Hydrogen Mobility Europe

Emerging Conclusions

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Document prepared by: Element Energy

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This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 671438 and No 700350. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

Clean Hydrogen Partnership

Co-funded by the European Union

This report has been prepared as part of the CH2 JU-funded project H2ME by Element Energy

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The report was prepared in consultation with by the H2ME projects partners

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List of projects partners:

AGA AB, Air Liquide Advanced Business, Air Liquide Advances Technologies SA, Air Liquide France Industrie, Alphabet Fuhrparkmanagement GMBH, Audi Aktiengesellschaft, B. Kerkhof & ZN BV, BOC LTD, Bayerische motoren Werke Aktiengesellschaft (BMW), Brintbranchen, Centre of excellence for low carbon and fuel cell technologies (CENEX), Communauté d'agglomeration Sarreguemines Confluences, Compagnie Nationale du Rhone SA, Danish Hydrogen Fuel AS, EIFER Europaisches Institut Fur Energieforschung EDF KIT EWIV, ERM France, GNVERT SAS, Elogen, H2 Mobility Deutschland GMBH & CO KG, HYOP AS, Honda R&D Europe (Deutschland) GMBH, Hydrogene de France, Hysetco, hySOLUTIONS GmbH, Hyundai Motor Europe GMBH, ITM power (trading) LTD, Icelandic New Energy LTD, Intelligent Energy LTD, Islenska Vetnisfelagid EHF, Kobenhavns Kommune, Linde GMBH, Manufacture française des pneumatiques (Michelin), McPhy Energy, Mercedes-Benz AG, Ministerie Vann Infrastructuur en Waterstaat, Nel Hydrogen AS, OMV Downstream GMBH, Open Energi LTD, R-Hynoca, Renault SAS, Renault Trucks SAS, Réseau GDS, HYPE, Société d'économie mixte des transports en commun de l'agglomeration Nantaise (SEMTAN), Stedin Netbeheer BV, Symbio SAS, The University of Manchester, Toyota Danmark AS, Toyota Motor Europe NV, Toyota Norge AS, and Waterstofnet VZW.

This document summarises the results of the H2ME initiative to mid-2022

- The H2ME initiative is a **flagship European project**, deploying hundreds of fuel cell hydrogen cars, vans and trucks and the associated refuelling infrastructure, across 9 countries in Europe. **It creates the basis for a first truly pan-European network, and contributes to building the world's largest network of H_2 refuelling stations.**

- The project is made up of two phases, H2ME (1), which started in 2015, and H2ME-2, which will end in 2023. Over the course of these two phases, **more than 1,400 vehicles and 45+ hydrogen refuelling stations** will be deployed. The deployments are intended to jump start the drive towards fuel cell vehicles and establish the conditions in which fuel cell vehicles and the underlying refuelling stations can thrive.

- The project is being supported by the European Union through the Clean Hydrogen Partnership (previously, FCH 2 JU) but is driven by the **continuous engagement of the industry.**

- This documents provides a **summary of the project status, highlights key achievements and also report on some of the emerging issues** which need to be tackled by the fuel cell vehicle sector as it moves towards a commercially viable mass market proposition.

- This is a living document that will continue to be updated to the end of the project. It is intended to:
  - Give first-hand information from real world activities to stakeholders, policy-makers, etc.;
  - Identify and communicate about the common themes emerging from these activities;
  - Serve as a basis for further deployments.

Executive Summary (1/2)

- H2ME in its two phases has been underway for nearly 8 years. The focus has been on clusters of larger numbers of light duty fuel cell vehicles (over 1,400 planned) and associated Hydrogen Refuelling Stations to test and develop business models, assess sentiment, prove technologies at scale and apply learning to overcome some of the barriers to more widespread application.

- H2ME has been successful so far in 10 key areas:
  1. Green mass mobility and logistics solutions have been proven in cities and regions, with ranges and refuelling time similar to conventional vehicles. The experience gained gives a robust springboard to further roll-outs.
  2. The fuel cell vehicles have worked reliably, with new models offering increased performance becoming available on the market.
  3. Fuel cell vehicles are finding niches where batteries are challenged, in extreme range and in intensive operation. While this applies to personal cars and commercial vans, it is even more so to heavy-duty trucks, city and long-distance buses. Last-mile deliveries (which require a significant overall range) are emerging as a good fit for fuel cell vehicles.
  4. The hydrogen supply infrastructure has been proven at scale, including green (electrolytic) hydrogen which can be produced on-site at periods of low electric grid demand. The expansion in refuelling station numbers and learning has improved availability. Learning is being applied in best practice in permitting, in failure modes and design workarounds, and in servicing.

Executive Summary (2/2)

5. Hydrogen Refuelling Stations are becoming more affordable as an economy of scale emerges in their roll-out and increased utilisation and higher dispensed H2 volumes are seen. This trend will continue. For mass transport (in the order of a million vehicles), the amortised cost of hydrogen infrastructures is lower than aggregate electric chargers.
6. H2 is a flexible energy vector, with cross-over benefits to hard-to-reach sectors, such as industry, shipping and aviation. As H2 (including imports) becomes more prevalent across applications, the cost and availability issues now seen in the early roll-out phase will lessen.
7. The roll-out of FCEVs in H2ME has demonstrated safe fuelling with H2 without compromise to safe vehicle operation.
8. End to end life cycle CO2 emissions relating to green hydrogen are similar to that of BEVs.
9. Significant gains in technical know-how has accrued, with potential gains in green jobs, energy security and CO2 savings.
10. Prior to H2ME, there were few large deployments of fuel cell vehicles in Europe. This is no longer the case for light duty vehicles, with taxi fleets growing, and H2ME has encouraged further activity in other vehicles segment (e.g., ZEFER, H2Haul, H2Bus). Prior to H2ME, almost no fuel cell vans were fielded, HRS were hugely underutilised, with breakdowns common – this too has changed.

- ❑ H2ME execution continues alongside ZEFER, with significant data collection that will further refine the development of models and business cases for FCEV and HRS.

Public resources with results of the first phase of the H2ME initiative

- This document provides an overarching summary of the activities undertaken in the project. However, more detailed reports are available on the website of the H2ME project: https://h2me.eu/publications/
- The key reports that contributed to forming the views in this report were prepared by the H2ME project partners. The publicly-available reports used are:
  - Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, H2ME (1) D2.6, Element Energy
  - Final yearly technical report reviewing the technical progress for FCEVs & HRS in the project, H2ME (1) D4.16, Cenex
  - Well to Wheels environmental impact assessment, H2ME (1) D4.19, Cenex
  - Vehicle user attitudes, driving behaviours and HRS network access trends, H2ME (1) D5.10, Element Energy
  - Summary and lessons learnt from the hydrogen mobility strategies tested in this project, H2ME (1) D5.13, Element Energy
  - Strategic recommendations for supporting the commercialization of fuel cell electric vehicles in Europe, H2ME (1) D5.16, Element Energy
  - Six Monthly Summary Technical Report Presenting Project Data to May 2022, H2ME (2) D5.12, Cenex
  - Annual H2ME Vehicle and Infrastructure Performance Reports (2015-2022), H2ME (2) D5.14-D5.17, Cenex
  - HRS Safety, Regulations, Codes and Standards. Lessons Learned: Interim Report 3, H2ME (2) D5.21, Cenex
  - Technical performance of HRS under high utilisation and recommendations, H2ME (2) D5.35, Element Energy
  - Overarching progress beyond the current state of the art and gaps preventing full commercialisation - Interim 2, H2ME (2) D6.12, Element Energy

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Why is hydrogen mobility important?

- **Environmental Improvements** – hydrogen can be generated through a range of zero carbon routes. Using hydrogen as a fuel in the transport sector will **reduce global emissions and improve local air quality**, thus addressing both climate change and a major public health issue whilst at the same time meeting EU legal requirements.

- **Energy Security** - **as hydrogen is widely available** and can be produced from a variety of local renewable and other energy resources, it offers **independence from energy imports.**

- **Economic Development** - The expansion of this new sector provides the opportunity to **create new local businesses and jobs, promote wider economic growth, and maintain Europe's technology leadership.**

- **Services for a greener grid -** generating hydrogen from electrolysis can help **incorporate renewable energy into the energy mix** by providing grid balancing services - the process of using excess electricity when energy supply temporarily exceeds demand.

- **Energy storage** – generating hydrogen from electricity helps further **incorporate renewable energy into the energy mix** by providing a higher storage capacity (and hence longer duration) option compared to batteries.

Why is hydrogen mobility important?
… perspectives for society and policy makers

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Local Air Quality improvements

- **A solution today for cities and regions**
  - Vehicle operation producing **zero tailpipe emissions. FCEVs do not release CO_2 or harmful particles such as nitrogen oxide (NOx), sulphur oxide (SOx) or fine particulate matter (PM2.5).**
  - … while offering fast refueling (3-5 minutes) and long driving range (500 km+ on a single tank).

A 'swiss army knife' for meeting energy and climate change policies

- **A solution making the energy transition feasible**
  - The technology is **needed to meet targets for CO_2 reduction and accommodate increases in Renewable Energy production.**
  - FCEVs have **significantly lower GHG emissions** compared to conventional vehicles and can be **zero-emission** when hydrogen is generated from renewable energy.
  - **FCEVs are complementary to Battery Electric Vehicle (BEV)**, allowing a transition to ZE (Zero Emission) vehicles today for applications that remain hard to decarbonise due to their operational needs.
  - **Electrolysis can be used as a grid balancing tool, mitigating increased costs and electricity demand** for network operators **from increases in RE production and BEV sales.**

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Why is hydrogen mobility important?
… perspectives for early adopters

Mercedes-Benz GLC F-Cell, Hamburg Police Service , Germany @Daimler

Toyota Mirai, Hype, France @Toyota

Renault Kangoo Z.E Hydrogen (by Symbio), France @Symbio

Zero emissions, zero compromise

- **A solution today for fleets and private customers**
  - Among zero emission (ZE) powertrains, **FCEVs provide the longest range and shortest refuelling times today.**
  - FCEVs provide a ZE emission powertrain option that **does not greatly limit productivity or operation** thanks to fast refueling (3-5 minutes) and a long driving range (500 km+ on a single tank). As the FCEVs mature, ranges approaching 1,000 km are to be expected, closer to those of ICEVs.

Supporting operation today and in the future

- **A solution to contribute to climate change mitigation efforts today while preparing for future regulations.**
  - FCEVs produce **zero tailpipe emissions** and **can be zero-emission** when hydrogen is generated from renewables.
  - They can support drivers and organisations in demonstrating their **commitment to addressing air quality and reducing CO_2 emissions.**
  - Use of light duty FCEVs today **prepares for future air quality/GHG policies introduced by national or city governments**, while demonstrating leadership in sustainable transport, and provides a common platform with HDVs.

Why is hydrogen mobility important?

… perspectives for energy providers

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Preparing for the future

- **Hydrogen can be easily stored when produced by water electrolysis, providing two key benefits to the grid:**
  - the flexibility to adapt to larger demand fluctuations on energy networks.
  - the flexibility to balance demand and supply as there is increasing penetration of renewable generation.

- The technology is **needed to meet targets for CO_2 reduction and the expected increases in Renewable Energy (RE) production.**
- **Electrolysis can be used as a grid balancing tool, mitigating increased costs and electricity demand** for network operators **from increases in RE production and BEV sales.**

A potential new source of revenue

- Due to the speed at which water electrolysers can vary their output (and hence electricity demand), it is possible that the **provision of grid balancing services such as frequency responses or balancing services can be monetised.**

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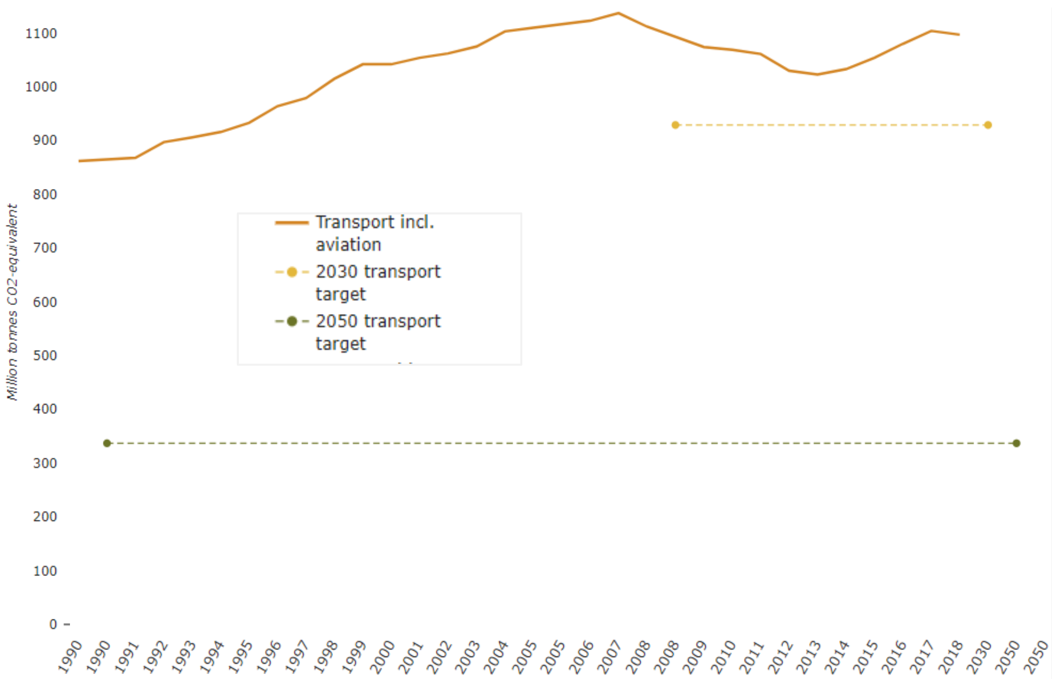
Societal challenge: Transport is the only sector with rising CO2 emissions

- **Transport emissions : 27% of all emissions in the EU;** a rising figure: + 26% compared with 1990.
- **Road transport accounts for 72 %** of total greenhouse gas emissions of the sector.
- **Air pollution responsible for over 400,000 premature deaths annually in Europe.**

Greenhouse gas emissions from transport are rising while the political ambition is increasing



Policy ambitions: EU Transport White Paper 2011 set targets at 30% CO2 emissions reduction by 2030 and 60% CO_2 by 2050 (compared with 1990 levels)

Air Quality Directive: sets maximum air pollution limit in each Member State with first infringements procedures launched against Member States failing to meet these targets

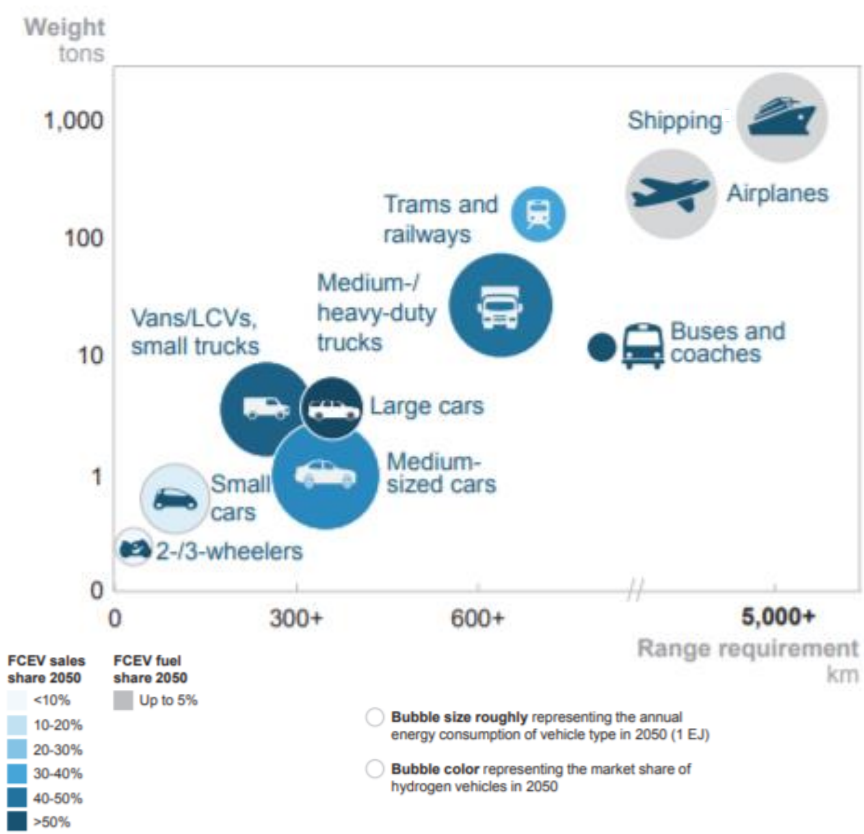
The Directive on Alternative Fuels Infrastructure (2014/94/EU) sets mandatory targets for alternative fuels infrastructure deployment. This was replaced with the Alternative Fuels Infrastructure Regulation under the 'Fit for 55 package' in 2022, which includes new CO2 emission performance standards for cars and vans.

Source graph: Environmental Energy Agency (EEA), 1990-2077 data. www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12#:~:text=In%202017%2C%2027%20%25%20of%20total,by%202.2%20%25%20compared%20with%202016

Societal challenge: How does hydrogen fit into today's green mobility efforts?

FCEVs are complementary to BEV, allowing a transition to ZE vehicles today for applications with longer ranges and more weight that remain hard to decarbonise due to their operational needs

Transportation market segmentation



Battery Electric Vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) have become the leading green mobility solutions in recent years in terms of market progression and technological advancements. However, there remain some challenges e.g., long range, continuous use, and heavy-duty applications that today they cannot fully address. **FCEVs offer a viable solution to better meet these challenges.**

Though historically a single powertrain (ICE) has dominated, **multiple complementary ZE powertrain solutions are now needed**. The complementary nature of these technologies is furthered by progress in BEV, PHEV, and FCEV development benefiting one another due to commonality in powertrains and components, including applying fuel cells as range-extenders.

Source graph: IEA ETP; HIS; A portfolio if powertrains for Europe (2010); Thiel (2014); Hydrogen Council https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

1. Introduction

Section overview

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- Barriers to be addressed

What is a Fuel Cell Electric Vehicle (FCEV)?

- **FCEVs run on hydrogen gas as a fuel. A highly efficient fuel cell transforms the hydrogen directly into electricity to power the electric motor(s).**

- FCEVs produce **zero harmful tailpipe emissions**, with **water vapour** being their **only exhaust. No CO_2 or harmful emissions such as nitrogen oxides (NOx), sulphur oxides (SOx) or fine particulate matter (PM2.5) are produced.**

- FCEVs offer a **long-distance range comparable to conventional petrol and diesel cars** and vans – with a **range of 500 km+ per refill today**, expected to increase to 1000 km , whilst providing a smoother, quieter and more responsive driving experience. **The refuelling time is comparable to conventional petrol and diesel cars (3 to 5 minutes).**

- FCEVs invariably have a battery, for recapturing braking energy, providing extra power during acceleration events, and to smooth out the power delivered from the fuel cell. But this battery is usually small, with only a few vehicles (like the GLC F-CELL) having a small electric plug-in (PHEV) ability. At the other extreme, the Kangoo ZE Hydrogen has a small fuel cell, used to continuously charge the battery and deliver range extension to the vehicle.

FCEVs are as safe, if not safer, than traditional gasoline vehicles
The carbon-fibre hydrogen tanks of the vehicles have withstood highly demanding crash, fire, and ballistic testing, and thanks to these high safety standards, FCEVs can meet the strict safety and quality regulations of the countries where they are being deployed (Europe, Japan, Korea and the USA).

How does the technology work?

A fuel cell powertrain generally comprises the following components: **fuel cell stack, hydrogen tanks, battery and power electronics, and electric motor.** Various configurations of the fuel cell stack and battery are possible.

