



## ZERO EMISSION FLEET VEHICLES FOR EUROPEAN ROLLOUT

# D3.4: Bi-Annual Technical Report on Vehicle and Refuelling Station Operation

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Data: Up to December 2020 (incl.)

Dissemination level: **PUBLIC**

Status: **DRAFT**



*A project co-funded by  
under the Grant Agreement no. 779538*



**FUEL CELLS AND HYDROGEN**  
JOINT UNDERTAKING



- ❑ 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 summarises the results of the operation **to the end of December 2020** 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 10 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 57 ZEFER-supported Toyota Mirai FCEVs taxis in Paris since August 2018. Hype now operates a 130+ strong FCEV taxi fleet.
  - The vehicles in London and Paris use a network of HRS across the cities.
- ❑ This report is **publicly available** and is updated bi-annually.



- ❑ To the end of September 2020, the ZEFER FCEVs drove **5 136 000 km\***.
- ❑ HRS used by ZEFER vehicles in France and the UK dispensed **32 500 kg of hydrogen in 2018, 58 300 kg in 2019 and 29 200 kg in 2020**. Please note the decrease in 2020 due to the pandemic. 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).
- ❑ There is a clear influence of seasonal variance on fuel economy.
- ❑ 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 MPS Aug 2019. The MPS distance has been estimated from refuelling records.

Last data received from STEP Mar 2020 as taxis are not operating because of French regulations due to Covid pandemic.

# 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
GTC	Green Tomato Cars
H <sub>2</sub>	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
STEP	Société du Taxi Electrique Parisien
ULEZ	London Ultra Low Emission Zone
ZEFER	Zero-Emission Fleet vehicles for European Rollout



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- **Introduction to ZEFER**
- Summary of results
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- FCEV safety and reliability
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- 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		Police vehicle
London	10		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





- ❑ 107 of ZEFER's planned 180 FCEVs have reported data so far (50 from GTC, 50 from STEP and 7 from MPS)
- ❑ **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 (until June 2020) included 120 vehicles: 50 deployed through ZEFER (all Mirais) and a further 70 supported by the H2ME2 project (mainly Hyundai ix35s).
  - French regulations stopped the taxi operation in March 2020 due to the ongoing Covid pandemic and it has not been resumed yet.



# 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)*	550 km
Stack Technology	PEM**
Stack Power Rating	113 kW
Tank Capacity	5 kg H <sub>2</sub>
Tank Pressure	700 bar
Battery Pack Size	1.6 kWh NiMH***

