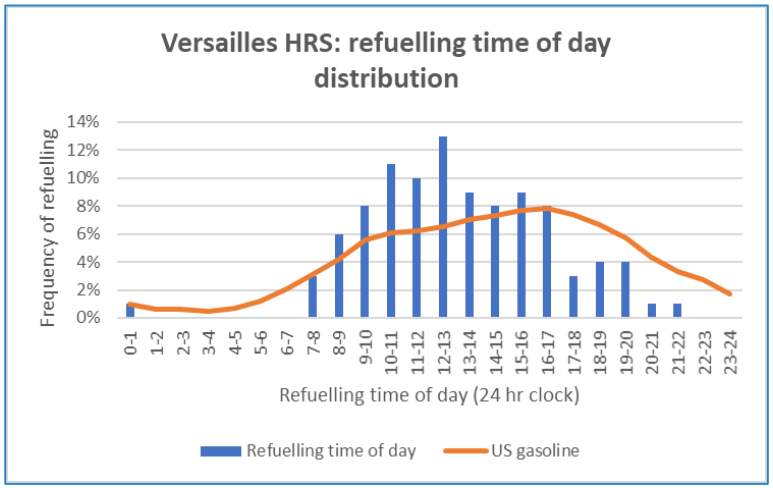


- The J2601 *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles* standard mandates a refuelling rate of 1 kg of hydrogen per minute.
- The mean refuelling rate of Teddington is 1.2 kg/min (based on 4 604 refuelling events at 700 bar) showing that this HRS (and other stations in ZEFER) meet the standard.

HRS Operational Monitoring – Paris

When do vehicles refuel?

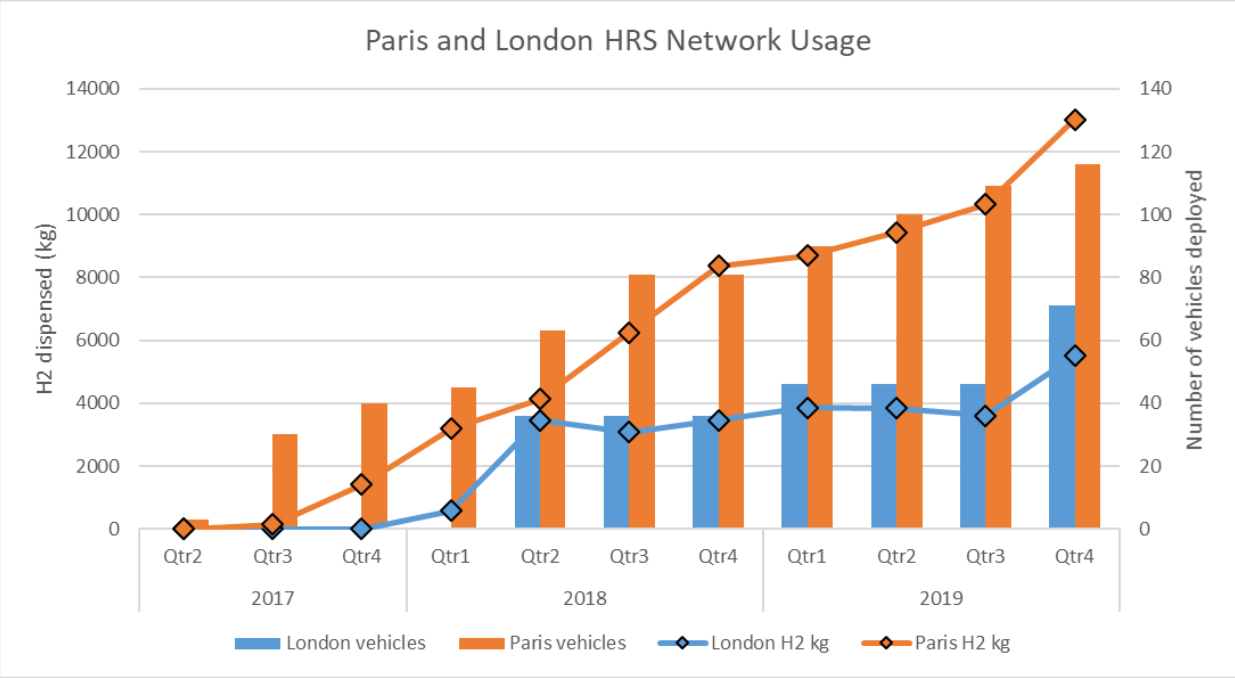




- The usage of the Orly station reflects the deployment of STEP taxis in ZEFER and H2ME2. 94% of its refuellings are 700 bar.
- As shown in the top graph, Orly station usage profile (and that of Teddington in the UK) most closely resembles that of a conventional gasoline station with usage throughout the 24 hour period (red line in graph).
- The Orly station load is now up to 44% based on its daily dispensing capacity of up to 200 kg/day of hydrogen.
- For comparison, the Versailles station (second graph) is currently mostly used to refuel buses and is little used outside working hours.

HRS Operational Monitoring

Growth in usage of the Paris and London HRS



- The graph above shows that the increase in usage and load of the London and Paris HRS network closely follows the increase of FCEV deployment as part of H2ME and ZEFER (please note that the graph data is combined for both projects)
- London HRS network: Rainham, Cobham, Teddington, Gatwick
- Paris HRS network: Orly, Roissy, Pont d'Alma, Versailles

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ZEFER
Conclusions

- Toyota Mirai fuel cell electric vehicles are operating effectively as zero tailpipe-emission taxis and police vehicles in London and Paris.
- Taxis are an excellent use-case to test the high utilisations of FCEVs, and placing number of taxis in a network of multiple HRS increases station usage which helps the business case for the stations.
- Since 2017, H2ME and ZEFER FCEV taxis have driven 5.4 million km (pending update from GTC).
- Using FCEVs as taxis requires only minor operational adjustments to keep journeys within reasonable range of refuelling stations.
- The FCEVs have proven to be reliable (> 99% availability). They are serviced every 10 000 km/miles. The vehicles have been involved in several accidents and collisions. **None of the incidents involved the release of hydrogen or problems with the fuel cell system.**
- **There have been no project HRS safety incidents reported.**
- Quantitative analysis during this project, feedback from drivers and partnership working with vehicle and station providers is being used to improve the operational efficiency of the vehicles and refuelling infrastructure.

Acknowledgements

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

These activities have received funding from the European Union's Horizon 2020 Programme through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) under grant agreement number 779538.