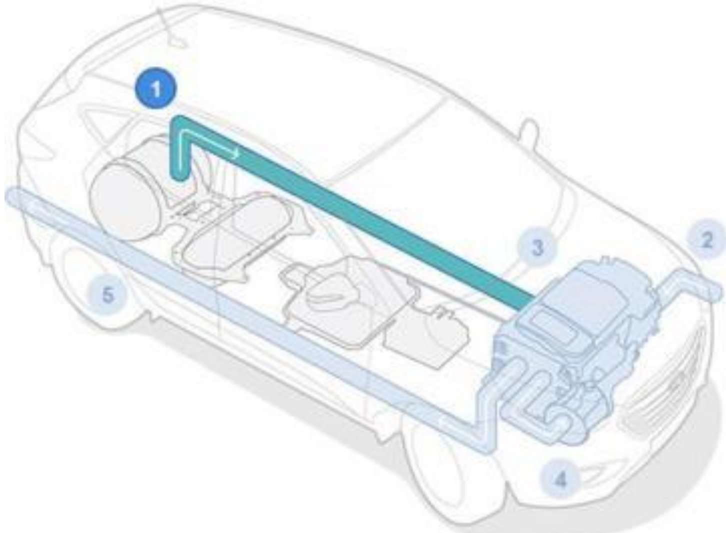
Step 1 Hydrogen stored in the tank is supplied to the fuel cell stack

Step 2 An inflow of air is supplied to the fuel cell stack

Step 3 The reaction of oxygen in the air and hydrogen in the fuel cell stack generates electricity and water

Step 4 Generated electricity is supplied to the electric motor

Step 5 Water is emitted and is the only by product



In H2ME, two main configurations are used.

- Full Fuel Cell Electric Vehicles (FCEVs) are **fuel cell dominant.** All the primary energy comes from the H_2 fuel cell, like the Toyota Mirai, with a 114 kW stack and 1.6 kWh battery or the GLC F-CELL, with a 135 kW stack and 13.5 kWh battery.
- The **Fuel Cell Range Extender mode (RE-FCEVs)** use energy from the battery, which is continuously charged by the fuel cell running at its optimum point. The battery in the RE-FCEVs can be plugged-in and charged from the grid. The RE-FCEVs span the Kangoo Z.E. Hydrogen (with its 5 kWe/10 kW gross output stack and 33 kWh battery) to the new Stellantis Ë-JUMPY, e-HYDROGEN and e-EXPERT vans (with a 45 kW gross output stack and 10.5 kWh battery).

What is a Hydrogen Refuelling Station (HRS)?

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- **The creation of a fuelling station network is essential** to the market development of Fuel Cell Electric Vehicles.
- **At the moment there is a limited number of HRS** in each of the partner countries, though networks are growing.
- Hydrogen (H_2) can be produced off site or on site and provide grid balancing services.

Off site production

In **off-site production** hydrogen is delivered to stations by tanker or pipeline, in the same way that fuel is delivered to petrol stations. It has the advantage of **allowing large scale production at low costs**. Currently the majority of hydrogen comes from natural gas but low carbon sources for production (including from electrolysis) or certificates for green hydrogen can be used to increase the proportion of green H2 at the stations as is the case in the H2ME project.

On site production

On-site production generates hydrogen by electrolysis, in the best case with the aid of renewable electricity. These stations have the potential to offer **clean fuel from renewable energy** as well as eliminating the need for fuel deliveries.

Grid balancing & servicing

Grid balancing is necessary to help match energy supply and demand. At times, the energy supply can exceed demand, with wasted capacity. The **'excess' energy can be used** in the electrolysis of water to make hydrogen, stored for supply to vehicles.

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Commercialisation insights
A growing vehicles market

- A large international effort over the past few decades by industry and governments has developed hydrogen vehicle technology to the point where they are ready for a first commercial roll-out.
- FCEVs and HRS are currently in the **early stages of market ramp-up**. A mature (self-sustaining) market is expected by the 2030s, with expected sales of tens of thousands of vehicles/year and a growing HRS network across Europe[1].
- **Vehicles have been available as demonstrators in Europe for a few years now from OEMs Hyundai and Toyota, with Renault & Stellantis (Symbio) building up small fleets of range-extended (RE) vans.** Honda and Mercedes have run small trials. While both companies no longer pursue fuel cell cars, they continue to support H2ME to its completion. Renault continues to work on a van platform, even as it repositions to PlugPower stacks following the formation of the Hyvia JV. Stellantis (PSA) has released its first FC-REEV vans (HKO), BMW will release prototype iX5 in 2023, mass production for sale of vehicles in 2025 has been announced. Audi and Jaguar are poised to field demonstrator cars.
- **Vehicles from other transport segments are also increasingly coming to market** (trucks, train, boats, aviation).

Models available in the EU market today

Nexo Fuel Cell
Hyundai

Mirai FCV
Toyota

Models available in the EU market from 2023

iX5*
BMW

HYVIA
Renault & PlugPower

HKO
Stellantis & Symbio

Models previously available in the EU market

ix35 Tucson Fuel Cell**
Hyundai

Clarity Fuel Cell*
Honda

B-Class Fuel cell*
Mercedes-Benz

GLC Fuel cell*
Mercedes-Benz

Renault Kangoo Z.E Hydrogen*
Symbio

**** Small trial ** new generation now available***

[1] In 2030, 1 in 12 cars sold in California, Germany, Japan, & South Korea could be powered by H_2, Source: Hydrogen Council, https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

Commercialisation status today

Number of FCEVs and HRS operating in Europe

Over three thousand hydrogen vehicles and over 200 HRS have now been deployed in Europe

Vehicles Data includes but is not limited to H2ME	Germany	France	UK	Nordic region	BeNeLux	EUROPE
Cars	1,240	396	241	329	605	2,786
Vans (including range extended vans)	16	273	7	2	15	306
Buses	92	28	58 (IPHE)	12	63	181
Trucks	20 (IPHE)	1	36 (IPHE)	5	15	17
Trains	2	-	-	-	-	2
Active HRS	101	41	11 (UK H_2Mobility)	18 (H2Stations)	18 (H2Stations)	228 (H2Stations)

Source: EAFO (excludes retirements) unless otherwise stated; IPHE country statements, UK H_2Mobility, H2Stations.org (LBST)

- The FCEVs (>1,400) & HRS (~49) planned in H2ME kick-started this growth and remain a large share of deployments.
- H2ME numbers are supplemented by private initiatives such as the HyTruck programme in Austria, the HyTrucks consortium in Northern Europe, Hyundai's plan to deploy 1,600 Xcient trucks in Switzerland, H2Bus with a planned initial deployment of 605 buses in Europe, and the EU project ZEFER, which is deploying 180 FC taxis in Paris.

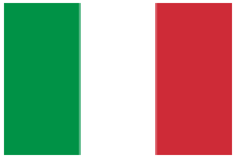
H2ME Observer Country highlights

- H2ME's 'observer countries' (the Netherlands, Belgium, Italy and Austria), are using the learnings from the project to inform their own hydrogen mobility strategies.

- The Netherlands currently has 514 fuel cell cars, 14 vans, 54 buses, 15 trucks, and 12 active HRS, one of the largest deployments in Europe. With a growing offshore wind base, high growth in fuel cells in mobility is expected. Local regions are scaling up H_2 activities including green H_2 generation. Alongside Belgium and Germany, it is part of the HyTrucks initiative, the REVIVE refuse truck demo, and a destination for many Hyzon deliveries.

- Belgium has 97 fuel cell cars, 1 van, 4 buses, and 5 active HRS. Activity is growing, with a Hydrogen Industry Cluster with >126 members. CMB.TECH is targeting dual-fuel trucks by 2022, which will benefit from the HRS network. VanHool has presented a new series FCEB.

- Italy has 45 fuel cell cars, 13 buses, and 3 active HRS. SNAM is leading much of the activity in the country. ENI is to open its first HRS in Venice. Several Hydrogen Valleys projects are planned in the country.



- Austria has 55 fuel cell cars and 6 active HRS. H2 Mobility Austria, a consortium of eleven Austrian companies, aims to put 2,000 H_2 trucks on the roads of the country by 2030. Hyzon has committed to supplying 70 fuel cell trucks to the Mpreis supermarket chain.

Commercialisation challenges

Remaining barriers to be overcome include:

- The number of FCEVs on Europe's roads remains limited. As a result, the early HRS have a **low utilisation** which limits revenues for early investors. This in turn means that **limited infrastructure** remains a key barrier to uptake of FCEVs. More research and **development is needed to mature the HRS supply chain.**

- Despite production costs for FCEVs falling significantly in recent years, **FCEVs are still more expensive** than conventional cars. During the 2020s, costs are expected to improve with the effect that FCEVs are expected to offer a cost-competitive alternative to long range electric vehicles for zero emission driving.
- Today, FCEVs are starting to provide a competitive Total Cost of Ownership only for specific fleets which value the advantages of H_2 fuel, such as taxis in polluted urban centres and urban delivery vehicles. ZEFER estimates FCEVs are now one generation away from being fully cost competitive.

- Achieving the mass market will require fuel cell vehicles manufacturers to **reduce prices through economies of scale** (ultimately to 10,000s of vehicles per year).
- This large market for vehicles will then justify commercial deployment of hydrogen stations to expand the network.
- The **H2ME** initiative is designed to support this early phase of roll-out for Europe, with the single largest number of vehicles and HRS (focused on electrolysis) yielding pooled data to date.

Technical advancements (HRS)
… and remaining barriers to be overcome

Improvements achieved to date

- **Common standards** have been agreed.
- **Safety** standards are in place.
- **Hydrogen (H_2) can be produced** at both small and large scale from centralised or decentralised production.

Though HRS are capable of serving the needs of customers today, further development is needed:

Further technical advancements required

- Improvements in **supply chain maturity (e.g., nearby spare parts availability, number of suppliers)**
- Further improvements in **availability and other areas relating to H_2 fuel retailing** (e.g., fuel quality assurance and accurate fuel metering
- **Demonstration of ability to provide electrolyser grid balancing services.**

Commercial advancements required

- **Reduction in H_2 production costs, through lower cost energy input and reduced cost of system components (e.g., water electrolysers)**.
- **Refinement of the customer experience** (billing & payment methods, user-friendliness of HRS, etc.)
- **Demonstration of smart trading strategies for green electrical power.**

The H2ME initiative is designed to demonstrate the technical early phase of roll-out for Europe and address the remaining commercial barriers – significant improvements have already been made through H2ME in several of these areas: in more mature HRS designs, with improved components, materials & software, in preventative maintenance, in training to deal with failure events, and in remote monitoring & sharing of operator experiences.

Sources: CH2 JU Review Days 2017 | CH2 JU, A portfolio of power-trains for Europe: a fact-based analysis. https://www.fch.europa.eu/sites/default/files/Power_trains_for_Europe_0.pdf

Technical advancements (vehicles)
… and remaining barriers to be overcome

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Hydrogen Mobility Europe

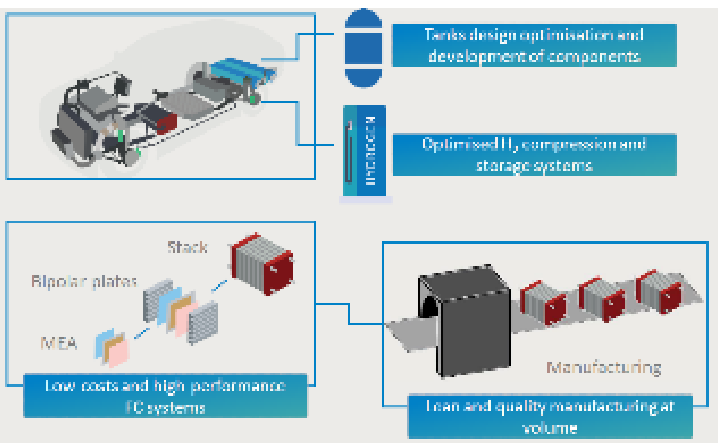
Improvements achieved to date

- Increase of H_2 storage capacity (700 bar) as vehicles have matured – resulting in **increased driving range**.
- **Safety** concerns have been addressed, with no significant H_2-related accidents for thousands of FCEVs.
- **Cold start** down to -25°C as the **heat management strategy** of the fuel cell engines has been optimised.
- **Durability** improvements in fuel cell stacks and systems.

Though FCEVs are capable of serving the needs of customers today, further development is needed:

Further technical advancements required

- **Improvements in design** (e.g., component count, reduced stack size).
- **Reduction in raw material** usage in vehicle production (e.g., platinum).



Commercial advancements required

- **Economies of scale.**
- Improvement in **production technology.**
- Increase in number of **FCEV models** offered by OEMs.
- **All of the above leading to reduction in vehicle costs.**

Sources: CH2 JU Review Days 2017 | CH2 JU, A portfolio of power-trains for Europe: a fact-based analysis.
https://www.fch.europa.eu/sites/default/files/Power_trains_for_Europe_0.pdf

Clean Hydrogen Partnership

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- Technological development and demonstration

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- Deployment timeline
- Vehicles deployment
- HRS deployment
- Cross cutting activities and objectives

H2ME brings together high level partners in these initiatives in a European approach

This project has received funding from the **Fuel Cells and Hydrogen 2 Joint Undertaking** (now the Clean Hydrogen Partnership) under grant agreement No 671438 and No 700350. This Joint Undertaking receives support from the EU's Horizon 2020 research and innovation programme, **Hydrogen Europe Research** and **Hydrogen Europe**.

H2ME is a major pan-European effort to support the commercialisation of hydrogen mobility

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Hydrogen Mobility Europe

HYPE fleet in Paris with 100 FCEVs reached in 2018 (video embedded)

H2ME vehicles travelled 6,000km to celebrate the expanding network of refuelling stations (video embedded)

www.h2me.eu

Clean Hydrogen Partnership

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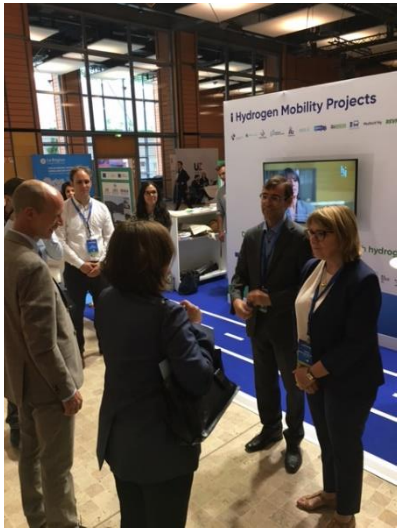
Hydrogen Mobility Europe

H2ME has been represented at key European transport events

100 vehicles funded by H2ME2 delivered to taxi firm DRIVR, in Copenhagen November 2021

H2ME Project representation and vehicle display at the Connecting Europe Days, June 2022

Project representatives were visited by the European Commissioner for Transport and the French Minister for Transport



Activities under H2ME and H2ME2 are part of a much larger vehicle and HRS rollout in Europe

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Hydrogen Mobility Europe

H2ME (1) targets

29 stations
>300 cars and vans
€60m total cost
€32m funding
Started June 2015

Hydrogen Mobility Europe

- **>45 refuelling stations**
- **>1,400 cars, and vans**
- **€160m total cost**
- **€67m funding from EU**
- **~50 organisations**

A major European activity!

Clean Hydrogen Partnership

Co-funded by the European Union

H2ME-2 targets

20 stations
>1,100 cars, vans and trucks
€100m total cost
€35m funding
Started May 2016

Clean Hydrogen Partnership

H2ME initiative (2015 – 2023)
Project overview

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Hydrogen Mobility Europe

HRS under commissioning

HRS commissioned

New hydrogen refuelling stations (HRS) to be fielded:

- **20** - 700bar HRS in Germany
- **9** - 700bar HRS in Scandinavia
- **13** - 350bar and 700bar HRS in France
- **6** – 350bar and 700bar HRS in the UK
- **1** - 700bar HRS in NL

Fuel cell vehicles to be fielded over project duration:

- **900+** OEM fuel cell electric vehicles (FCEVs)
- **500+** fuel cell range-extended (RE-EV) vans

Hydrogen HRS and vehicles rollout areas:

- Scandinavia, Germany, France, UK, The Netherlands

Observer coalitions and further vehicles rollout areas:

- Belgium, Luxembourg, Italy

Industry observer partners:

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

Follow-up work facilitated:

- ZEFER, aiming to reduce the 40% TCO gap of light duty FCEVs to parity with petrol hybrids by 2025; fielding a further 300 FCEVs across London, Paris & Copenhagen.

Clean Hydrogen Partnership

Achievements to date
A flagship project for Hydrogen Mobility **1/2**

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Hydrogen Mobility Europe

Industry, SMEs and University collaboration
49 organisations

Advancements in commercialization strategies

Gather evidences for new deployment and business cases
-> Focus on co-location of demand and HRS usage for different vehicles type .
-> For vehicles, small and large fleet (>100)

Testing in real work conditions
Product ready for commercialisation
-> Up to 594 km of driving range – availability close to 100% – reached 100km/1kg H_2
-> max HRS load reaching 45% - Availability >95% - back to back refuelling for 6 vehicles

Building a rich dataset valuable for Europe
Achieved since 2016 (as of Q1 2022)
- > 23.1 million km driven
- > 326t of H_2 distributed (134 900 refuelling events)

Technical advancements

Deployment of new fuel cell electric vehicles models and hydrogen refueling stations technologies
Mercedes-Benz GLC, Hyundai Nexo new model of Renault Kangoo Z.E. Hydrogen (by Symbio) and Toyota Mirai

Development of new technologies and services
-> Maintenance strategies for HRS
-> payment by card and app increasingly common
-> Fleet uses validated for taxi and carsharing

Clean Hydrogen Partnership

Achievements to date
A flagship project for Hydrogen Mobility **2/2**

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Hydrogen Mobility Europe

Largest European deployment to date for hydrogen mobility

39 HRS and 905 vehicles have been deployed in 9 countries incl. 20% of German national network

Largest fuel cell electric vehicles fleet in the world

100 Fuel Cell taxis in Paris, 114 Fuel Cell Range Extender vans

High visibility first of a kind initiative

First deployment with European vehicles OEMs

First deployment for Daimler and Symbio

Fostering additional activities in existing regions and for partners

Most advanced coalitions in Germany, Scandinavia, France and the UK collaborating with observer coalitions becoming increasingly active (Benelux, Austria and Italy)

Dissemination of results to all relevant stakeholders

To date: > 90 articles and 7 newsletters published, social media presence, 3 conferences and 4 roundtables held in addition to 17 vehicles hand-over and 19 HRS openings and "ride and drives" events, 37 national events and presentations at conferences

Cross countries events

H2ME vehicles took a 6,000km road trip through Europe showing the advantages of the technology

Knowledge development

Analysis and summary of key trends and best practices for the sector

To date: 94 reports produced

Clean Hydrogen Partnership

Deployment projects timeline in Europe

These activities have been supported by CH2 JU

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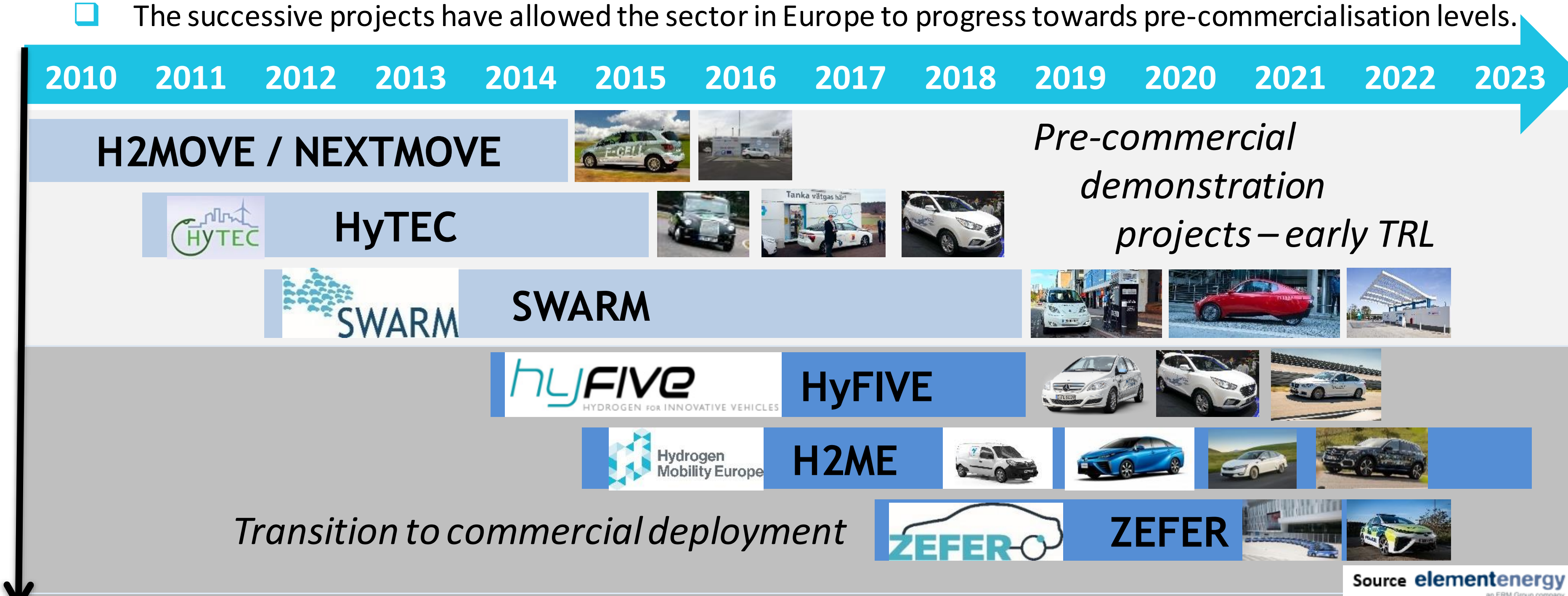
Hydrogen Mobility Europe

- The Fuel Cells and Hydrogen Joint Undertaking (FCH JU), now Clean Hydrogen Partnership (CH2 JU), has funded the majority of the R&D and demonstration projects supporting the deployment of light duty fuel cell electric vehicles and the associated infrastructure.
- The successive projects have allowed the sector in Europe to progress towards pre-commercialisation levels.