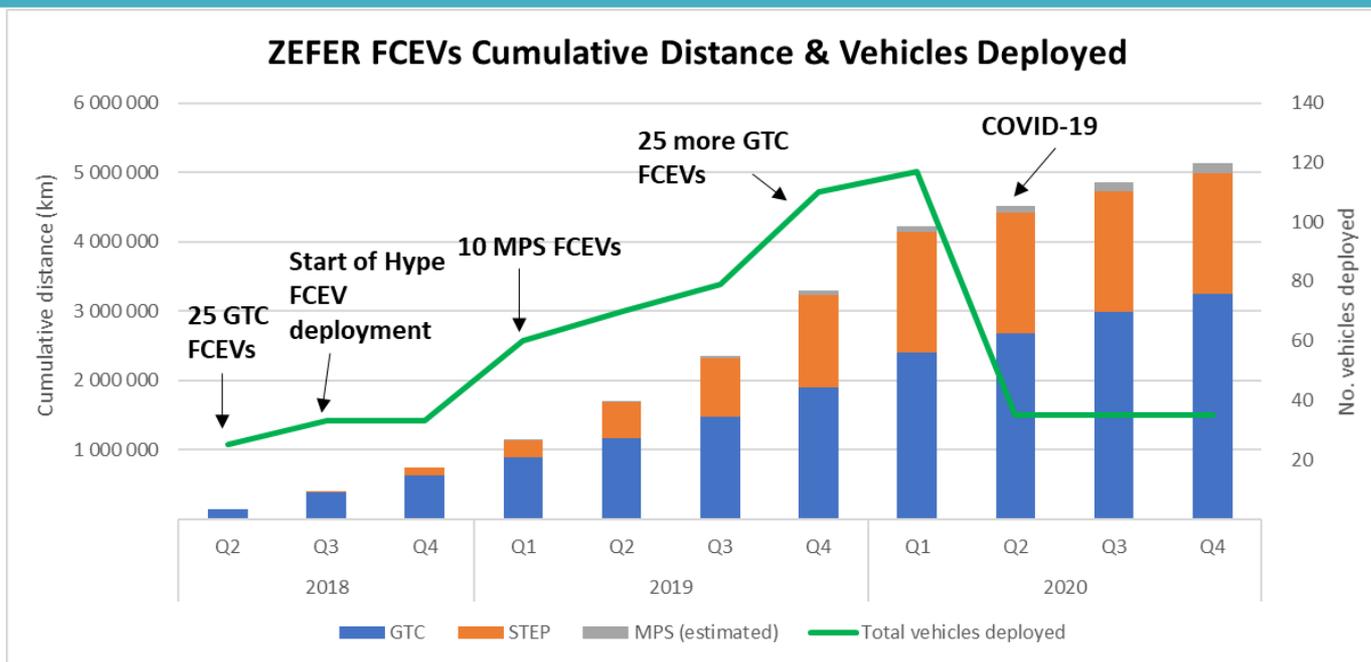
\* New European Drive Cycle

\*\* Proton Exchange Membrane

\*\*\* Nickel Metal Hydride

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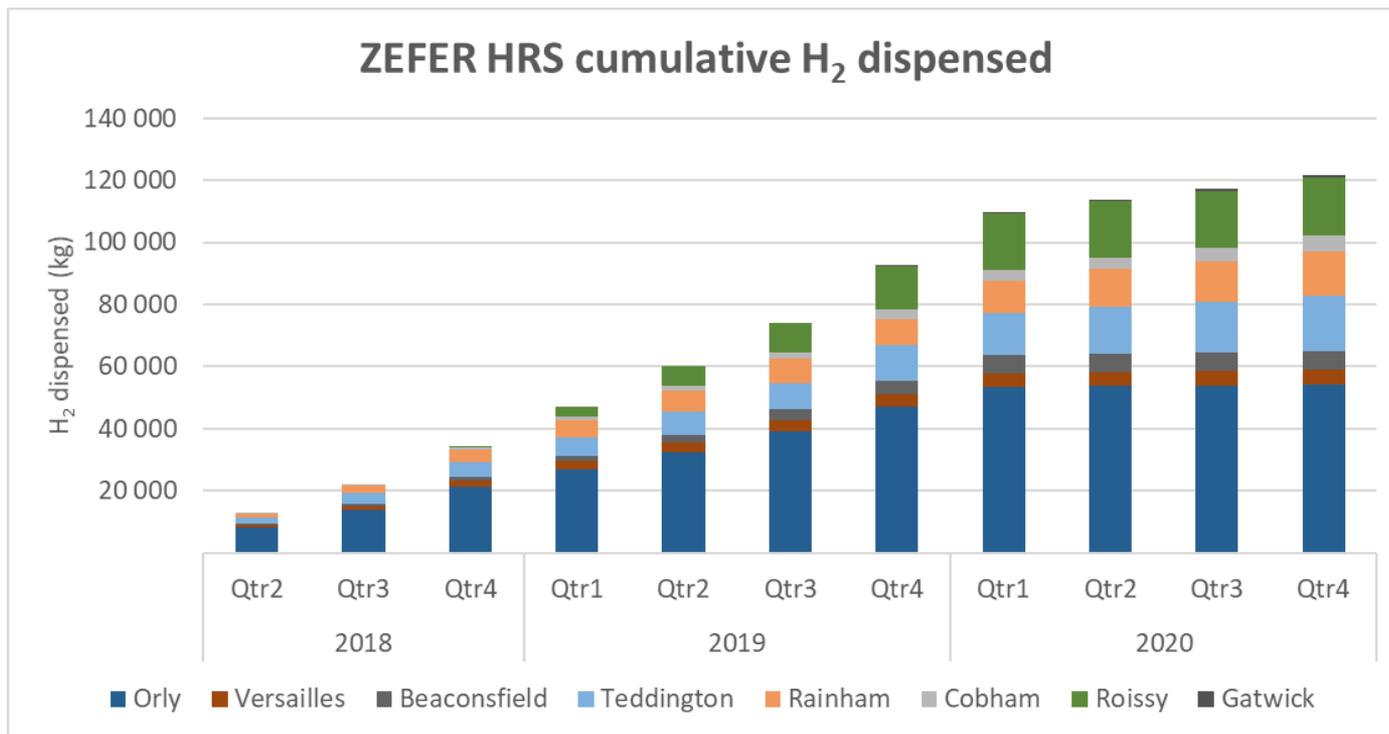
- ❑ ZEFER FCEV taxis in London and Paris, plus the MPS police vehicles in London, have reported **5 136 000 km** driven since April 2018\*.
- ❑ Peak of deployment (117 vehicles) was reached in Q1 2020, when GTC had already deployed their remaining 25 taxis to reach their total of 50, and STEP deployed the last few taxis to reach 57 taxis (with just 3 remaining for their total of 60).
- ❑ However, the Covid pandemic caused the number of taxis deployed by GTC to reduce by 50% in London, while STEP could not operate any taxis in Paris. The current number of taxis deployed is approximately 35.

\* Last data received from MPS Aug 2019. The MPS distance is estimated from refuelling records.

Last data received from STEP Mar 2020 as taxis are not operating because of French regulations due to Covid pandemic.

# HRS

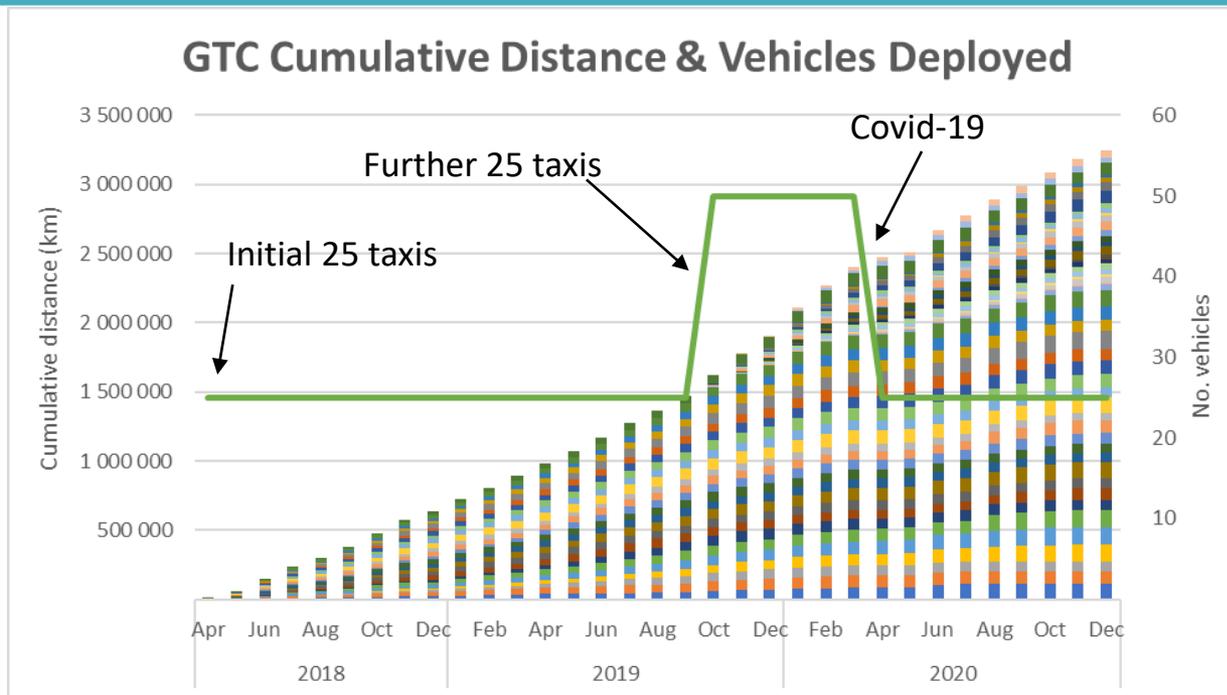
## Cumulative Hydrogen Dispensed



- ❑ HRS in France and the UK used by ZEFER vehicles have dispensed **121 800 kg H<sub>2</sub>**. The Orly station alone has dispensed 54 300 kg (45%).
- ❑ Due to the Covid pandemic, only 12 200 kg of hydrogen have been dispensed from Q2 to Q4 2020.
- ❑ 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.

## Content

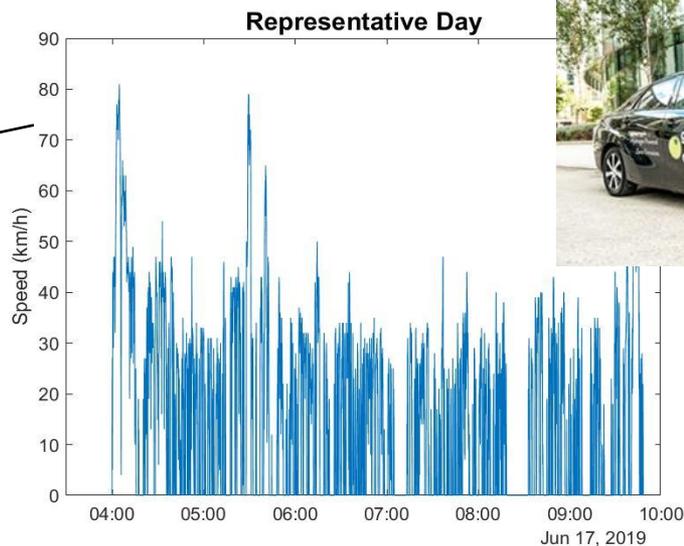
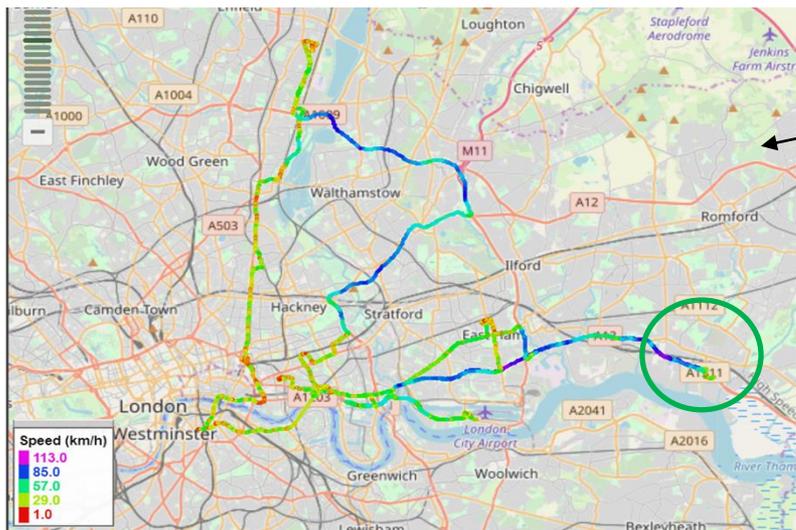
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- ❑ GTC's 50 FCEV taxis have driven 3 246 000 km since April 2018 (the different-coloured bars on the graph represent the cumulative distance driven by individual vehicles, while the green line is the no. of vehicles deployed).
- ❑ The average distance driven by each taxi per month is 4 000 km (~180 km/day).
- ❑ The average annual distance driven by each FCEV taxi is 48 000 km. This compares favourably to the fleet's petrol/diesel and plug-in hybrid vehicles, which drive 39 000 km/year on average.
- ❑ The furthest driven by one of the vehicles in a month was 10 114 km.

# London

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



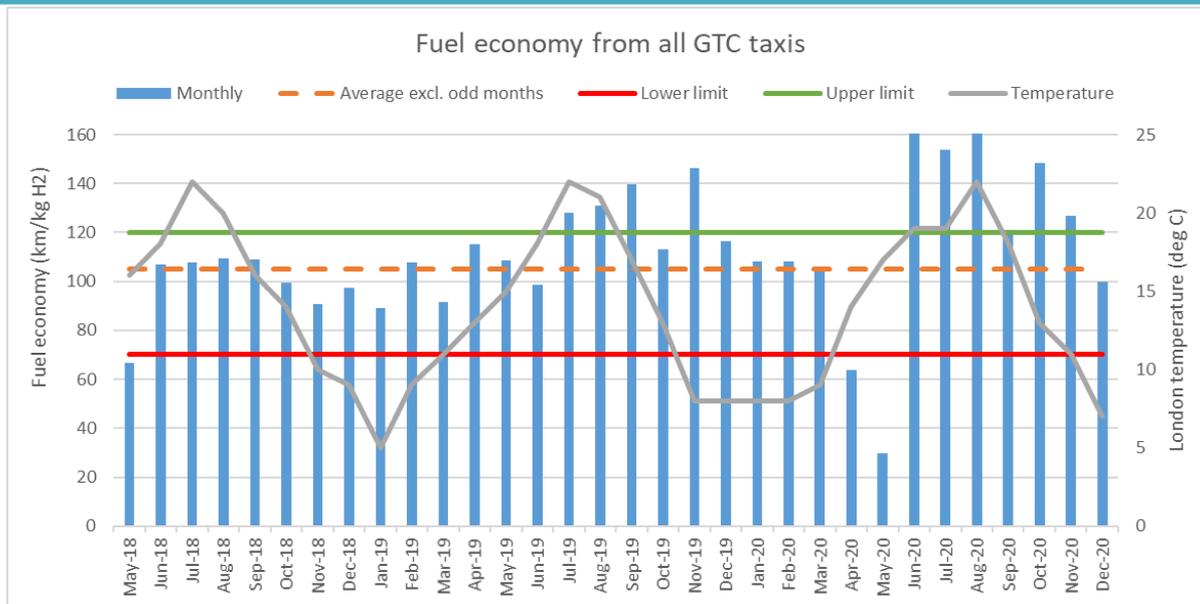
*\*A new journey starts after the vehicle has been stationary for more than 1.5 mins.*