Source elementenergy

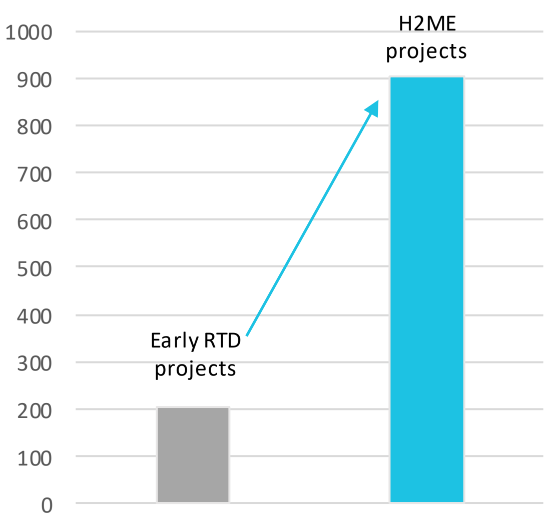
- The Clean Hydrogen Partnership aims to scale up the development and deployment of the European value chain for safe and sustainable clean H_2 technologies, strengthening its competitiveness to support business. The forerunner FCH JU supported research, technological development and demonstration (RTD) activities in fuel cell & hydrogen energy technologies in Europe, aiming to the market introduction of these technologies.

Clean Hydrogen Partnership

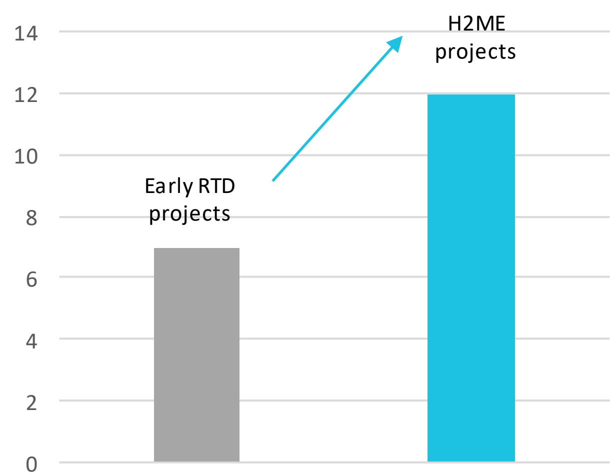
Technological development and demonstration
KPIs and other indicators for vehicles

- The H2ME initiative has gathered significantly more information about the technology and its performance compared to earlier projects while raising visibility on its potential.
- To date the project has deployed another 5 models/generations of FCEVs, nearly quadrupled the number of vehicles on the road and multiplied by almost 8 times the number of km driven by the vehicles while collecting data.

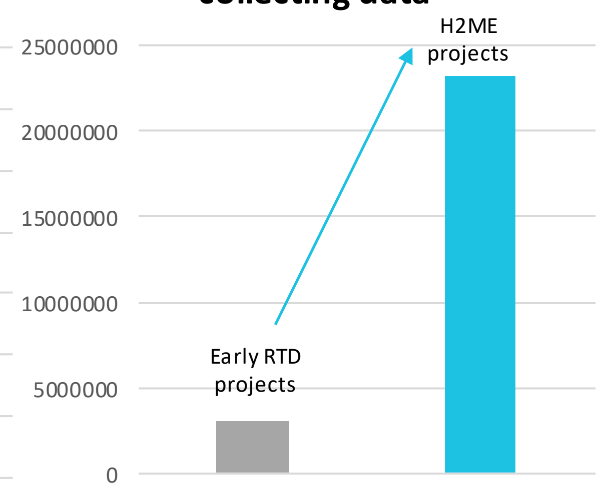
Total vehicles deployed



Models and generation of vehicles deployed



km driven by fleet while collecting data



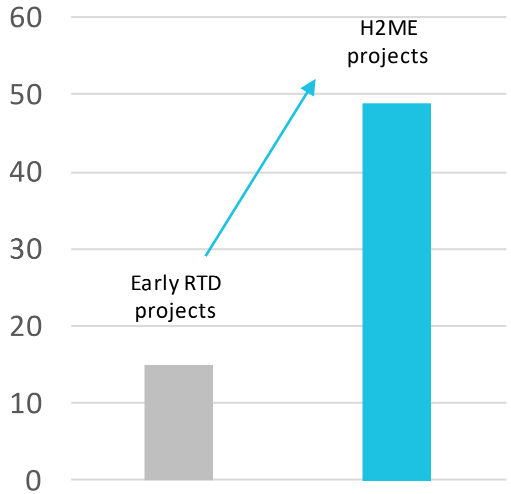
- Other Key Performance Indicators are being analysed for vehicles such as availability and time in operation. The vehicles have performed very well with availability of 99% estimated while they have been in extended operation since 2015/2016. Further analysis on KPIs related to the performances of the vehicles is included in Section 4 of this report: “Evidence from utilisation”.

Source: CH2 JU, TRUST database. The grey (left hand) bars represent all vehicles fielded in projects prior to H2ME.

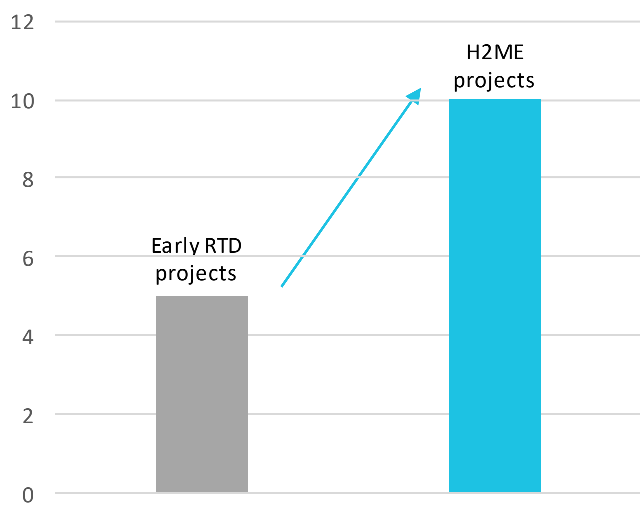
Technological development and demonstration
KPIs and other indicators for HRS

- To date the project has deployed 47 stations in 7 countries, adding key nodes on the European refuelling infrastructure and contributing to enable a pan-European network.
- This has increased both the number of pure equipment provider partners as well as, significantly, operators of stations.

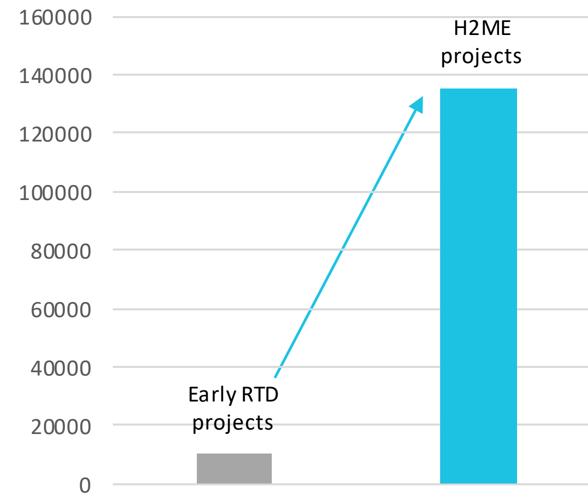
# of stations



# of suppliers



Number of refuelling events



- Other Key Performance Indicators are being analysed for HRS such as availability, utilisation and time in operation. The HRS have achieved availability of ≥ 95% on average and have been in extended operation since 2015/2016. Further analysis on KPIs related to the performances of the HRS is included in Section 4 of this report: “Evidence from utilization”.

Source: CH2 JU, TRUST database.

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Hydrogen Mobility Europe

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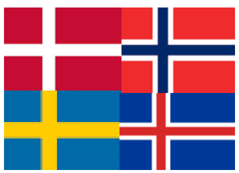
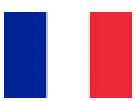
Deployment & National refuelling infrastructure introduction strategies – H2ME & broader context

	National Strategy[2]	HRS in H2ME[1]	Vehicles in H2ME[1]
	❑ ***Risk sharing JV*** - Widespread deployment of 100 HRS by 2020/2021 and further expansion in line with development of vehicle numbers to provide a national network and allow OEM vehicle introduction	❑ 20 x 700 bar HRS in Germany	❑ >900 FCEVs across Scandinavia, Germany, France, the UK and the Netherlands
	❑ Deployment based on ***expected sales of OEM vehicles (facilitated by tax regime)***. Aiming at a network of stations across the Nordic region to allow transnational driving within the region	❑ 8 x 700 bar HRS in Scandinavia	
	❑ Aim to establish **viable local networks** in 2015-2020, followed by accelerated ramp-up (2020-2025) and market establishment	❑ 6 x 350/700 bar HRS in the UK	❑ >500 RE-EV vans and trucks initially in France and Germany then across Europe
	❑ ***Initial strategy based on 350bar RE-EVs in captive fleets*** linking H_2 supply and vehicles, which de-risks early hydrogen infrastructure investments across the country before OEM vehicles arrive	❑ 13 x 350/700 bar HRS in France	
	❑ ***Deployment in 3 stages -*** market preparation (2015-2020), early market introduction (2020-2025) and full market introduction (2025-2030) with a progressive introduction	❑ 1 x 700 bar HRS in the Netherlands	

[1] Planned deployments throughout lifetime of the H2ME project

[2] National Strategies have evolved over time, refer to section 3 for detailed National Strategies

Hydrogen Mobility Europe deployment timeline

Deployment phase

Vehicles planned to be in operation

	2015	2016	2017	2018	2019	2020	2021	2022	2023

Mercedes-Benz FCEVs

B-Class F-Cell from 2015Q2

40 in operation

GLC F-Cell from 2018Q3

157 in operation

Honda FCEVs

Honda Clarity from 2017Q1

10 in operation

Toyota FCEVs

Toyota Mirai from 2017Q3

262 planned

Procurement of other FCEVs

other vehicle types procured and deployed from 2017Q2

436 planned

FC range-extended electric vans

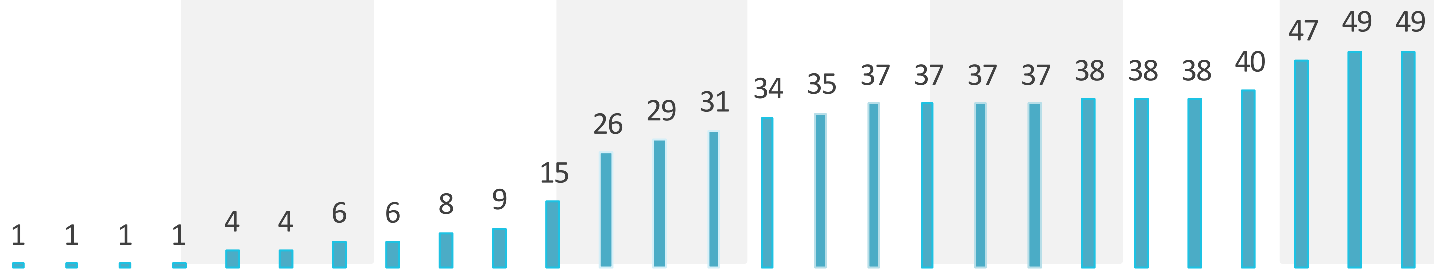
Renault Kangoo ZE RE H2 from 2015Q3

HKO Stellantis & Symbio from 2021Q4

230+ in operation

270+ planned

HRS



Significant HRS & vehicle deployments are now taking place outside the H2ME projects

Vehicles deployed under H2ME initiative

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Hydrogen Mobility Europe

Deployment of partner models

Mercedes-Benz B-Class F-CELL

- 700 bar H_2 tank
- 40 deployed

Mercedes-Benz GLC F-CELL

- 700 bar plug-in H_2 tank and 13.5 kWh battery
- 157 deployed

Toyota Mirai

- 700 bar H_2 tank
- > 140 being deployed

Honda Clarity Fuel Cell

- 700 bar H_2 tank
- 10 deployed

Renault Kangoo Z.E Hydrogen (by Symbio)

- 5 kW fuel cell module with 350-bar or 700-bar
- >120 being deployed

HKO (by Stellantis with Symbio)

- 700 bar H_2 tank
- >270 being deployed

Other vehicles procured

Toyota Mirai

- 700 bar H_2 tank
- >260 being deployed

Hyundai ix35

- 700 bar H_2 tank
- 60 being deployed

Hyundai Nexo

- 700 bar H_2 tank
- 34 deployed

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HRS deployed under H2ME initiative (1/6)
Germany

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Hydrogen Mobility Europe

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
Germany (operated by H2Mobility Deutschland)					
Air Liquide	Laatzen, Leverkusen, Magdeburg, Erfurt, Dortmund, Bayreuth, Mönchengladbach, Furth, Passau, Schnelldorf	**10 HRS ≥** 200kg/day @700 bar All HRS are integrated into petrol refuelling station operated by Shell, Total or OMV Authorization/payment via fuel card	Supplied with trucked in H_2	H2ME-1	
Linde	Leipzig, Potsdam, Berlin, Berg bei hof, Frankfurt, Aachen, Essen, Meerane, Halle, Herten	**10 HRS** ≥ 150kg/day @700 bar 8 HRS are integrated into petrol refuelling station operated by Shell and Total Authorization/payment via fuel card	Supplied with trucked in H_2	H2ME-1	

Clean Hydrogen Partnership

Air Liquide creative oxygen

THE LINDE GROUP

H2MOBILITY The infrastructure company

HRS deployed under H2ME initiative (2/6)
The UK

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Hydrogen Mobility Europe

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
United Kingdom					
BOC (Linde)	Aberdeen	**1 HRS** ≥ 320kg/day @dual pressure	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-1	
Motive Fuels	Beaconsfield, Gatwick	**2 HRS** ≥ 100kg/day, @dual pressure HRS are integrated into petrol refuelling station operated by Shell Payment by Fuel card/Credit Card	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-1	
Motive Fuels	Swindon, Birmingham, London	**3 HRS** ≥ 200kg/day @dual pressure 1 HRS integrated into petrol refuelling station operated by Shell Payment by Fuel card/Credit Card	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-2	

Clean Hydrogen Partnership

BOC A Linde company

MOTIVE

HRS deployed under H2ME initiative (3/6)

France (1/2)

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
France					
Air Liquide	Paris Sud (Orly), Paris North, Paris West, Versailles, Creteil	**1 HRS** ≥ 200kg/day @ dual pressure **4 HRS** ≥ 200kg/day @ dual pressure Payment by fuel card or mobile application	Supplied with trucked in low carbon H2	H2ME-1 & H2ME-2	
ArevaH2Gen/ EIFER	Rodez	**1 HRS** ≥ 160kg/day @350bar	On-site water electrolysis fed by 100% renewable electricity tariff	H2ME-1	
ArevaH2Gen/ SEMITAN	Nantes	**1 HRS** ≥ 80kg/day @350bar	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-2	
McPhy	Sarreguemines	**1 HRS** ≥ 40kg/day @350 bar Free dispensing	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-1	

HRS deployed under H2ME initiative (4/6)

France (2/2)

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
France					
McPhy/ CNR/ GNVERT	Lyon	1 HRS ≥ 100kg/day @350 bar Payment by Mobile App	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-2	
GNVERT /ITM	Vannes	**1 HRS** ≥ 200kg/day @dual pressure	On- site water electrolyser	H2ME-2	
HysetCo	Porte de St Cloud & Le Bourget	**2 HRS** ≥ 9000kg/day @ dual pressure Payment by Payment by Mobile App	On- site water electrolyser fed by 100% renewable electricity tariff	H2ME-2	
R-GDS / R-HYNOCA	Strasbourg	**1 HRS** [1] ≥ 750kg/day @ dual pressure Payment by Fuel card/Credit Card	Supplied with on site production of green hydrogen produced by thermolysis of biomass	H2ME-2	

[1] Sketch of the future station not definitive

HRS deployed under H2ME initiative (5/6)
Scandinavia

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Hydrogen Mobility Europe

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
Scandinavia					
AGA (Linde)	Sandviken, SW	**1 HRS** ≥ 800kg/day @700bar	Off-site water electrolysis delivered via district pipelines	H2ME-1 & H2ME-2	
Nel	Mariestad, SW	**1 HRS** ≥ 200kg/day @700 bar Payment by Credit Card	Supplied with trucked in H_2 from centralised electrolysers fed by 100% renewable electricity tariff	H2ME-2	
HYOP	Hovik, NO	**1 HRS** ≥ 200kg/day @700bar	On-site water electrolysers and trucked in H_2	H2ME-1	
Nel H2	Kolding, DK Copenhagen Herning, DK	**1 HRS** ≥ 200kg/day @700bar HRS are integrated into petrol refuelling station operated by OK a.m.b.a. **1 HRS** ≥ 200kg/day @700bar **1 HRS** ≥ 1500kg/day @700bar	Supplied with trucked in H_2 from centralised electrolysers fed by 100% renewable electricity tariff	H2ME-1 & H2ME-2	
Nel H2	Reykjavik, Keflavik, Aarhus DK	**3 HRS** ≥ 200kg/day @dual pressure Integrated into petrol refuelling station operated by Orkan. Payment by Credit Card	Supplied with trucked in H_2 from centralised electrolysers fed by geothermal plant	H2ME-2	

Clean Hydrogen Partnership

AGA   Danish Hydrogen Fuel   nel   Íslenska Vetnisfélagið ehf.

HRS deployed under H2ME initiative (6/6)
The Netherlands

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Hydrogen Mobility Europe

OEM	Site(s)	Type of HRS	Source of H_2	Project	Image
Netherlands					
Kerkhof (Resato)	The Hague	**1 HRS** ≥ 480kg/day @dual pressure HRS are integrated into petrol refuelling station operated by BP	Supplied with trucked in H_2 from centralised electrolysers	H2ME-2	

Clean Hydrogen Partnership

Rijkswaterstaat
Ministry of Infrastructure and the Environment

Resato

In addition to deployment, the H2ME initiative is conducting valuable cross-cutting activities

The H2ME initiative aims to:

- **Share best practices and lessons learnt between industry partners** to ensure processes such as HRS installation, metering and billing etc. are streamlined and improved across Europe.

- Use data collected as part of the project to **better understand the status of vehicle and HRS technology.**

- Conduct analysis to **better understand customers' needs and experience of the technology.**

- Conduct economic and strategic analysis to provide **recommendations for the rollout of hydrogen mobility**, with a particular focus on national rollout strategies and business cases for early adopters.

- Analyse the **impact of hydrogen generation by electrolysis on the efficiency of the energy system and demonstrate the ability to monetise the provision of grid balancing services** using water electrolysers via real world tests of HRS-electrolysers.

The results generated by the project are shared with industry, politicians, and the wider public to support the commercialisation of hydrogen mobility.

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- Ownership models and characteristics for refuelling stations
- Vehicle deployment in each region

National, regional and local case studies

- Details of national strategies
- Case studies for regional strategies
- Emerging trends

Clean Hydrogen Partnership

The hydrogen refuelling network in Europe is growing steadily, with over 200 stations installed

- Hydrogen Europe's Technology Roadmap sets a target of **1,000 public hydrogen refuelling stations (HRS) across Europe by 2025**.
- Significant acceleration in the deployment of new HRS over the next 5 years will be required to achieve this: as of September 2022, there were 180 public operational HRS in Europe, most of which are installed in Germany, the Netherlands, and Switzerland. A further 45 stations are currently planned or under construction.
- While this represents the start of a pan-European refuelling network, **many of the existing stations currently only have the capacity to refuel relatively small numbers of light duty vehicles** (i.e. cars and vans), with only a few stations having the capacity to serve fleets of taxis, buses or other high-demand vehicles.
- **Significant further investment is required** to provide a sufficient network of refuelling stations to meet the potential needs of the hydrogen mobility market, especially when considering the adoption of heavy duty hydrogen vehicles such as trucks, which will also require national networks of high capacity refuelling stations.