- ❑ 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 refueled.
- ❑ Please note that the statistics on the right and in the next slides are only for the 5 taxis with telematics, and may differ to the total for the whole fleet.

Average daily distance (km)	<b>177</b>
Max. daily distance (km)	<b>516</b>
Average journeys per day*	<b>14</b>
Average days/week of usage	<b>5</b>
Average daily driving time	<b>5h 42min</b>
Average speed (km/h)	<b>31</b>
Urban driving %	<b>47</b>
Road driving %	<b>37</b>
Motorway driving %	<b>16</b>



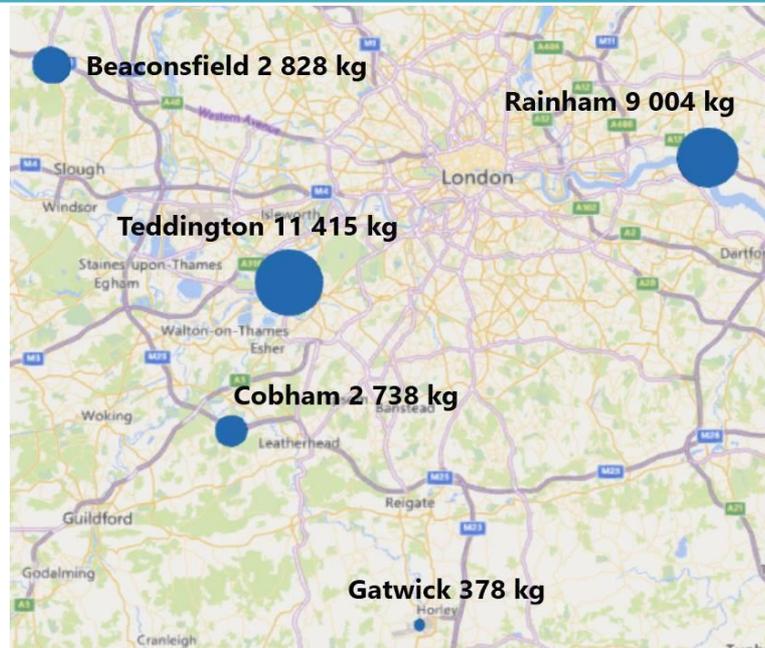
- ❑ GTC taxis show an average fuel economy of **105 km/kg H2**. This average was calculated by excluding any months with an unreasonable fuel economy outside the limits indicated in the graph: 70 and 120 km/kg (considering the NEDC value of 110 km/kg).
- ❑ The reason for unreasonable fuel economy values could be gaps in the refuelling records or odometer readings, partly caused by the pandemic.



- ❑ 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.
- ❑ There is an evident seasonal variance in fuel economy, with a 25% difference between the worse value (89 km/kg in Jan-19) and the best (119 km/kg in Sep-20). However, there is only a 4% difference between the average for the coolest months (103 km/kg from November to April) and the warmest months (108 km/kg from May to October).