Operational public HRS in Europe (September 2022)

Map of operational 700-bar hydrogen refuelling stations as of September 2022. Source: H2Live [1]

Source: Hydrogen mobility strategies, 2020, H2ME (1) Deliverable 5.13. Element Energy

[1]French number has been edited to reflect the additional 350 bar refuelling stations. Note that there are many additional private HRS in France (29 HRS in total)

A number of strategies for infrastructure network development have been tested in different regions

HRS network development strategies tested in different regions (with strategies still in development)

- **Germany: Extensive national coverage** & major cities – strong focus on achieving national network to maximise appeal to mass market customers with ubiquitous fuelling opportunities
- **France: Local/regional clusters linked to H_2 demand (captive fleet approach)** – maximising driving within regions, lower need for motorway coverage
- **UK: Regional (initially south-east) focus to build 'H2 hubs'** – focus on ensuring viable local network for early customers rather than long distance focus
- **Nordic region: Creation of a network to allow long distance mobility across the region** – first plausible network coverage already achieved in Denmark, with the rest of Scandinavia & Iceland looking to follow
- **BeNeLux region:** strategies within this region are in development. The H2Benelux project aims to enable enable national travel across the Belgium, the Netherlands and Luxembourg. Further plans are likely to involve expansion based on a "cluster" approach.

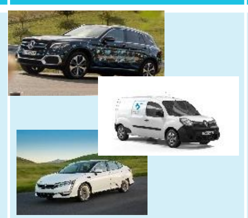
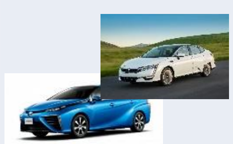
Source: Hydrogen mobility strategies, 2020, H2ME (1) Deliverable 5.13. Element Energy

The different strategies result in many ownership models and characteristics for refuelling stations

Region	Initial strategy for HRS network development	Level of risk: low utilisation	Ownership models	Number of HRS in July 2022	HRS pressures for light vehicles
Germany	Extensive national coverage + major cities	**High:** first 100 HRS will have been installed regardless of demand. However, letters of intent to deploy vehicles increasingly sought to minimise risk of low utilisation.	H2MOBILITY is a joint venture between industry partners from hydrogen production and retail, as well as some automotive involvement: demonstrates commitment and shares the risk. Funding is received from National and European programs.	101 (20*)	Mainly 700 bar
France	Local/regional clusters linked to demand (captive fleet approach)	**Low:** demand is secured in advance of investment decision	Individual investments, with coordination by Mobilité Hydrogène France; joint venture in Paris (HysetCo)	41 (13)	700 bar, 350 bar and dual pressure (350 bar + 700 bar)
UK	Mainly regional (south-east) focus to build 'H2 hubs'	**Moderate:** stations built with a mix of public and private investment in projects which group vehicles and stations	Individual investments with government support	11 (6)	Mainly dual pressure (350 bar + 700 bar)
Nordic region	Develop network to allow long distance mobility across the region	**High:** network coverage achieved in advance of significant vehicle deployment	Predominantly individual investments, with a joint venture structure in Denmark. Case is based on expected increases in vehicle deployment	18 (9)	Mainly 700 bar

Source: Hydrogen mobility strategies, 2020, H2ME (1) Deliverable 5.13. Element Energy
Figures updated to 2022. Numbers in brackets are units deployed under the H2ME project

The characteristics of regional vehicle deployments also reflect the different strategies

Region	Initial light vehicle types	FCEVs on the road in summer 2022 (with H2ME units in brackets	Diversity of vehicles deployed	Light duty vehicle applications	Implications for overall hydrogen demand and HRS utilization
Germany		1,368 (264)	Mainly cars to date; growing numbers of trucks & buses	Car clubs; B2B leasing; Ride Pooling; local authorities	Demand is **distributed across several cities**; very few HRS are seeing high levels of utilisation
France		698 (364, including RE-FCEVs)	Range-extended vans; cars as taxis; buses	Utility fleets; delivery vans; local & national agencies; taxis	Recent adoption of taxis in **Paris** has led to significant increases to the hydrogen demand on the local network
UK		353 (34)	Passenger cars, vans and buses	Taxis; police vehicles; local authorities	Recent adoption of taxis in **London** has led to significant increases to the hydrogen demand on the local network, but HRS utilisation remains low currently
Nordic region		348 (222)	Passenger cars; some buses and trucks	Local & national government agency fleets; taxis; private customers	Demand is **distributed across several cities**; few HRS are seeing high levels of utilization. Programs now being established to promote taxi use.

Source: Hydrogen mobility strategies, 2020, H2ME (1) Deliverable 5.13. Element Energy
Figures updated to 2022. Numbers in brackets are units deployed under the H2ME project

3. Hydrogen mobility strategies
Section overview

Overview of strategies

- Overview H2 Mobility Strategies
- Ownership models and characteristics for refuelling stations
- Vehicle deployment in each region

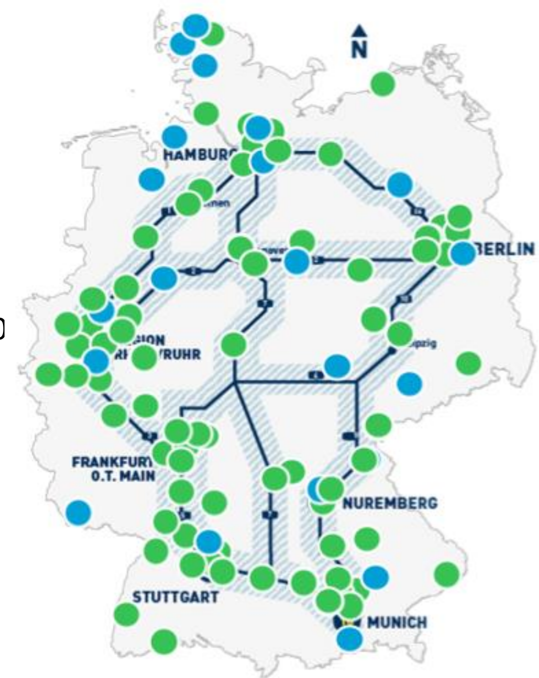
National, regional and local case studies

- Details of national strategies
- Case studies for regional strategies
- Emerging trends

Germany: The initial strategy was focused on achieving a national network by connecting six conurbations

Key aspects of the German Hydrogen Mobility strategy

- 10 stations in each of six urban conurbations (Hamburg, Berlin, Rhine-Ruhr, Frankfurt, Stuttgart, Munich), plus H_2 corridors along motorways: **100 HRS were set to be in place by the end of 2021.** These **first 100 stations are being built unconditionally**, irrespective of the number of FCEVs sold. As of August 2022, Germany had 96 active HRS, with some HRS lost as older stations were retired. All German stations are now 700 bar and SAE J2600 protocol compliant. Most are located at petrol forecourts.
- The **second phase** of the strategy will focus on vehicle deployment. HRS will be linked to the number of FCEVs on the road, with demand of 6 tonnes H_2/year for the next 20 HRS, and 12 tonnes/year for the following 20. Demand is presently averaging around 7 tonnes H_2/year across the HRS.
- **By 2027, up to 400 HRS will be operational in Germany**, depending on demand. These stations will use the highest possible amount of renewable hydrogen.
- According to H2MOBILITY, in February 2021, there were 630 active HRS customers in Germany. By May 2022, IPHE reported 1,528 fuel cell cars in Germany (less retirements).
- The German government provides **grants for station installation** and incentives covering up to 40% of the cost premium, and **tax exemptions for FCEVs.**
- In 2018 the Federal Ministry of Transport, Building and Digital Infrastructure (BMVI) released a call for bids with a total of up to **15 million euros of funding available for FCEVs and HRS.** The call has been repeated in the years following, between €5-15M.



Sources: H2Live, July 2020

Current status

- **84** In operation
- **22** In progress

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, CONFIDENTIAL, Element Energy

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Hydrogen Mobility Europe

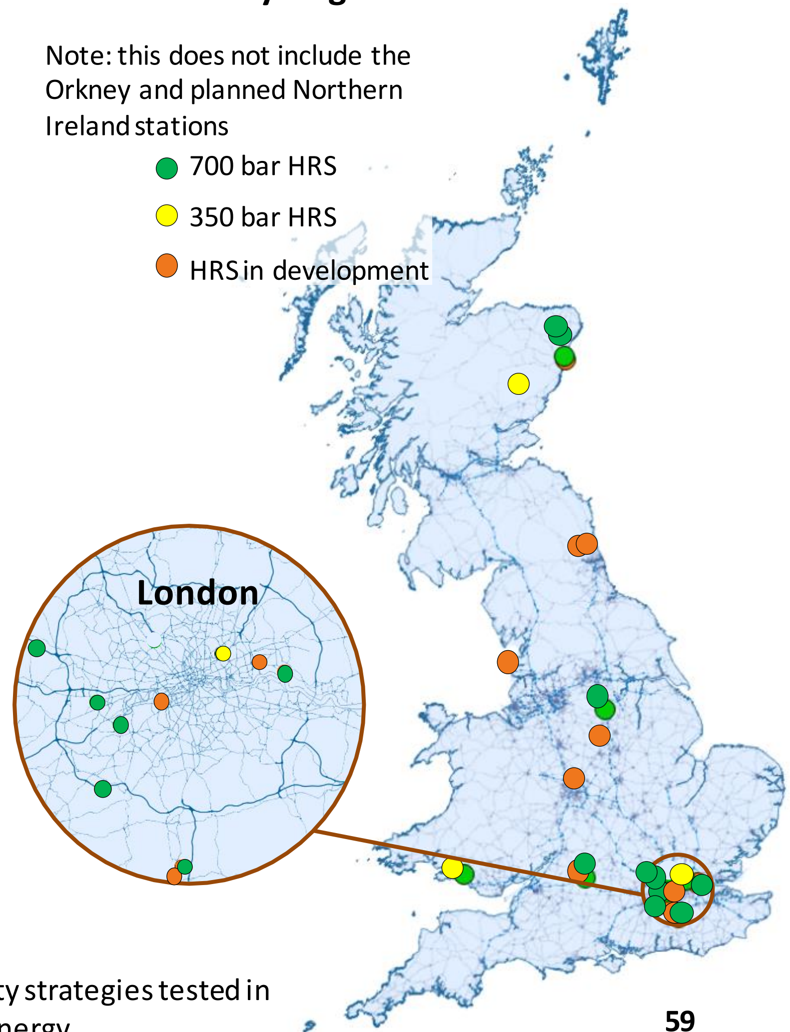
UK: strategy for hydrogen mobility development has evolved to focus on the development of HRS clusters

Deployment strategy & status

- In early 2017, the UKH2Mobility consortium published an update on their **proposed three-stage strategy** for the rollout of the initial network of HRS. The first phase was to deploy twenty 700 bar HRS in the South-East by 2020, to provide "drivability" for initial customers.
- Following lower than expected FCEV deployment in the initial cluster (largely due to vehicle supply to European markets being lower than expected), the strategy shifted in 2018 to focus on **clustering HRS around demand hotspots** which had begun to emerge (particularly as a result of increased demand from fleet applications). The clustered approach minimises dealer training costs for OEMs, and makes it more efficient for HRS operators to provide local maintenance for the stations, providing an improved customer experience, and provides a platform for HDV application.
- As of May 2022, **353 registered FCEVs** are on the road as well as **11 publicly-accessible 700 bar HRS**. (There are more HRS in the UK, but some early stations are now retired).
- The UK government provides **grants for both HRS installation and purchase/lease of FCEVs for fleets.** The Office for Low Emission Vehicles (OLEV) created a **£23 million fund** to accelerate the uptake of FCEVs and HRS (2018). Most funding since is focused on buses.

Planned UK hydrogen infrastructure in 2020

Note: this does not include the Orkney and planned Northern Ireland stations



Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, Element Energy

Clean Hydrogen Partnership

France: outside of Paris, H_2 demand for the initial HRS has been relatively low, due to the types of vehicle deployed

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Hydrogen Mobility Europe

Strategy for HRS deployment

- Strategy based on **captive fleet applications** with HRS deployed at the same time as a vehicle fleet, thereby securing demand and de-risking early HRS investments. Letters of intent are obtained prior to HRS investment decisions, thereby **confirming demand and HRS utilisation**.

Current deployment outlook

- As of June 2022, there were 382 fuel cell cars and vans in France, with 243 units (79 Renault Kangoo ZE range extended vans and 164 OEM taxis) fielded through H2ME. There were 55 HRS (41 active), with 12 of the HRS fielded through H2ME.
- The 164 STEP taxis in Paris (deployed through the HysetCo initiative) means the HRS network in the city sees relatively high utilisation.
- Outside Paris, **HRS utilisation has been lower than anticipated** due to relatively low H2 demand from the range extended vehicles deployed to date. This is expected to increase with the increased deployment of passenger cars and/or a changes in user driving patterns.
- The national network started using lower-cost 350 bar HRS to support local captive fleets with limited dual-pressure (700 & 350 bar) HRS deployed. There is now an **increasing focus on dual-pressure stations** to ensure future-proofing for passenger cars.

HRS in France – open and under construction

X Number of HRS in town / city

Open

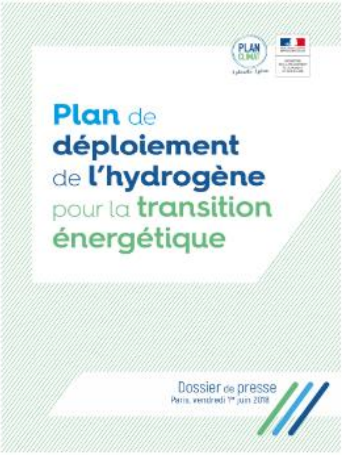
Under construction

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, Element Energy

Clean Hydrogen Partnership

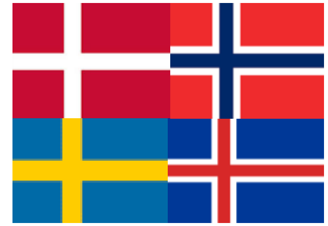
France: policy statements including a National Hydrogen Plan have led to the development of numerous regional H_2 mobility plans

- Policy and funding have been major drivers to increased support and demand for H_2 mobility:
- The **Loi de Transition Energétique (2015)** set out aims to renew >50% of public transport fleets with low emission vehicles by 2020 and 100% by January 2025.
- The **Plan National Hydrogène (2018)** set targets to transition French transport to hydrogen, with supporting funding of ~€100 million through public tenders. Specific targets include:
  - 5,000 light commercial vehicles and 200 heavy vehicles in operation by 2023
  - 100 new HRS using H_2 produced locally by 2023, increasing to 400-1,000 HRS by 2028
  - 20,000-50,000 light commercial vehicles and 800-2,000 heavy vehicles by 2028
- Following the Plan National Hydrogène, ADEME published calls for hydrogen mobility projects, aiming to support projects with a total budget of over 1 billion euros. **The COVID recovery plan of September 2020 allocated a total of 7.2 billion euros to deliver on the Plan**.
- In November 2021, President Macron confirmed **€1.9 billion will be dedicated to the objective of "making France the leader in green hydrogen"** as part of the France 2030 investment plan, in addition to the €7.2 billion of the National Hydrogen Strategy.
- Largely as a result of this clear ambition from the National government, **numerous regions of France have now developed (and allocated funding for) their own H_2 mobility deployment plans.** Many of the plans include heavy duty transport applications alongside the deployment of cars and vans, with strategies following **an integrated approach to activation of regional demand,** pioneered by the Zero Emission Valley initiative.
- Alongside the development of regional government plans, the high level of national ambition and support has stimulated the development of **numerous hydrogen transport initiatives being led by the private sector**. Some key examples are set out on the following pages.



Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, Element Energy

Nordic region: the strategy aimed to introduce a basic network across Scandinavia to enable FCEV uptake

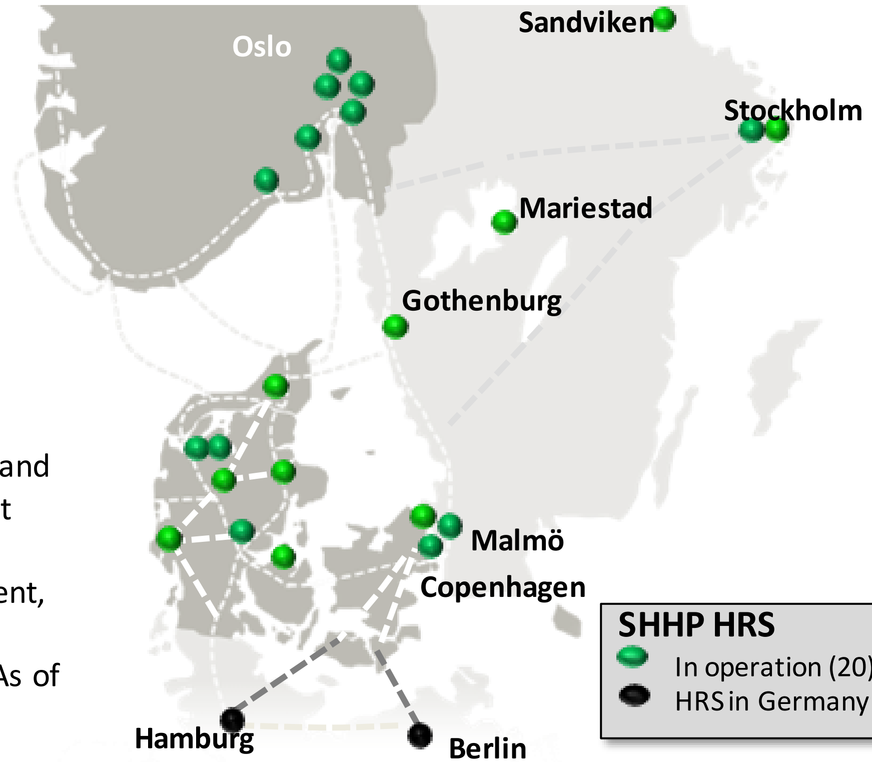


Strategy for HRS deployment

- The Nordic strategy for hydrogen mobility was based on the introduction of 700bar OEM FCEVs to create a first network across Scandinavia. Vehicle deployment is **supported by generous national tax regimes** and other support mechanisms (free public parking, etc.)