# London

## Where GTC FCEVs are Refuelling

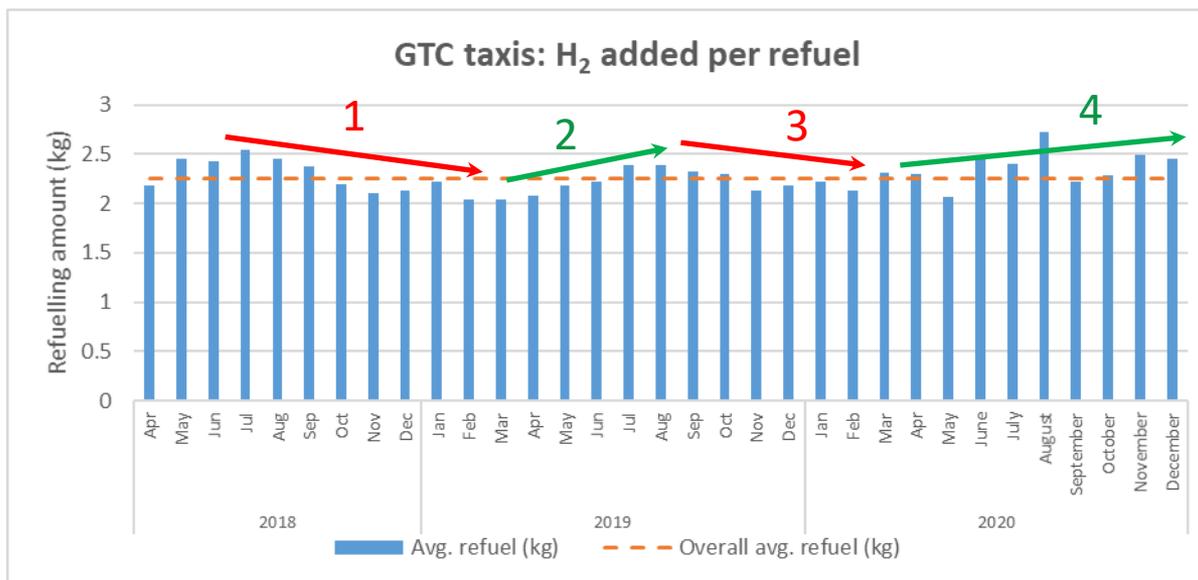


- The figure above shows the location of ITM Power HRS around London and the number of kg of hydrogen dispensed to GTC FCEVs between April 2018 and December 2020. In that period, there have been **26 374 kg of hydrogen** dispensed in 11 667 refuelling events, averaging 2.3 kg per refuel (45% of the 5 kg hydrogen tank capacity).
- The FCEVs use all the ITM London HRS, but the two most popular stations are the more centrally-located ZEFER stations: 77% of the total fleet hydrogen is dispensed by the Rainham and Teddington HRS. The mean distance between refuels for the GTC taxi fleet is 237 km.

# London

## How GTC FCEVs are Being Refuelled

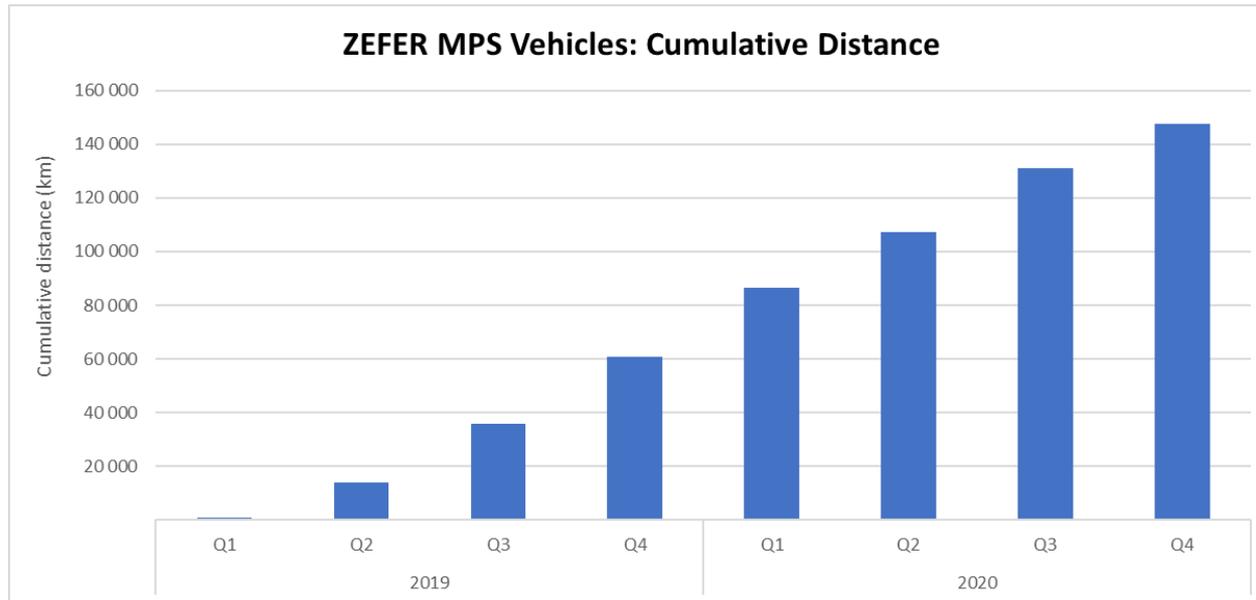
### Driver Refuelling Behaviour



- ❑ Overall average refuelling amount is 2.3 kg (45% of tank capacity of 5 kg). This compares to 57% of the tank refuelled in GTC’s petrol/diesel taxis and 71% in plug-in hybrid taxis.
- ❑ Four periods of driver refuelling behaviour are noted on the graph above:
  1. Drivers in late 2018 and early 2019 were refuelling more frequently than necessary: unnecessary trips to refuel reduce the economic efficiency of the drivers.
  2. ITM’s app and HRS status info provided to drivers. Also, GTC changed the FCEV drivers from contracted to self-employed which incentivises them to increase productivity and reduce unnecessary refuelling trips.
  3. Refuelling efficiency dropped again from September 2019. 25 new vehicles were introduced to the fleet: new drivers with no experience in refuelling FCEVs were recruited so needed to be trained.
  4. Due to the Covid pandemic, there was a reduction of around 50% in the number of taxis used. The most veteran FCEV drivers were placed in these vehicles, which increased the refuelling efficiency to values above the average.

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- The graph above shows the cumulative distance from the 10 ZEFER vehicles deployed. Due to data unavailability from Aug-19, this has been estimated using refuelling records and an assumed fuel economy of 90 km/kg (average of other ZEFER and H2ME Toyota Mirais used in non-aggressive driving duties, as these are general purpose vehicles). Total cumulative estimation of **148 000 km**.