Current deployment outlook

- HRS rollout across the region has been based on vehicle sales, and delivered predominantly via individual investments, with a joint venture structure in Denmark.
- Despite good network coverage and a favourable tax environment, **vehicle rollout has been slower than expected**, due mainly to constrained production/deliveries to Europe of OEM vehicles. As of November 2019, there over **300 FCEVs and 20 public HRS** (6 in Norway, 8 in Denmark, 3 in Sweden, and 3 in Iceland) deployed.
  - Norway: Trondheim, Alna (Oslo), Bergen, Høvik (Oslo), Hvam (Oslo)
  - Sweden: Umeå, Sandviken, Stockholm, Mariestad, Göthenburg
  - Denmark: Copenhagen Prag Boulevard, Korsør, Kolding, Herning, Aarhus, Esbjerg, Copenhagen H.C. Ørsted, Strandmøllen (private)
  - Iceland: Vesturlandsvegur, Keflavík
  - Finland: none

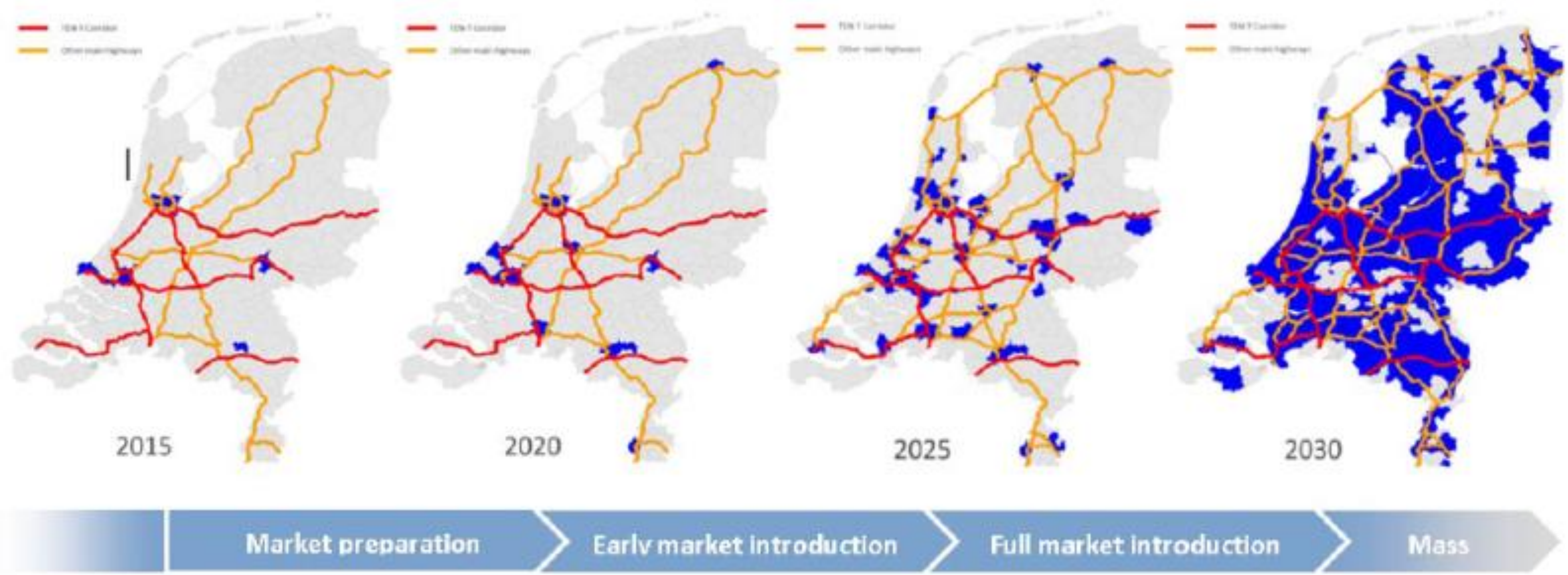


- **The Nordic Hydrogen Partnership (SHHP) aims to have >2,000 light FCEVs, ~800 heavy duty vehicles and >90 HRS by 2025.**
- Vehicle deployment is supported by **generous national tax regimes & other support mechanisms** (free public parking, etc.).

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, CONFIDENTIAL, Element Energy

Dutch strategy: Deployment of hydrogen mobility has significantly increased from 2019

HRS network rollout from 2015 to 2030



- Vehicle and infrastructure deployment is supported by **generous national tax regimes and other support mechanisms** (free public parking, access to bus lanes etc.).
- Ministry activities are currently focused on **demand aggregation for the 15 planned HRS**, targeting high demand groups such as taxis, corporate fleets, and local/regional public sector fleets (including heavy duty applications).
- In addition, the Netherlands Government is planning to **invest €30-40m annually to stimulate demonstration and pilot projects for hydrogen production, with targets to deploy 500 MW electrolysis capacity by 2025 and 3-4 GW by 2030.** There are also several regional initiatives, such as in the north of Netherlands, which presented plans in 2019 to invest €2.8 billion (public and private funding) in sustainably generated H_2 over the next 12 years (later raised to over €9 billion).

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, Element Energy

Regional strategy: Zero Emission Valley is an ambitious initiative for hydrogen mobility in the Auvergne Rhône Alpes region (France)

Zero Emission Valley case study

- Auvergne-Rhône-Alpes region became the first hydrogen territory in Europe, with a commitment to 1,000 FCEVs and 20 HRS (3 of these being renewable) in the valley.
- A public-private partnership with stakeholders spanning the entire H_2 value chain will fund the project, with an expected budget of €70M to be spent over 10 years.

Source: fuelcellworks.com

Challenges of deployment at scale

- The need for multiple HRS in one location and high cost of FCEVs results in prohibitively high capital investment to kick-start large projects.

Policy context

- Regional support for the project in the form of €15M in grants or direct investment.

Collaboration between local governments and private investors brings the following benefits:

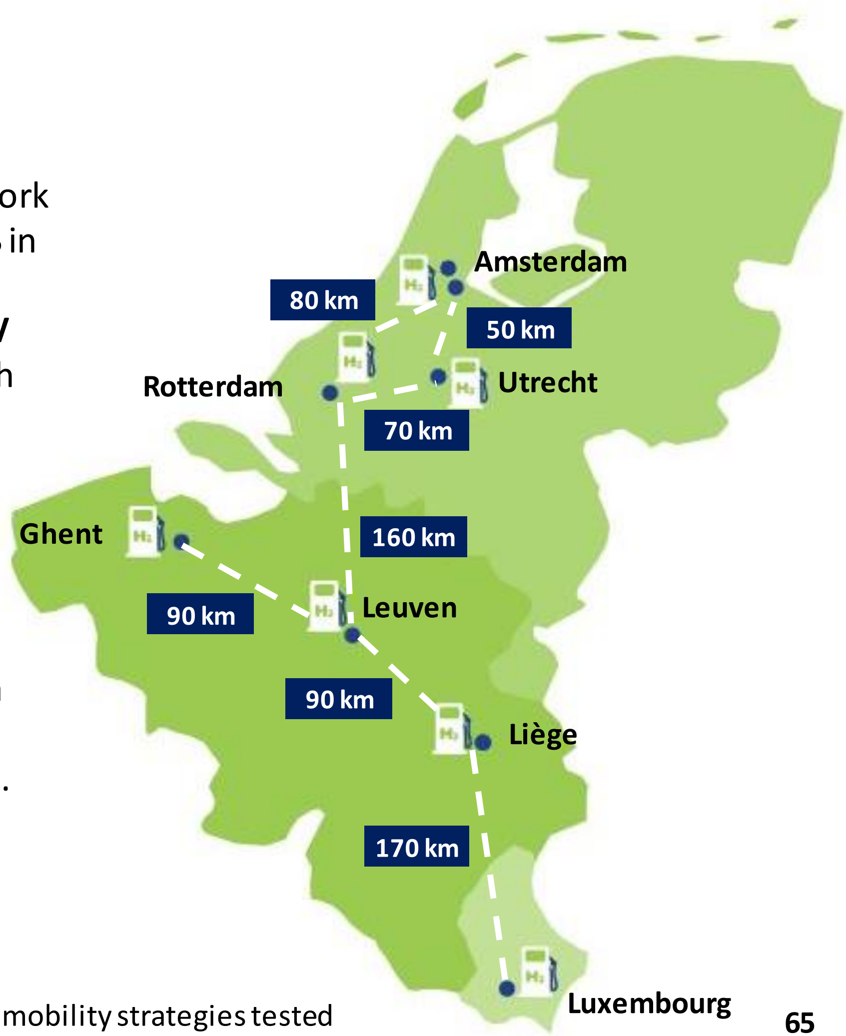
- The engagement of a variety of stakeholders enables commitment to a hydrogen project across the entire value chain in a region.
- Stakeholders have greater economic security, leading to higher levels of investment and larger scale infrastructure and vehicle deployment.
- The increased scale of infrastructure deployment benefits FCEV end users by offering more convenient and further ranging refuelling.
- The demonstration of hydrogen projects of scale will draw further investment to a region.

- The company HYmpulsion SAS was created to facilitate delivery, with Michelin and ENGIE as industrials alongside Crédit Agricole and Banque des Territoires. 33% of the HYmpulsion share capital is owned by the Auvergne-Rhône-Alpes region.
- After a first station in the Chambéry agglomeration in February 2020, HYmpulsion will expand its network with 5 further stations in 2022 located in Clermont-Ferrand, Saint-Priest, Vénissieux, Grenoble and Moûtiers (now supplied by Atawey).

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Regional strategy: H2Benelux sets out a strategy to enable connected hydrogen mobility across the region

- The **H2Benelux project** is coordinated by non-profit organisation WaterstofNet and is partnered with the Netherlands Ministry of Infrastructure and Water Management, as well as three industrial partners.
- The project aims to roll out a sufficient refuelling network to enable travel across the three countries, with 4 HRS in the Netherlands, 3 in Belgium and 1 in Luxembourg.
- **HRS will be based around urban centres, with 10 FCEV cars set to be deployed around each station**, with each HRS location forming a pilot project.
- The **HRS deployed will be located on existing TEN-T corridors, enabling the HRS network to connect to networks in countries such as Germany and France.** This aims to contribute to the development of a continuous network of HRS across Europe.
- Data from the 8 pilot projects will be used to develop a future roadmap for the further development of HRS networks and FCEV deployment in the BeNeLux region. Further roll out of HRS in the region is expected to be demand-lead and financed by hydrogen sales.



Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, Element Energy

New national and regional level approaches, combined with private sector initiatives, are driving the development of hydrogen mobility

Emerging approaches to developing hydrogen mobility

- While FCEV and HRS deployment continues to expand, **roll-out of public infrastructure and vehicles has been slower than was planned in 2015**. The level of ambition of the initial strategies exceeded the sector's capacity to deliver on these aims, with strong competition for vehicle availability from global markets outside Europe, combined with various challenges in identifying and securing sites for refuelling stations in urban centres delaying the roll-out.
- In the absence of high volumes of FCEV passenger cars in Europe, hydrogen mobility initiatives (both nationally and at the European level) are increasingly converging on the following approaches:
  - Continued targeting of end users that require the specific operational advantages that hydrogen mobility can provide, where attractive business cases for hydrogen vehicles are now emerging (including **taxis and heavy vehicles, particularly in countries with high taxes for fossil fuel vehicles**).
  - Developing **viable clusters of stations in key locations** where the redundancy and convenience of multiple stations increases the attractiveness of fuel cell vehicles to fleet operators. Within these clusters, and to justify development of new clusters, **demand aggregation activities** (e.g. via letters of intent or fuel purchase agreements from customers near potential refuelling locations) are used to strengthen the business case for new stations and attract investment. Installing small, low-cost HRS in regions with larger existing stations, and/or on motorways between existing "clusters" could be a cost-effective way to improve network coverage for passenger cars.
  - **Deploying heavy vehicles (e.g. buses, refuse trucks) as well as high demand car applications (e.g. taxis)** to help scale up hydrogen demand and the development of infrastructure supply chains in advance of mass passenger car roll-out. **Achieving larger scale hydrogen ecosystems** (i.e. involving numerous vehicle types) is seen as key to reaching the scale of demand to make station operation economic. As such, some cities and HRS operators are considering the potential benefits and requirements of dual-purpose refuelling stations, i.e. allowing cars to make use of refuelling facilities for heavy vehicles such as buses and refuse trucks. This approach could offer business case advantages for HRS operators while demand increases.
  - Alongside the national and regional approaches, numerous **deployment initiatives led by the private sector** are emerging, at local and national scales (e.g., the taxi deployments in Paris and the Swiss trucks scheme). These initiatives show how with ambition it is possible to deploy H_2 economically, and to policy frameworks that support ambitious scale-up plans.

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Hydrogen strategies for energy system decarbonisation are now emerging across Europe, and mobility is seen as a key aspect

National and regional strategies

In the past four years, numerous national hydrogen strategies have been released which have emphasised the role of hydrogen in delivering the transition to net-zero energy economy, and the potential benefits of deploying hydrogen technologies at scale for applications such as industrial energy, transport applications (including marine and aviation as well as road transport) and heating.

The development of hydrogen for mobility is seen as playing a key early role in facilitating the ramp up of the supply chain and skills needed to deliver the wider hydrogen economy. To support this all of the national strategies set out ambitions and funding commitments to support the development of green hydrogen production and the refuelling infrastructure needed to enable vehicle uptake. Often these strategies assume hydrogen transport will begin with heavier duty bus, truck and rail transport. A few examples are set out below; many other countries and regions across the world have released or are developing hydrogen strategies.

- **France:** National Hydrogen Plan (French Government, 2018)
- **Germany:** National Hydrogen Strategy (German Government, 2020)
- **Norway:** Norwegian Government's Hydrogen Strategy (Norwegian Government, 2020)
- **Netherlands:** Government Strategy on Hydrogen (The Netherlands Government, 2020)
- **Iceland:** 2030 vision for H_2 in Iceland (Icelandic New Energy Ltd., 2020)

Strategy and funding at European level

The European Commission released *A hydrogen strategy for a climate-neutral Europe* in July 2020, as part of the European Green Deal (a policy package intended to deliver net-zero by 2050). The strategy objectives are consistent with the national strategies, setting out the investments required to deliver the hydrogen economy, as part of a sustainable economic recovery from Covid-19 impacts.

- Where previously, European funding for hydrogen activities had been largely contained within The Clean Hydrogen Partnership, support for hydrogen technologies will now be integrated within all packages in the Green Deal, with funding to be made avail able across transport, industry, heat and wider energy system applications. Targets for renewable hydrogen in specific end-use sectors will also be considered as part of future European policy measures.

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

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- Business cases
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Evidence from utilisation: Deployment activities to date

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H2ME deployment to date (Q2 2022)

47 HRS and 1019 vehicles active in 8 countries

- 344 Symbio ZE H2 FC RE
- 40 B Class F-CELL
- 157 Mercedes-Benz GLC F-Cell
- 225 Toyota Mirai
- 10 Honda Clarity
- 243 vehicles procured by project partners

- **5 HRS operational in the UK (6) including 5 with on-site electrolysis**
- **5 HRS operational (13) in France including 7 with on-site electrolysis**

- **8 HRS operational in Scandinavia (9) with all stations receiving H_2 from decentralised electrolyzers**
- **20 HRS operational (20) in Germany with green or low carbon H2 delivered for ~ 40% of the stations**

- H2ME HRS commissioned under H2ME1
- Other HRS planned under H2ME2 - illustrative

Clean Hydrogen Partnership

*Numbers in brackets () denote the total number of HRS planned for deployment under the H2ME initiative

**Significant HRS and Vehicle deployment is taking place outside of the H2ME initiative

Overview of vehicles deployed in H2ME

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
							
Dates reporting data to H2ME	2015-2018 (retired)	2019-	2017-	2017-	2019-	2017-	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

The following pages provide an overview of data accumulated on FCEVs as part of H2ME from 2015 to the end of May 2022:

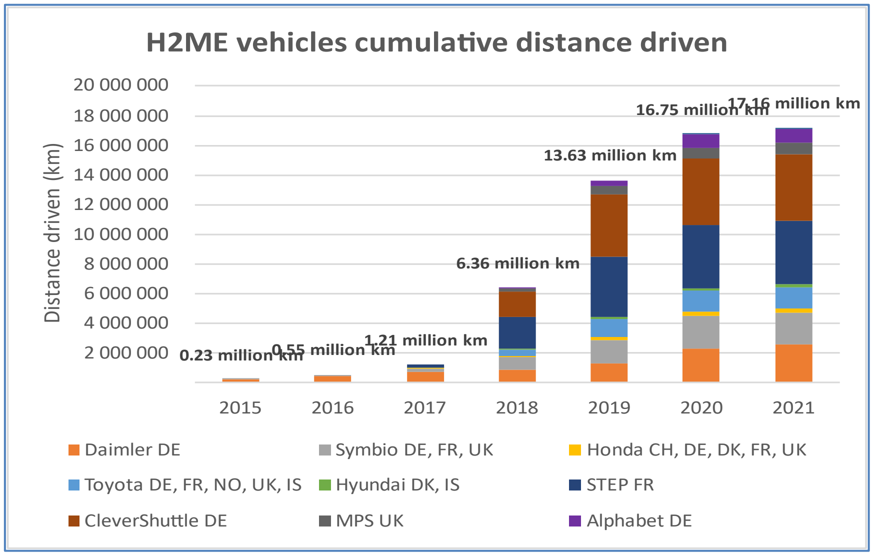
- **535** fuel cell electric vehicles (FCEVs) made by Daimler, Honda, Hyundai and Toyota
- **246** fuel cell range-extended electric vehicles (RE-FCEVs) from Symbio

Source: *Cenex analysis based on H2ME-2 Vehicle and Infrastructure Performance Report 4 (2015-2021), D5.17, Cenex* *https://h2me.eu/wp-content/uploads/2021/11/H2ME2-D5.17-Public-FV-Report-4-Interim-and-final-summary-%E2%80%A6-1.pdf*

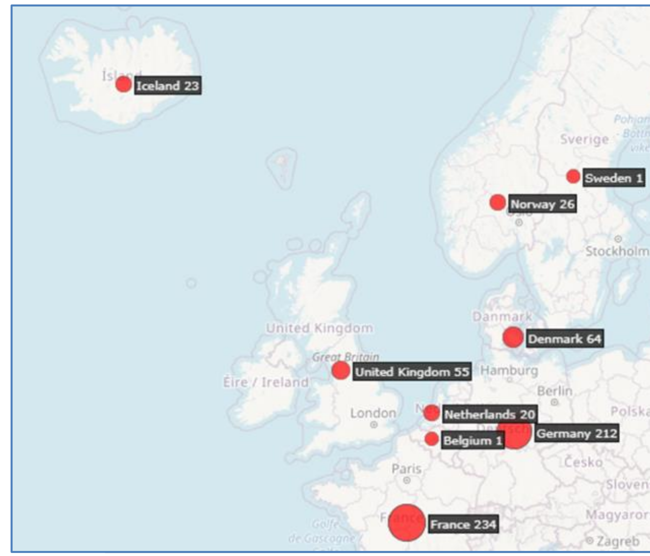
Overview of vehicle utilisation in H2ME

To date, data was collected for close to 550 vehicles

H2ME vehicles cumulative distance driven



Locations and type of vehicles collecting data



The total distance reported by vehicles monitored by H2ME from Q3 2015 to Q1 2022 was 23,170,000 km, with a significant increase in the distance driven since late 2017 due to deployments with end-users including:

- STEP taxis in France – 5.2 million km driven in H2ME since 2017 (further 2,750,000 km in ZEFER)
- Deployments in Germany (Alphabet), Denmark & Norway (Toyota NMSCs) and the Netherlands (Noot taxis)

Source: H2ME2 WP5 Technical Readiness summary, June 2022, Cenex
CleverShuttle taxis in Germany demonstrated >4.4 million km driven in H2ME since 2017, but the ride-sharing business model was undermined by the COVID-19 shutdowns and the business no longer operates FCEVs

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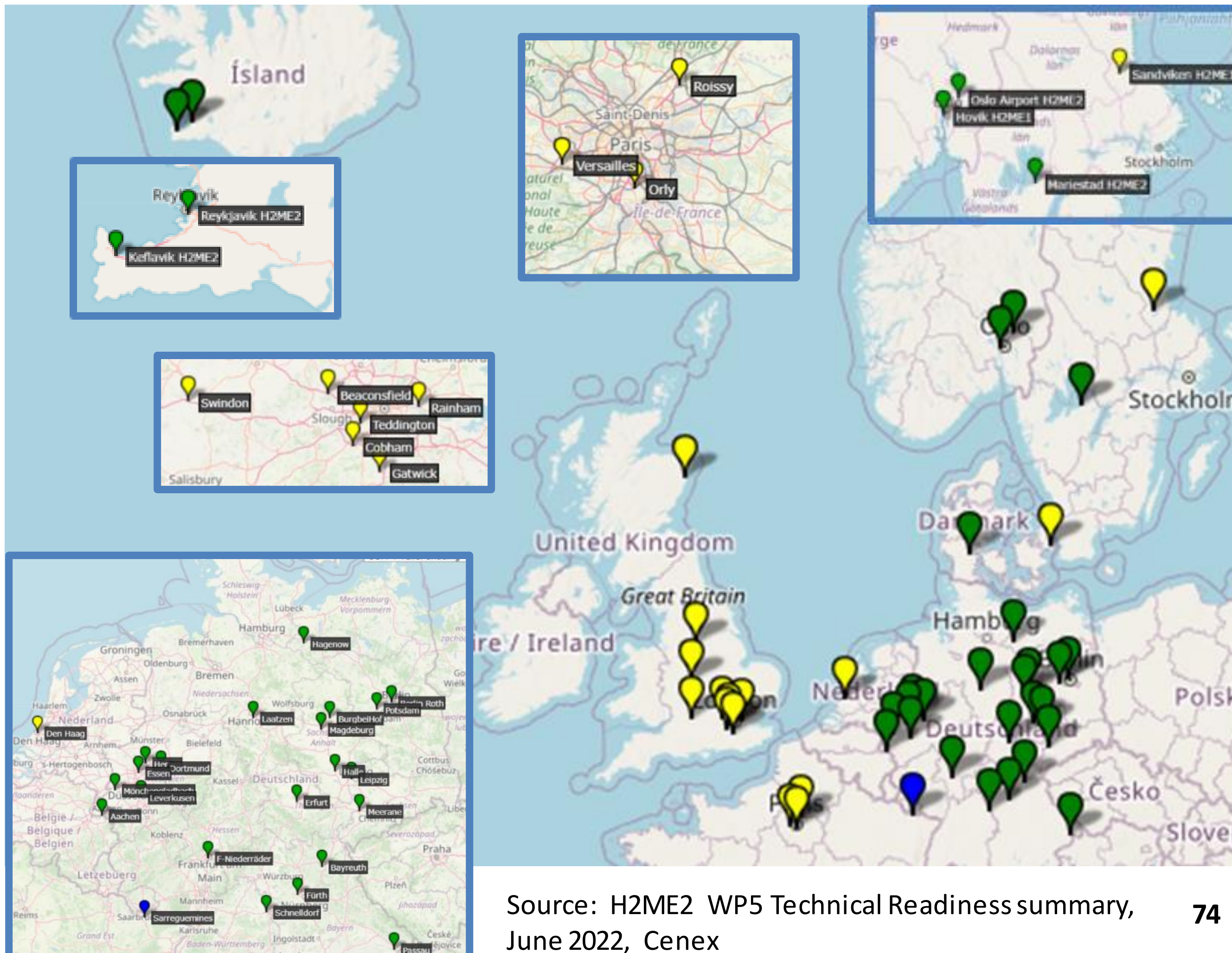
Overview of HRS deployed in H2ME

- **43 hydrogen refuelling stations (HRS) have been installed** as part of the project, supplied by Air Liquide, ITM Power, Linde (including its subsidiaries AGA and BOC), McPhy and NEL Hydrogen Fueling.
- Data has been gathered from these HRS as part of H2ME from 2015 to the middle of 2022.



700 bar station

700 & 350 bar station

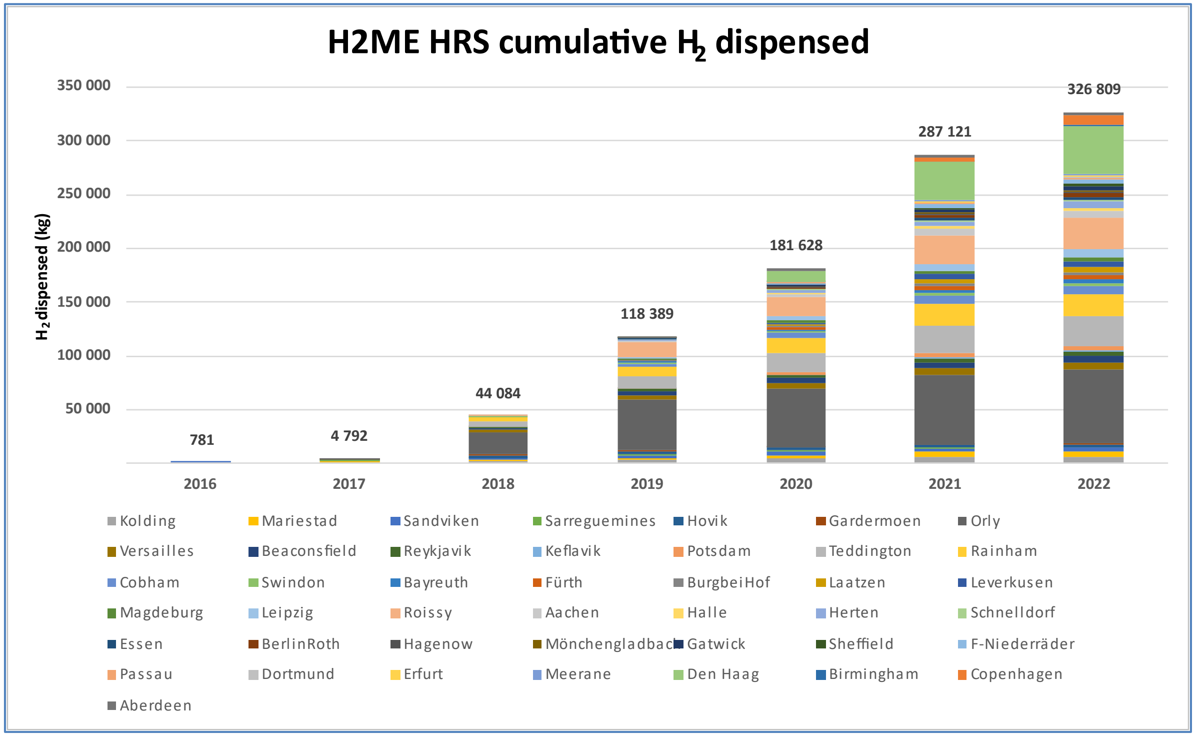
350 bar station

Source: H2ME2 WP5 Technical Readiness summary, June 2022, Cenex

Clean Hydrogen Partnership

Overview of HRS utilisation
H2ME installations and associated stations

To date 43 HRS are in operation, with data provided as they enter into operation over time



- 43 stations that report data to H2ME have dispensed **326,800 kg** H_2 in **134,900** refuelling events since March 2016**.** Prior to H2ME there was almost no demand.
- Five of the HRS have dispensed 59% of the H_2 reported by H2ME. These are in locations where FCEV taxis are deployed, showing the criticality of high-use vehicles in making the HRS business case:
  - Orly (Paris) 69,300 kg
  - Roissy (Paris) 29,300 kg
  - Rainham (London) 20,200 kg
  - Teddington (London) 28,100 kg
  - Den Haag (NL) 44,500 kg







Source: H2ME2 WP5 Technical Readiness summary, June 2022, Cenex

Evidence from utilisation: Vehicle utilisation and experiences

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Hydrogen Mobility Europe

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Clean Hydrogen Partnership

A range of FCEV applications have been tested in the project, with a range of different needs

FCEV applications in the H2ME project

- The vehicles deployed as part of the H2ME initiative cover a wide range of end-user applications; the main examples are listed below. This section of the report explores the specific needs of these end users, and the extent to which these needs are being met by FCEVs with the current refuelling infrastructure provision.
  - Private users
  - Taxi fleets, e.g., HYPE taxis (Paris), Green Tomato Cars (London), DRIVR (Copenhagen)
  - Emergency services, e.g., London Metropolitan Police Service, La Manche Fire Service
  - Ridesharing fleets, e.g., CleverShuttle (Berlin)
  - Business mobility solutions, e.g., Alphabet (BMW), HYPE, HysetCo (Air Liquide, Idex, STEP, & Toyota)
  - Local governmental organisations, e.g., City of Copenhagen
  - Delivery services, e.g., La Poste (Kangoo ZE Hydrogen trials), HYPE/Akuo Energy (last mile delivery)
  - Utility fleets: water companies; energy companies, e.g., ENGIE Cofely

Attractive business models are emerging in some applications, and hundreds of vehicles have already been deployed in various fleets

- In H2ME, light duty hydrogen vehicles have been used in multiple proof of capability demonstrations, leading to refinements of business models:
  - **HYPE: >100 fuel cell taxis in Paris**, with initial plans for a total of 600 taxis to be in operation by the end of 2020
  - **Green Tomato Cars: 50+ fuel cell taxis in London** (finishing in 2022)
  - **CleverShuttle: 45 FCEVs in ride-sharing fleets in Germany:** >4.4 million km covered until 2020 (when the fleet was disbanded)
  - **Delivery & utility vans**: Plans for demonstrations by DHL, La Poste, City Logistics, water & energy companies: >150 Kangoo ZE H_2 vans in France
  - **Last Mile delivery**: HYPE/Akuo Energy facilitating Galeries Lafayette in the wholesale delivery to its stores in the Paris Area, HYPE/Ecolotrans (now part of the ADEME H24byHype project)
- Currently, specific market conditions (which apply in the cases above) make fuel cell vehicles particularly attractive for these applications:
  - Fleets have high daily mileages and/or a need for fast refueling to enable flexible operations
  - Strong regional incentives for zero emission vehicles make the purchase or lease price more attractive and/or increase the financial burden associated with operating fossil fuel vehicles
  - Operational area aligns with locations of refueling infrastructure

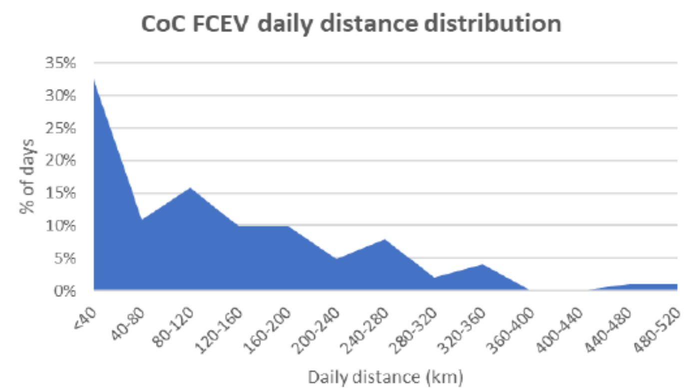
Key findings from FCEV utilisation trends in different applications (1/3)

Mercedes-Benz GLC F-CELL (Germany)

- Comfortably capable of fulfilling average German driver's needs (annual average distance travelled ~14,000 km, average daily distance ~40 km[1]).
- As a plug-in hybrid FCEV, the GLC can be fuelled by H_2, electricity or a combination of both, which gives them flexibility of usage. In H2ME, 85% of the fleet's kilometrage has been fuelled by H_2.
- Users are not habitually plugging in the vehicle. Possible reasons include:
  - Suitability of HRS network available in Germany
  - "Inconvenience" of plugging
  - Limited availability of home charging more
- The GLC F-CELL has been discontinued as the company now focuses on heavy-duty H_2 trucks in its cellcentric joint venture with Volvo.

Hyundai ix35 (Denmark)

- Three H2ME Hyundai ix35 FCEVs are used by the Municipality of Copenhagen for varied duties.
  - Average daily distance travelled is 120 km.
  - The vehicles travel <100 km on 50% of the days, the maximum distance travelled in one day was ~500 km.
- The Danish refuelling network allows the vehicle to travel well beyond Copenhagen. The return distance from its base to the Veljehydrogen HRS is ~500 km.



Source: Yearly Vehicle and Infrastructure Performance Report 4 (2015-2020), D4.13, Cenex

[1] Motor Vehicle Use and Travel Behaviour in Germany, www.diw.de/documents/publikationen/73/diw_01.c.44461.de/dp602.pdf

Key findings from FCEV utilisation trends in different applications (2/3)

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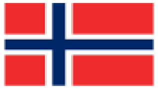
Toyota Mirai (comparison)

Vehicle id	H2ME1	H2ME6	H2ME8
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

Comparison of the efficiency of Mirais in different roles:

- CleverShuttle drivers (Germany) are incentivised for eco driving, resulting in lower maximum speeds and less harsh driving.
- Police Incident Response Vehicles in London have to get quickly to incidents as they occur so are inevitably driven relatively harshly, but also spend a lot of time idling waiting for dispatch.
- The passenger car vehicle in Norway exhibits the typical fuel economy and driving behaviour of a baseline H2ME Mirai. Longer trips with medium speed driving facilitate highest range.

Toyota Mirai (France)

- STEP/HYPE FCEVs have reported a total of 4.3 million km driven since 2017.
- The taxis drive an average of 3,670 km per month (150 km per day).
- The furthest driven by one of the vehicles in a month was 6,460 km.
- The mean distance between refuels for the STEP taxi fleet is 177 km.
- Taxis in Paris refuel 24/7 which, as well as increasing overall HRS load, also spreads the load.

Clean Hydrogen Partnership

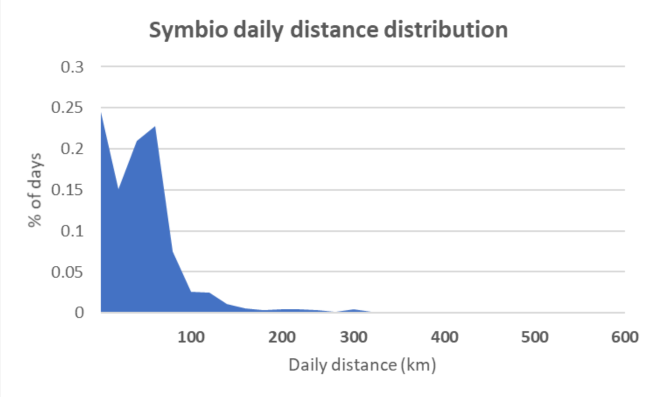
Source: Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), D4.12, Cenex

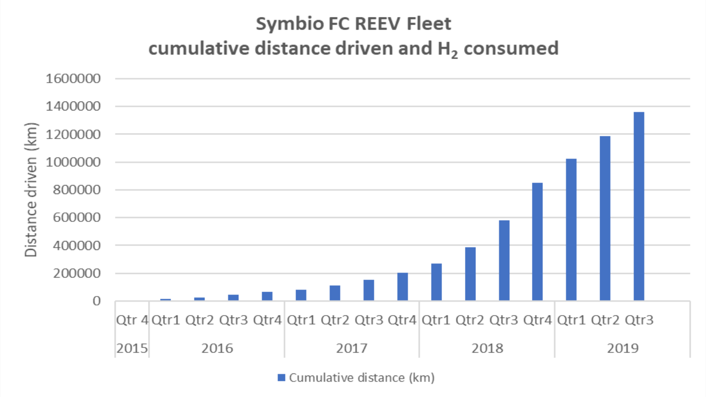
Key findings from FCEV utilisation trends in different applications (3/3)

Renault Kangoo Z.E Hydrogen (by Symbio)

- 125 Renault Kangoo ZE Hydrogen units were fielded in H2ME1 with 114 underway in H2ME2.
- The fleets in France, Germany and the UK reported nearly 2 million km driven since 2015. The average daily distance travelled by the fleet has been 54 km. The furthest distance travelled by a vehicle is 288 km.
- The data shows that under the demonstrated usage patterns the Symbio is capable of fulfilling the daily driving needs of the vast majority of van drivers.

- The Renault Kangoo ZE RE H2 is a fuel cell range-extended electric vehicle (FC REEV) – i.e., it can be fuelled by H_2, electricity or a combination of both, which offers flexibility of usage.
- In H2ME, around 50% of the fleet's travelled km was fuelled by H_2 in 2018, but this has fallen below 30% in 2020.





Source: Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), D4.12, Cenex

Case study 1: Taxis
Needs & characteristics of taxi fleets

As a long-range, rapid refuelling, zero-emission technology, FCEVs are well suited to taxi service applications

- Taxi vehicles are a high mileage application, and critical to their business models is the ability of vehicles to be driving around for many hours, and able to make long journeys at short notice. As such, the relatively high range and fast refuelling times of vehicles (3-5 minutes) makes FCEVs well suited to operations. In addition, taxi fleets make the vast majority of their journeys within a specific area around the city they operate in, meaning that sufficient coverage can be achieved with a relatively small number of refuelling stations.
- Within the H2ME projects, FCEVs have been deployed in several taxi fleets, including **HYPE** based in Paris, France and **Green Tomato Cars** (GTC), in London, UK. **HYPE** is an entirely FCEV fleet, and by October 2019, over 100 FCEVs were in operation. **GTC** has a wider range of vehicle types within its fleet, and by October 2019, approx. 35 FCEVs were in operation. This number was increased to 50 within the follow-up ZEFER project.
- H2ME has proven the technical viability of H_2 taxis but the increased TCO over fossil fuels remains a challenge.

Toyota Mirai, Hype, France

Toyota Mirai, Green Tomato Cars, UK

Source: Vehicle user attitudes driving behaviours and HRS network access trends, 2020, H2ME (1), D5.9. Element Energy

Case study 1: Taxis
Utilisation data

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Impacts of limited infrastructure

- Despite the relatively high range and fast refuelling times of vehicles (3-5 minutes) some challenges remain which can lead to inefficient driving patterns.
- Relatively **limited infrastructure** means drivers may have to travel off route, and relatively far distances, in order to refuel, which is a disincentive, or alternatively restrict vehicle operations close to the HRS.
- **Drivers currently refuel more frequently than is required;** the mean distance between refuels for Hype drivers is 177 km, less than half the maximum range of vehicles (~400km), and 228km for GTC drivers (frequent refuelling is encouraged to some extent in the Hype fleet to ensure that all journeys can be completed). Frequent recharge is also encouraged while the fear of downtime exists for earlier HRS designs.

Daily distances

- Data from the project shows the Hype vehicles to have an average daily distance of **151 km**.
- Whilst this falls within the range of some BEVs, it is important to consider the frequency of events (days) where drivers go beyond this average in order to understand further the advantages of FCEV operation.
- This demonstrates the need for taxi fleet operators to have vehicles with the ability to deliver high mileages in a single day, and therefore reinforces the importance of long range and rapid refuelling to maximise operating time. This is further explored in the following slide.

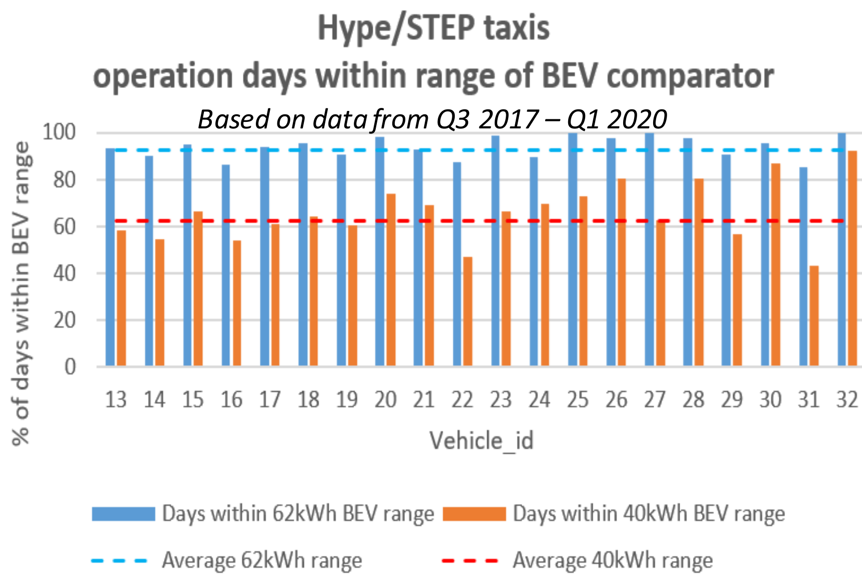
Source: Vehicle user attitudes driving behaviours and HRS network access trends, 2020, H2ME (1), D5.9, Element Energy

Ref: H2ME D4.12 – Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), Cenex, 2020

Case study 1: Taxis
Utilisation data (comparison with BEV capabilities)

FCEVs offer an operational advantage against other zero-emission mobility solutions in applications such as taxi

- Many modern large-battery BEVs have ranges capable of meeting the average daily distances travelled by the Hype taxi fleet (161 km, for the selection of vehicles shown in the chart).
- However in order to better understand the operational suitability of a vehicle, it is necessary to consider daily distances that fall outside, and specifically above, the daily average.
- The graph on the right shows the number of days that the taxi driving falls within the range of:
  - A 62 kWh BEV: **93% overall**, assuming 312 km real-world range on a single charge (based on BEV operational data).
  - A 40 kWh BEV: **62% overall**, assuming 200 km real-world range.



Ref: H2ME D4.14 Technical Performance Report, Cenex, 2020

- ~ 93% of daily operation could, in theory, be covered by a modern large-battery BEV without recharging; this would increase to 99% for a BEV with an 85 kWh capacity battery. Yet longer journeys would require a recharge.
- However, at present, taxi business models rely on minimal refuelling during operational hours, and when refuelling is necessary, quick refuelling times. Further, evidence from H2ME shows that drivers are unwilling to run the vehicle energy store down to near its minimum, so it is expected that the practical BEV range would be less than the nameplate capacity.
- As such, **FCEVs offer an operational advantage against other zero-emission mobility solutions in high mileage and high required availability applications, such as taxi fleets**.