# London

## Where MPS FCEVs are Refuelling

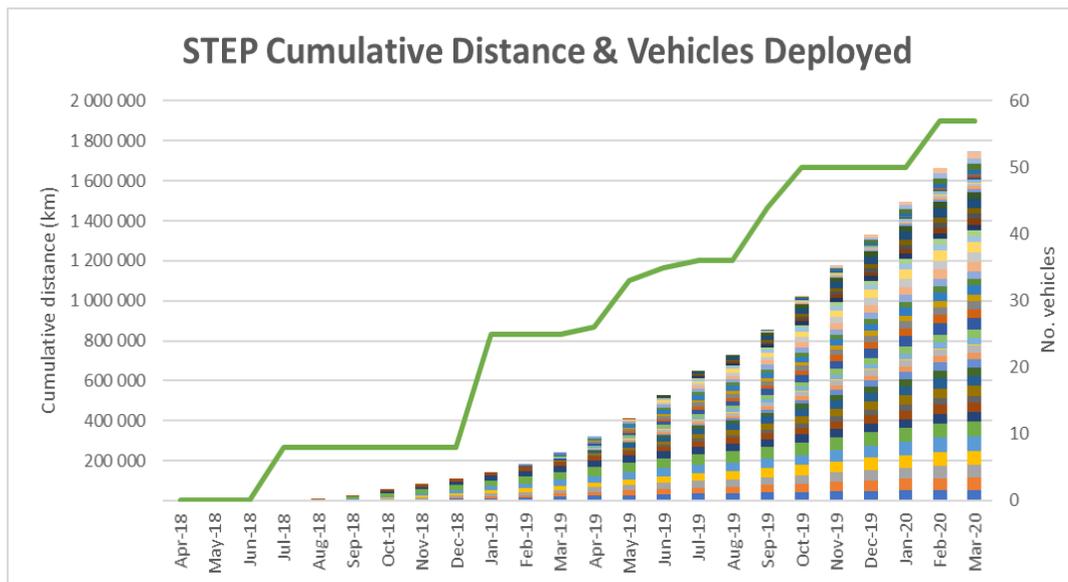


- ❑ The figure shows where H2ME and ZEFER MPS vehicles refuel. In West London, vehicles use multiple refuelling stations (even Beaconsfield and Cobham, which are both outside the M25). In East London the vehicles only use the Rainham station.
- ❑ On average, each ZEFER vehicle uses 107 kg/year, while each H2ME vehicle uses 282 kg /year. An additional HRS will be located in Barking (East London) with an expected commissioning in Q3/Q4 2021. This will provide an additional local option for vehicles in the area, both for GTC and MPS.

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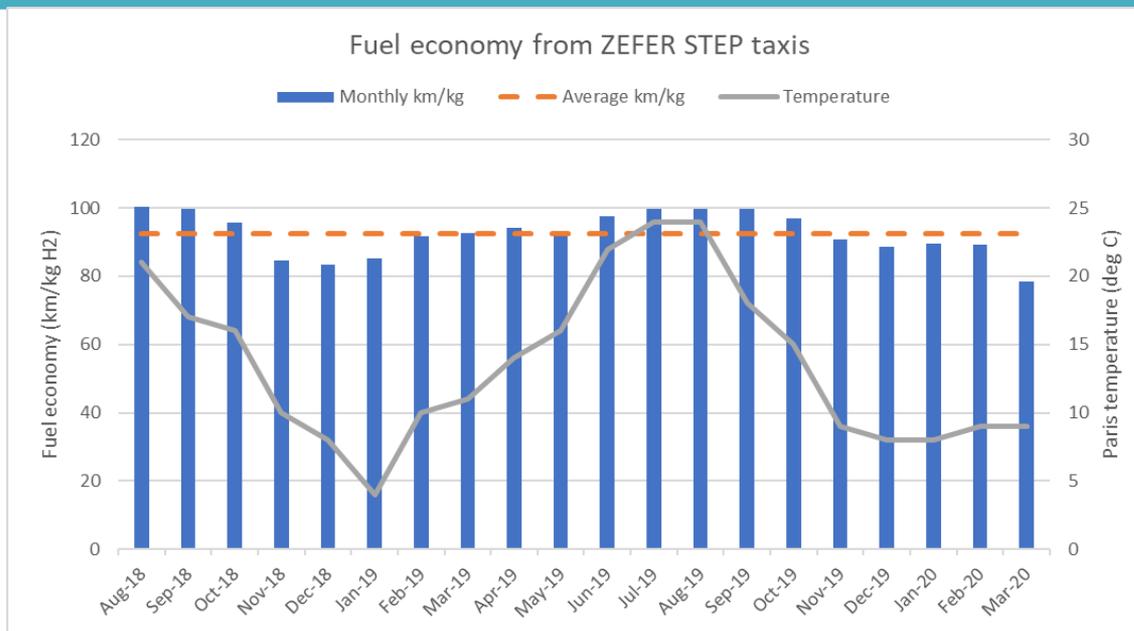
# Paris FCEV Taxi Operation to end of March 2020



- ❑ The bars show cumulative distance per vehicle (one colour per vehicle), while the green line shows the no. of vehicles deployed. Unfortunately, STEP has not yet restarted operation in Paris as COVID 19 is still impacting economic activities.
- ❑ The ZEFER Hype/STEP FCEVs have reported a total of **1 743 000 km** driven. The ZEFER taxis drive an average of 3 260 km per month (150 km per day and 39 000 km/year), note that this average is calculated only for the months when vehicles are actually driven.
- ❑ The furthest driven by one of the vehicles in a month was 7 470 km.