Source: Vehicle user attitudes driving behaviours and HRS network access trends, 2020, H2ME (1) Deliverable 5.9. Element Energy

Case study 2: Utility service vans
Needs & characteristics of utility fleets

ENGIE Solutions operates 50 fuel cell range-extended vans in their fleet in the Paris area

- ENGIE Solutions is a utility company focusing on energy efficiency and environmental services. The company has adopted 50 FCEV vans into their wider fleet of vehicles operating **in the Paris region**, mainly in urban areas. Each vehicle is assigned to one driver, who has access to the vehicle 24/7.
- For utility fleets, the operational area can be extensive, long journeys may occasionally be required at short notice to fulfil services. This means that the ability to refuel quickly and carry out long journeys is important. Another challenge ahead, key determinant of the project's success, is the efficient maintenance of fleets to guarantee their full availability for their drivers' daily use. Frequent failures proved to be an impediment to drivers' comfort. For the Symbio vans, the critical use-cases degrading the availability were identified and technical improvements were made successfully.
- **Vans are a difficult segment of vehicles to electrify** due to their weight, range requirements, potential for parasitic loads, and high speed or off-street refuelling needs. Fuel cell range-extended vans offer a greater range compared to pure electric options, and the range of a partially charged battery can be quickly "topped up" by refuelling with hydrogen, to complete journeys at short notice.

Renault van equipped with Symbio FC range extension system, France

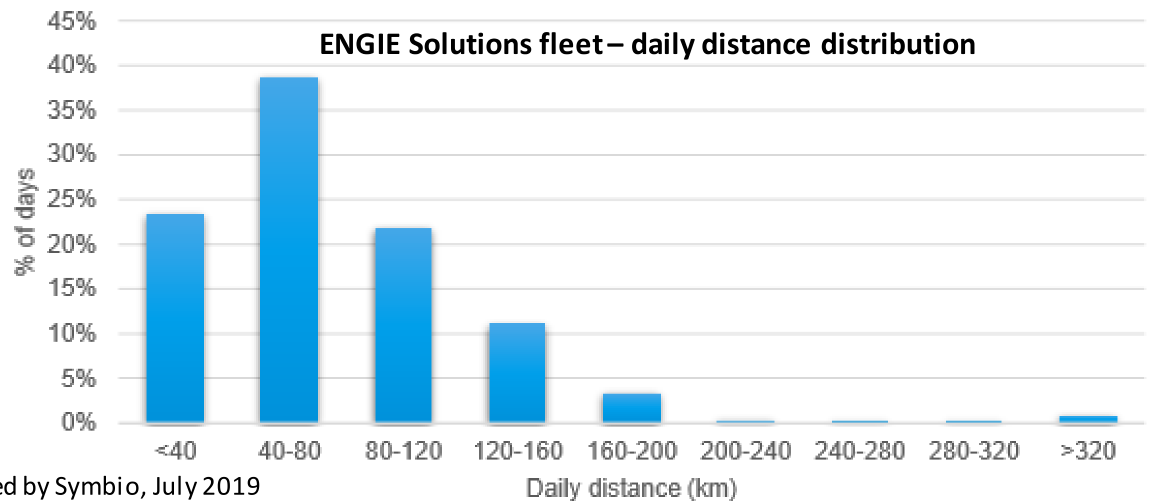
Localisation ENGIE Solutions, France

Source: Vehicle user attitudes driving behaviours and HRS network access trends, 2020, H2ME (1) Deliverable 5.9. Element Energy

Case study 2: Utility service vans
Utilisation data

Fuel cell range extended vans in the ENGIE Solutions fleet travel less than 100km on 75% of days

- Based on utilisation data from the ENGIE Solutions fleet, the average daily distance travelled by the range-extended vans is 48 km, with the fleet travelling under 100 km on ~75% of days. Most of these journeys can be met using a BEV.
- However, 2% of daily distances were >320km, suggesting that occasionally the vehicles are used for much longer journeys. Paris is currently relatively well-equipped in terms of refuelling stations, with 4 HRS distributed across the Paris area; as with the Hype fleet, this supports the ability to refuel quickly without extensive detours. However, compared to the taxis, which operate mainly in the city, a utility vehicle may be less likely to pass one of these HRS as part of their normal operations, and if a long journey is required outside the city it is possible that refuelling at an HRS would involve a considerable detour which could act as a deterrent to choosing the fuel cell range extended van for this journey.
- Further work is required to understand to what extent the ENGIE Solutions fleet FCEV vans are being used in the same way as other vehicles in the wider ENGIE Solutions fleet.

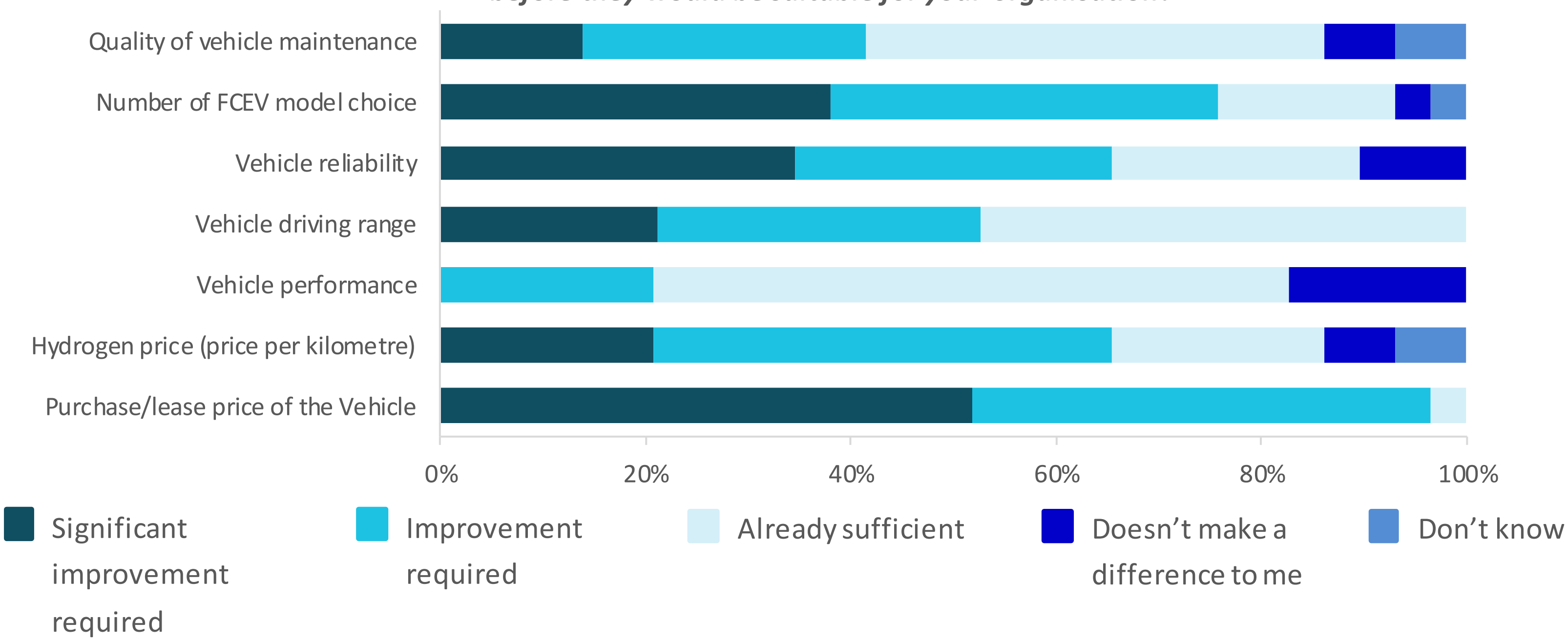


Data collected by Symbio, July 2019

Source: Vehicle user attitudes driving behaviours and HRS network access trends, 2020, H2ME (1) Deliverable 5.9. Element Energy

Improvements to FCEVs required for future use
Fleet operators interviews

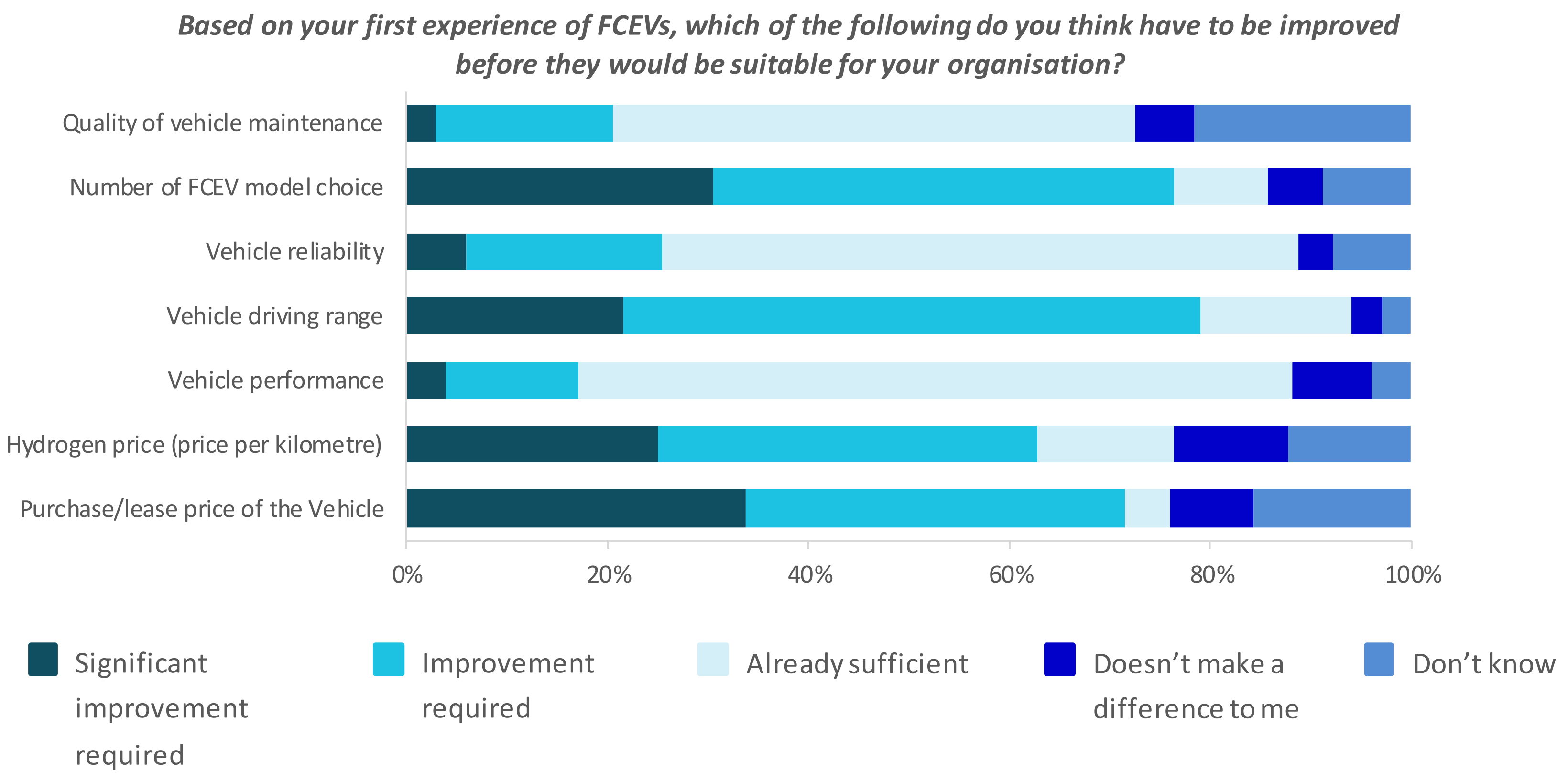
Based on your first experience of FCEVs, which of the following do you think have to be improved before they would be suitable for your organisation?



- The FCEV aspect requiring improvement for the highest number of fleet operators was the **purchase/lease price of the vehicle**, with 28 out of 29 respondents requesting some improvement.
- Another aspect requiring improvement was the **number of models available;** this would allow fleet operators to tailor their vehicle choice more to the specific requirements of their operations. The majority of fleet operators citing this as a key requirement were those using vans; currently, the range-extended Renault Kangoo is the only fuel cell van model available on the market, whereas several fuel cell cars are available.
- Many van fleet operators also felt that improvements would also be needed to driving range, vehicle maintenance and vehicle reliability.

Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME-2 Deliverable 6.21. Element Energy

Improvements to FCEVs required for future use
Fleet drivers interviews



- The views of fleet drivers on required FCEV improvements follow generally the same trends as those of fleet operators, although drivers tended to be more **agnostic about price-related issues** than operators.
- Drivers had a **more positive outlook on vehicle reliability, performance and quality of maintenance than operators**. This is likely to be because operators are responsible for maintaining vehicles and are more exposed to issues.

Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME-2 Deliverable 6.21. Element Energy

Satisfaction with vehicle driving range
Fleet operators & drivers interviews

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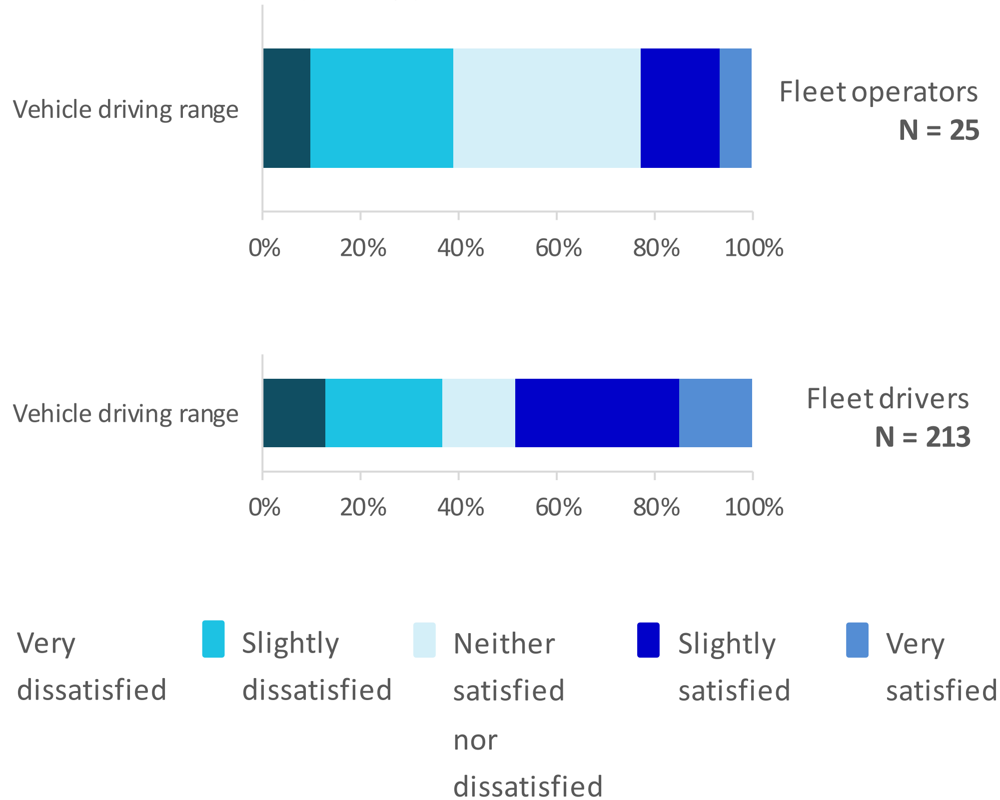
Satisfaction with vehicle range varies between different user groups

- 39% of fleet operators and 36% of fleet drivers were dissatisfied with vehicle range to some extent after using the vehicle.
- The responses received **indicate a range of experiences,** which corresponds with the diverse range of applications (and thus requirements) for FCEVs.
- Amongst fleet operators, **van operators were more likely to be dissatisfied,** compared to car operators (64% to 37%).
- Anecdotal feedback from fleet managers and data collected by vehicle manufacturers also notes some instances of vehicle range being lower than expected. There is some evidence that **technical and behavioural reasons** such as low State Of Charges (SOC)s being achieved at refuelling stations, or inefficient driving, may be contributing factors.

How satisfied are you with the following aspects of your FCEVs?



Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME-2 Deliverable 6.21.Element Energy

Satisfaction with driving range

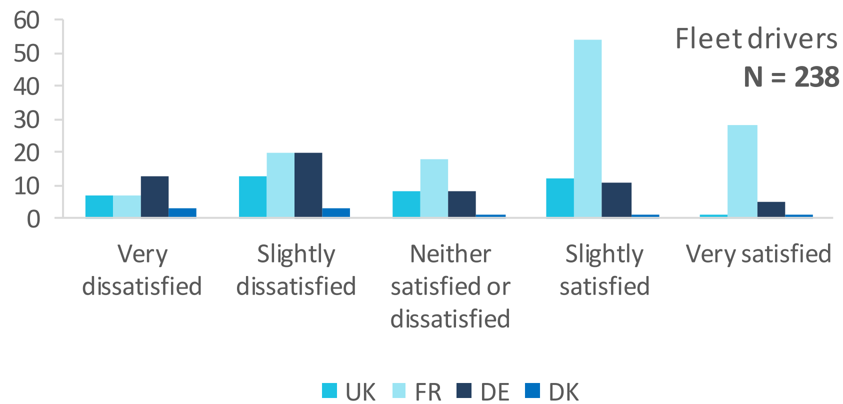
Differences between regions and vehicle types

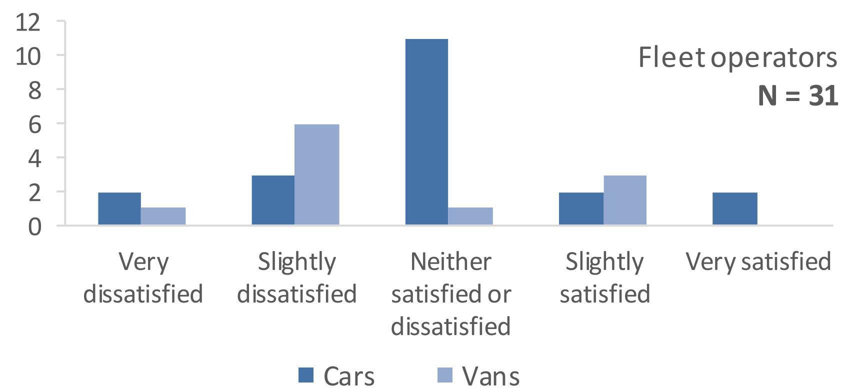
French fleet drivers expressed higher satisfaction with range than other groups

- **French drivers appear to be more satisfied than drivers from other countries.** Note that the French driver group is dominated by Hype taxi drivers, using exclusively fuel cell cars. As such, Hype drivers do not have co-workers who drive petrol or diesel vehicles, so a direct comparison of range is not possible. In addition, the fact that these drivers have chosen to work for a company that only uses hydrogen vehicles suggests that they are likely to have a degree of enthusiasm for the technology (compared to fleet drivers who have had FCEVs introduced to their existing fleet).

- In general, **fleet operators with cars are more satisfied with range than fleet operators with range-extended vans** (which are mainly based in France). This could be due to the following factors:
  - The **range of the vans is shorter** than those of the cars (particularly due to refuelling at 350 bar instead of 700 bar in some cases and the design of the range-extender powertrain).
  - The **need to travel greater distances** than is possible with the current refuelling network; vans have been deployed in a number of locations in France, including those where HRS networks are in earlier stages of development than in Paris.