# Paris

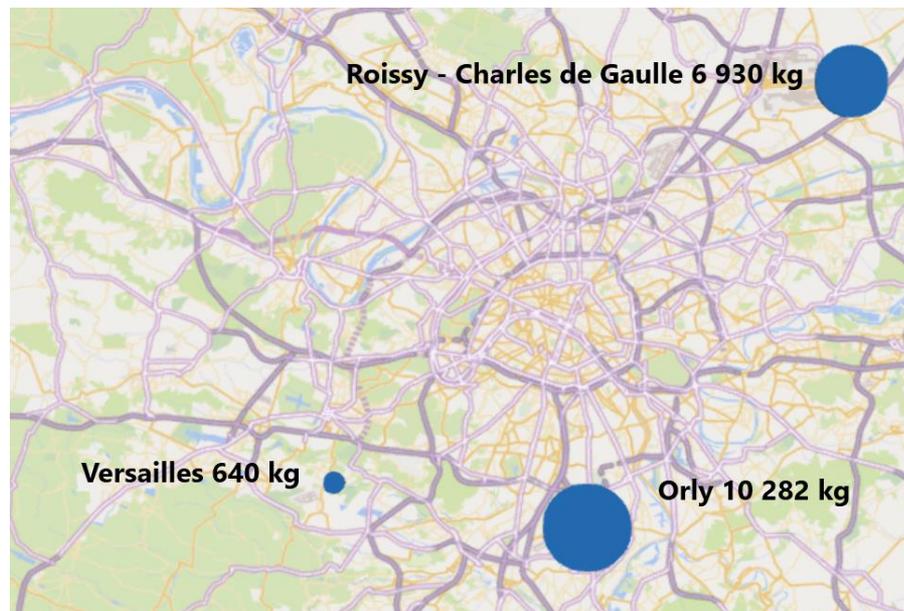
## How FCEV Taxis are Being Driven



- ❑ The average fuel economy across all STEP (ZEFER) vehicles and months is **92 km/kg**, as opposed to GTC's 105 km/kg in London.
- ❑ The values for all months were within the considered reasonable range of 70 to 120 km/kg, probably because the data comes from vehicle telemetry rather than manual odometer readings or refuelling records.
- ❑ There is an evident seasonal variance in fuel economy, with a 22% difference between the worse value (78 km/kg in Mar-20) and the best (100 km/kg in Aug-18). However, there is a smaller difference of 9% between the average for the coolest months (89 km/kg from November to April) and the warmest months (98 km/kg from May to October).

# Paris

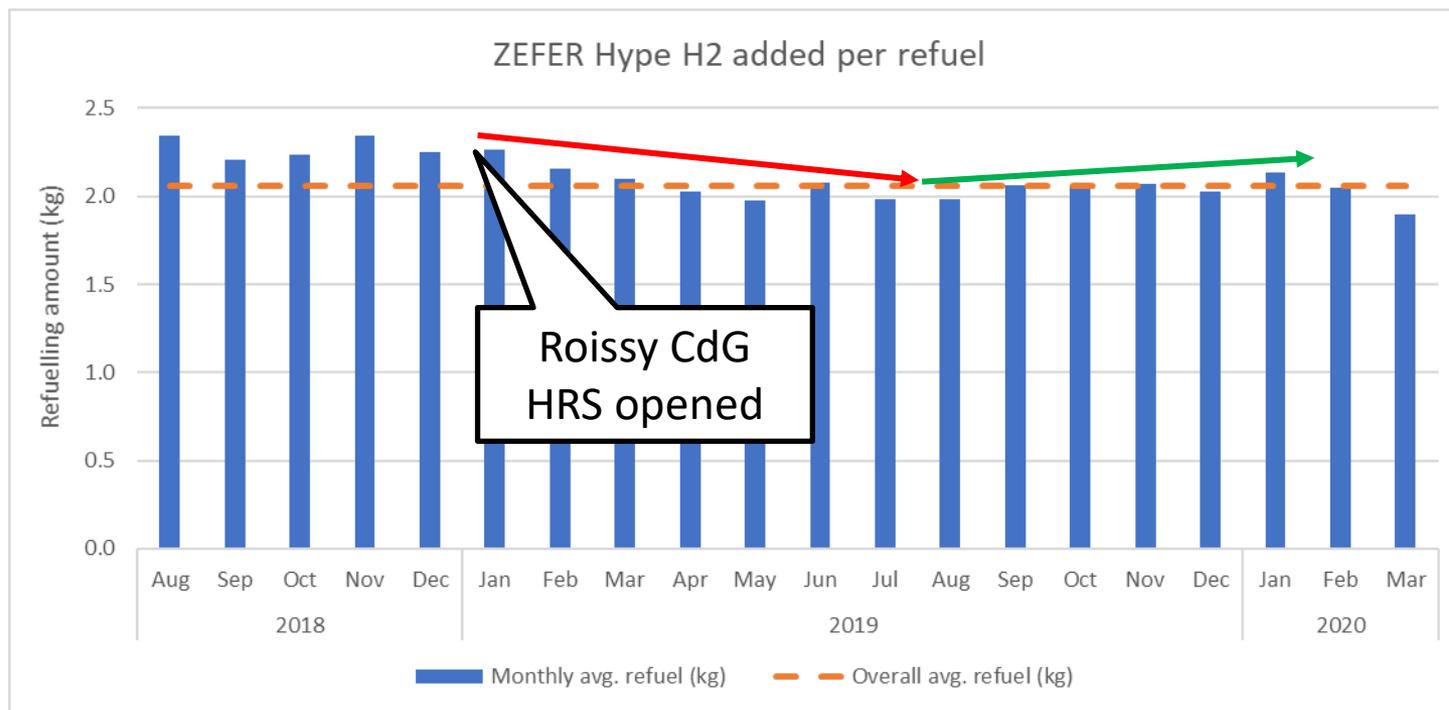
## Where FCEVs are Refuelling



- ❑ The figure above shows the location of Air Liquide HRS around Paris and the number of kg of H<sub>2</sub> dispensed to ZEFER Hype FCEVs between August 2018 and March 2020, when the taxi operations stopped due to the pandemic. In that period, the vehicles have averaged 2.3 kg per refuel (45% of the 5 kg hydrogen tank capacity). Please note that this data comes from vehicle telemetry and has been produced using Cenex geofencing algorithms.
- ❑ The FCEVs use all the Paris HRS, but the most popular stations are the ones located in the airports (Orly and CdG/Roissy), as the taxis refuel there when they leave and pick up passengers and they do not need to detour to refuel, like it often happens in London. The temporary Pont de L'Alma HRS had also a high usage from STEP taxis due to its central location. The mean distance between refuels for the ZEFER STEP taxi fleet is 197 km.

# Paris

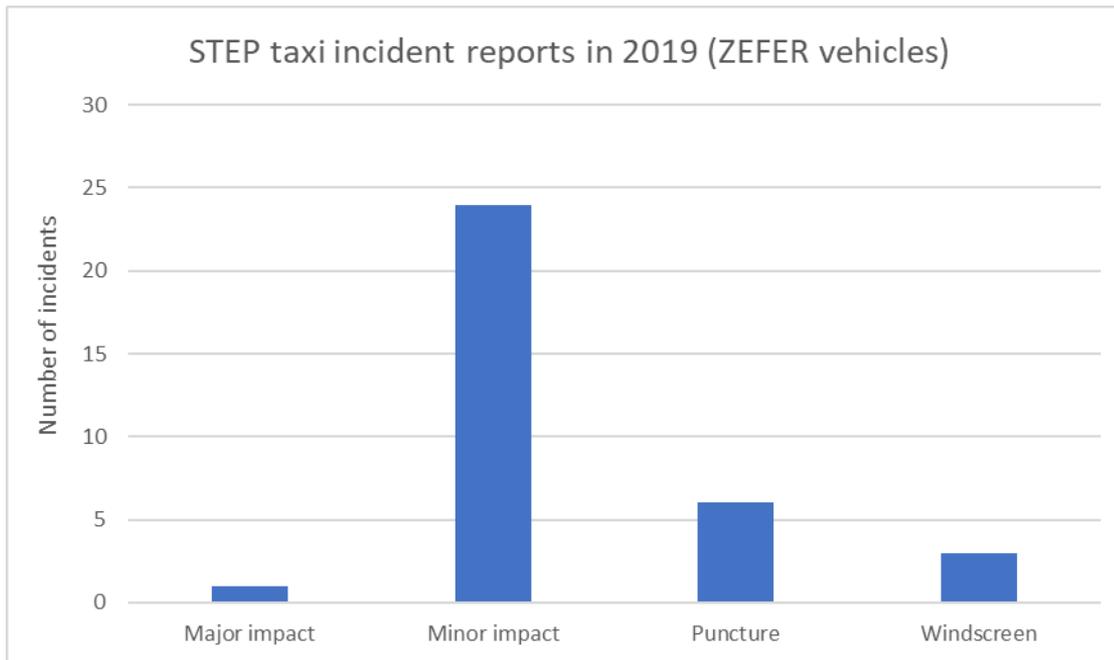
## How FCEVs are being refuelled



- ❑ The overall average refuelling amount is 2.1 kg (42% of the tank capacity of 5kg).
- ❑ Amount of H<sub>2</sub> per refuel decreased since the opening of the Roissy/CdG HRS, likely due to drivers accessing an additional HRS in their airport jobs.

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- The STEP taxis drive a lot. Inevitably, they are involved in incidents.
- The taxis have the same types of incidents as normal taxis.
- 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.**

- ❑ 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<sub>2</sub> 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).

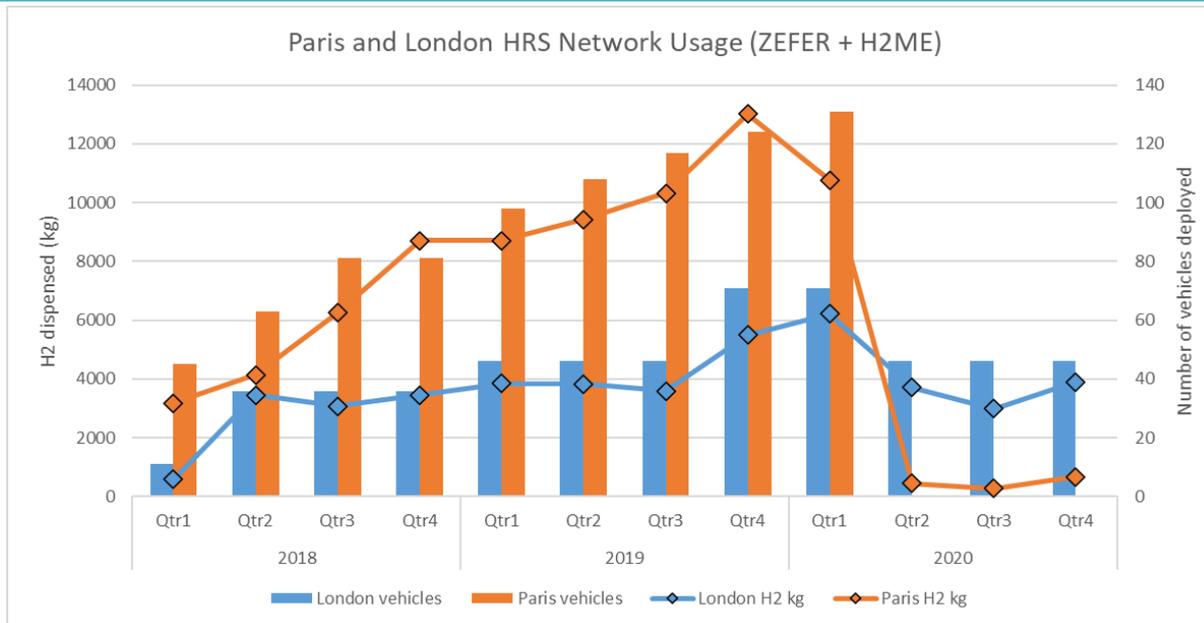
\*Source: Toyota UK

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# 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.
- ❑ The taxis in Paris stopped their operation in March 2020 due to the Covid pandemic so no hydrogen was dispensed to cars, while a small amount was dispensed to buses.
- ❑ The GTC fleet reduced operations by 50% causing a decrease in hydrogen dispensed in London.
- ❑ The London HRS network is formed by the stations in Rainham, Cobham, Teddington, Beaconsfield and Gatwick. The Paris HRS network is formed by the stations in Orly, Roissy and Versailles.

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- ❑ 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 2018, ZEFER FCEVs have driven **5.14 million km**.
- ❑ 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



elementenergy



MAYOR OF LONDON  
OFFICE FOR POLICING AND CRIME



MAIRIE DE PARIS



*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.*