How satisfied or dissatisfied are you with the following aspects of your FCEV – Driving range of the vehicle (maximum distance between recharging/refuelling)





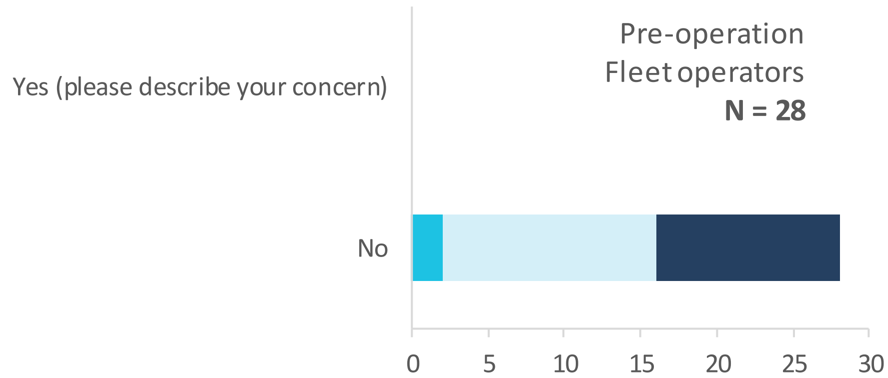
Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME-2 Deliverable 6.21. Element Energy

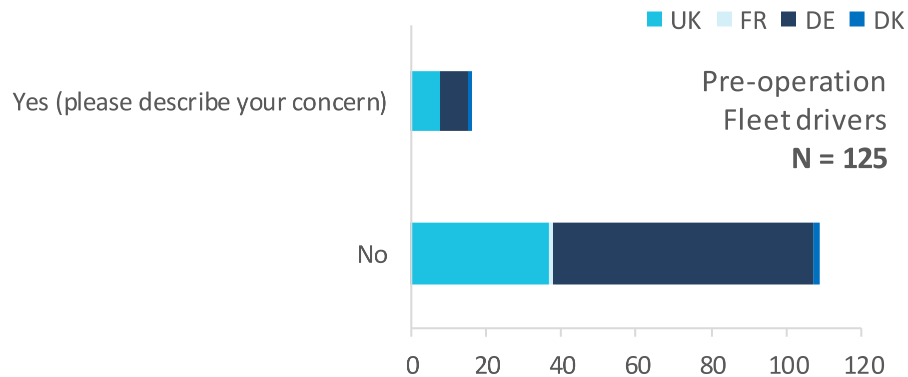
Perceived safety of FCEVs before vehicle operation
Drivers interviews

Before vehicle operation, some FCEV drivers expressed safety concerns

- Prior to vehicle operation, **all fleet operators stated that they had no concerns** about the safety of their FCEV relative to a petrol/diesel vehicle. In contrast, a small number (13%) of fleet drivers had concerns.
- The main type of safety concern expressed by drivers related to the **high pressure systems** in the vehicle and the **potential of explosion of the hydrogen tank**. This was noted as a particular concern in the event of an accident or if the tank was used beyond its lifespan or repaired by an unqualified person.
- Other safety concerns included:
  - **Pedestrian safety** at crossings due to lack of noise produced by vehicle
  - **HRS non-compliance with standards** potentially causing tank overheating
  - **HRS nozzles getting stuck** in the vehicle (based on previous issues experienced by drivers).

Do you have any concerns about the safety of the FCEV compared to a petrol/diesel vehicle?





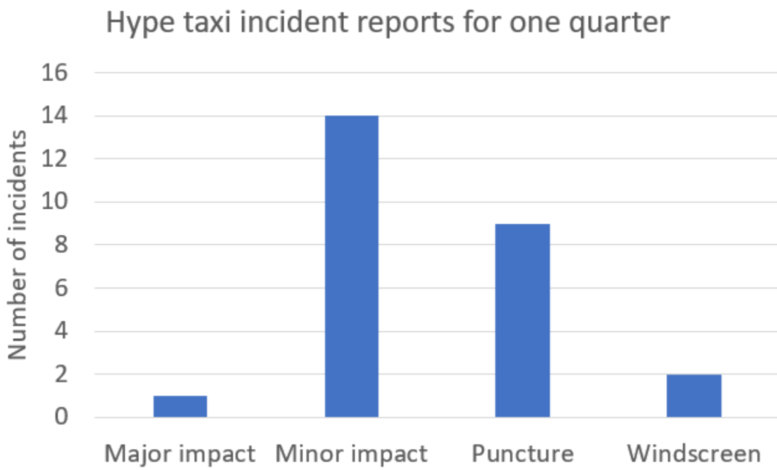
Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME-2 Deliverable 6.21. Element Energy

Vehicle safety: Hype taxis case study

Utilisation data

FCEVs have demonstrated they can endure major impact incidences with no release of hydrogen

- The graph on the right captures all incidents reported in a single quarter for Hype taxis.
- The frequency of incidents reported is in line with those of fossil fuel taxis.
- As the graph shows, **one vehicle was involved in a major impact incident in this period.** The accompanying image shows the scale of the major impact incident.
- **None of the incidents, including the major impact incident, involved any release of hydrogen** or problems with the fuel cell system.



- Efforts should be made to **disseminate more widely the safety results coming out of the H2ME project** in order to allay fears around safety of hydrogen mobility. Particular emphasis could be made with regards to collisions and the lack of associated explosions, as this is a specific worry for some users (as per previous slide).

Source: Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), Cenex, 2020

Recommendations based on existing sales strategies and emerging trends from the H2ME deployment (FCEVs)

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Recommendations can be drawn on sales strategies for FCEVs:

- Focus on the **ZE credentials** of FCEVs as well as on **financial opportunities** when subsidies are available.
- Additional focus on **technological performance and maturity** of the technology would be beneficial.
- **Concentrate efforts where there is a greater interest**, based on potential early adopters. **Fleet users are thought to provide a good opportunity** to enter the market as they can provide scalable demands to reduce the overall capital cost of the vehicle.
- **Working collaboratively with local authorities and hydrogen stakeholders is required** at this stage of commercialisation to activate opportunities.

The importance of governmental and local support FCEVs :

- **National, regional and local incentives are needed** to ensure continued deployment. This is required **to create a level playing field** with other zero emission vehicles as the price of FCEVs heavily influences access to end-users.
- National, regional and local incentives should not only support deployment of vehicles but also **implement strategies for further HRS deployment and sustained operation.** This can be linked with a staged approach, **giving confidence** that once sufficient interest is generated locally with additional users confirmed, a larger and/or additional HRS can be deployed locally, with HRS ideally in cities.
- **Policy makers can attract vehicles OEMs geographically by establishing policies supporting FCEVs and/or provide financial supports**. This supports sales but also creates confidence in the technology, both of which makes it worthwhile for the vehicle OEMs to invest efforts into deploying resources and developing routes to market in these locations.
- **Policy makers can develop policies that benefit targeted groups of users in line with their mobility strategies.** For example, the case of fleet operation in cities centres for which the operational benefits of FCEVs compared to EVs may make the transition of these fleets to zero emissions vehicles less constraining. Information on vehicles options should be made available to fleet operat ors.
- **Activating leads locally requires significant resources**, beyond what may be reasonably expected of vehicles OEMs and /or HRS operators. **The local authority should act as a champion** liaising with the relevant stakeholders and identifying and facilitating dialogues with local users to help initiate a market in the area.

Source: Summary of vehicle sales approach, Element Energy, 2020

Evidence from utilisation: HRS utilisation and experiences

Deployment activities to date

- Overview of vehicle & HRS deployment in H2ME
- Specifications and utilisation data for vehicles in the project
- Specifications and utilisation data for HRS in the project

Vehicle utilisation and experiences

- Applications tested in the project
- Utilisation trends
- Case studies
- End user needs for further adoption
- Safety
- Conclusions for further uptake of FCEVs

HRS utilisation and experiences

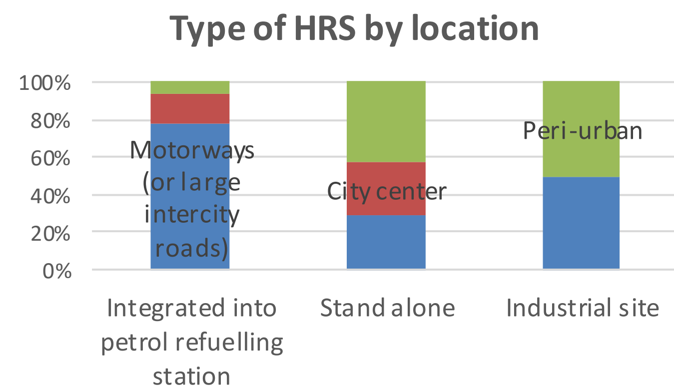
- Characteristics of H2ME network
- Utilisation trends
- End user needs for further adoption
- Business cases
- Case study: National infrastructure implementation (Germany)
- Safety

Characteristics of H2ME network (1/2)

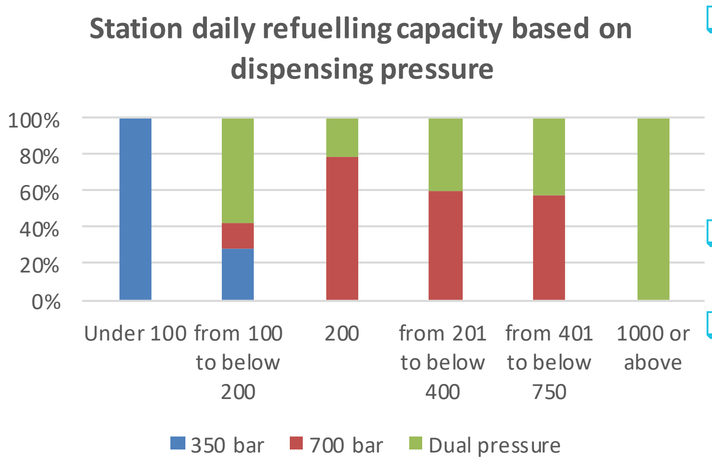
HRS in operation and planned

Sites characteristics

- A majority of the HRS in the projects are or will be commissioned on motorways or large intercity roads (>60%) or in city center (18%). The majority of the HRS (>60%) are or will be integrated into petrol stations.
- The approach to sitting generally reflects the strategy employed by each coalition to date, with Germany, the UK and Scandinavia favouring HRS on major transports corridors with HRS integrated into petrol stations while location of HRS tends to be more varied in France which has followed a more regionalised approach to date.



Dispensing characteristics



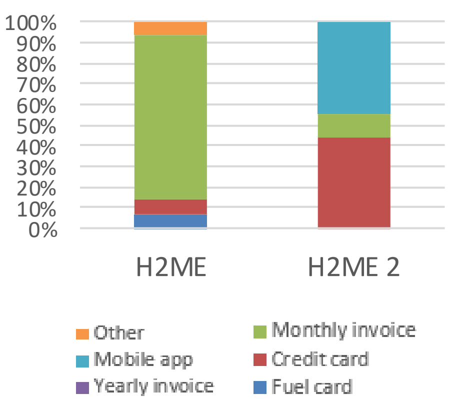
- The large majority of the HRS in the projects are or will provide refuelling at 700 bar or both at 700 bar and 350 bar. The 350 bar HRS deployed have been deployed in France to support the Symbio fleet which operates on 350 bar. At these HRS, refuelling of 700 bar vehicles is possible but not for a full tank.
- The large majority of the HRS (81%) have daily dispensing capacity ≥ 200kg/day.
- HRS with capacity <200kg/day are HRS designed to cater for the Symbio fleet. HRS with the higher daily capacity are typically designed as multi-use stations that will cater for different vehicles types (currently: buses, refuse trucks etc.).

Source: data H2ME projects, Element Energy, 2022

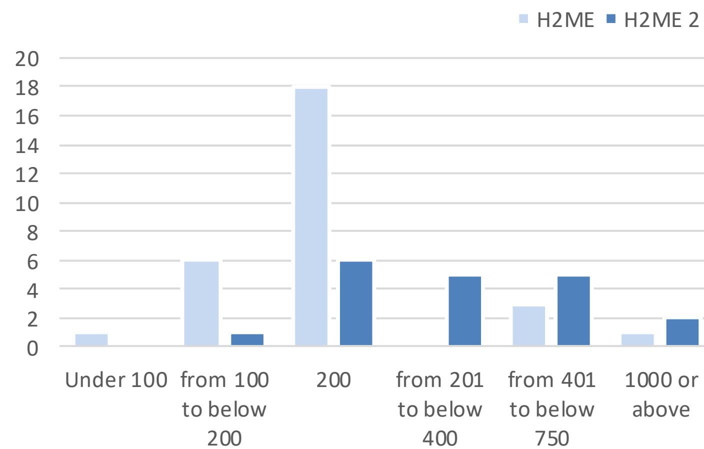
Characteristics of H2ME network (2/2)
Evolution over time

Approaches and strategies have evolved over time which has been reflected in the characteristics of the stations deployed in the project in the first and second phase of the deployment

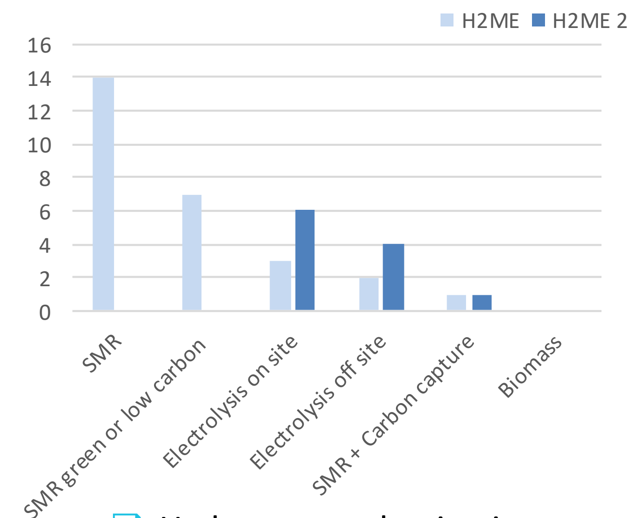
Payment system



Station capacity by project



Type of station by H2 production and project



- Payments systems have evolved from invoicing to a limited poll of clients to credit card and mobile app payments allowing
- The daily capacity of the stations has increased over time, reflecting the increase in multi-use stations with dual pressure options.
- Hydrogen production is increasingly based on green or low carbon solutions, reflecting the political agenda.

Source: data H2ME projects, Element Energy, 2022

Key findings from utilisation of HRS networks:
Estimated demand per HRS by country (1/2)

Average hydrogen demand per HRS in Europe is currently low for light vehicles

- Estimated average hydrogen demand per HRS in different regions is shown below. For comparison, the majority of current HRS serving light vehicles have refuelling capacities of 80 kg/day to 200 kg/day. Overall, based on demand from light vehicles alone, HRS utilisation is currently low.

UK

FCEV light vehicles: 235

HRS: 8

Estimated hydrogen demand per HRS:

kg/day

France

FCEV light vehicles: 396

HRS: 4

Estimated hy8drogen demand per HRS:

205 kg/day

Scandinavia

FCEV light vehicles: 521

HRS: 22

Estimated hydrogen demand per HRS:

47 kg/day

Benelux

FCEV light vehicles: 576

HRS: 15

Estimated hydrogen demand per HRS:

77 kg/day

Germany

FCEV light vehicles: 1,236

HRS: 94

Estimated hydrogen demand per HRS:

26 kg/day

Source: Map of operational 700-bar hydrogen refuelling stations as of Sept 2022 from H2Live Website.
Scandinavia includes data from Denmark, Norway, Sweden, Iceland and Finland.
HRS demand / day calculated from assumed vehicle demand (see following page).

Key findings from utilisation of HRS networks: Estimated demand per HRS by country (2/2)

Assumptions: Estimated hydrogen demand in Europe for light vehicles

- The "average" utilisation of HRS for light duty vehicles in Germany, France, the UK and Scandinavia has been estimated based on the approximate **number and type of fuel cell cars and vans deployed, and number of HRS deployed in each country.** Note that these H_2 demand estimates are likely to be high, as the assumed demand is based on the typical daily demand from highly utilised fleets.
- Germany has deployed significantly more HRS than other countries, yet demand for hydrogen is yet to meet this (given the correspondingly high number of FCEVs), with an estimated utilisation of 26 kg of H_2 a day at each HRS.
- Based on these estimates, of the countries & regions considered below, HRS in France and Scandinavia currently see the highest levels of utilisation. In France, this reflects the "captive fleet" deployment strategy where HRS are built in response to local demand for FCEVs in fleet applications, clustering and fewer FCEVs than Germany.

Region	**Germany**	**France**	**UK**	**Scandinavia**	**Benelux**
Number of FCEV cars	1,236	396	235	521	576
Assumed demand per FCEV car (kg/day)	2	2	2	2	2
Number of FCEV vans	16	273	7	-	15
Assumed demand per FCEV van (kg/day)	0.1	0.1	0.1	-	0.1
Total demand per day (kg)	2,473	819	470		1,153
# of HRS for cars and vans	94	4	8	22	15
Average daily demand per HRS (kg)	**26**	**205**	**58**	**47**	**77**

Scandinavia includes data from Denmark, Norway, Sweden, Iceland and Finland. Note data in table is to September 2022 with more vehicles being shipped to the countries and some earlier model fuel cell vehicle retirements over time.

Key findings from utilisation of HRS networks:
Analysis of H2ME stations deployment

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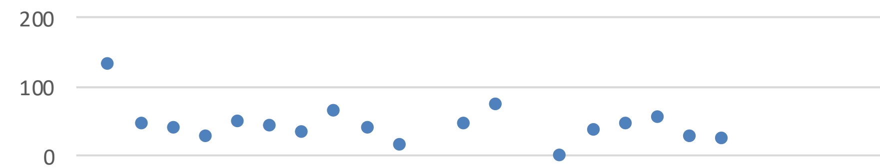
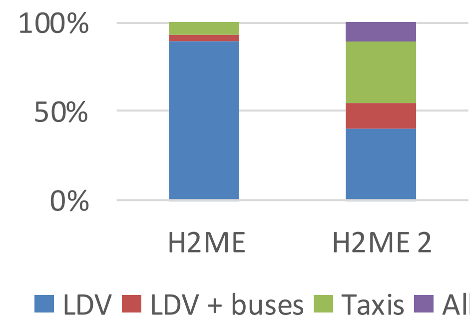
The HRS are increasing in dispensing and back to back capacity to prepare for higher and more demanding operation

- **On average, the current number of dispensing events and H2 dispensed remains low over time.** The graph on the right illustrates the average amounts dispensed per month compared to the time of operation for the stations.
- **This is expected to improve over time as business cases emerge** to support the commercial operation of HRS. This is reflected in the increasingly varied type of users for **the HRS in the projects, which have transitioned from HRS mainly designed to cater for LDV to HRS designed to cater for higher utilisation and heavy duty applications** – increasing daily dispensing capacity as well as back to back capacity.
- **This approach has proved successful in the project, with HRS catering for taxi vehicles having significantly increased their utilisation level in the course of the project.**
- However, the majority of HRS still have utilisation levels below 20%, with only 10% of the HRS in the projects with utilisation level above 30%.

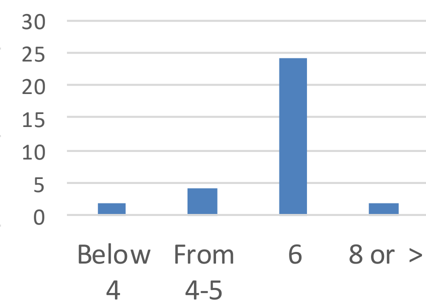
Average kg H2 dispensing during time in operation (for a subset of stations)



Main vehicle type using stations or planned for stations of H2ME 1 and H2ME 2 projects



Back to Back Refuelling



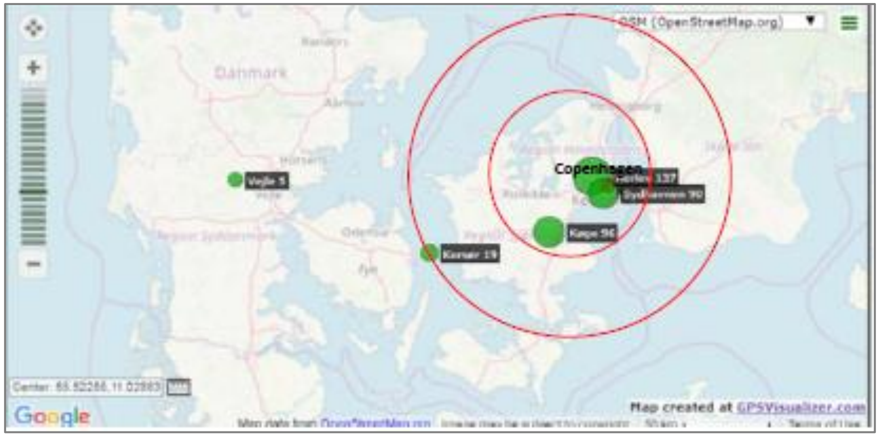
Clean Hydrogen Partnership

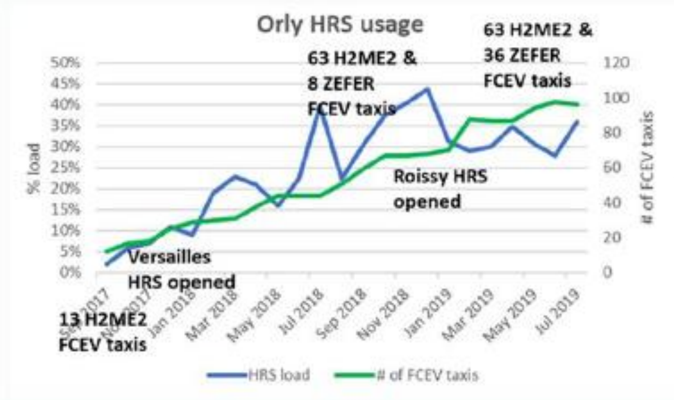
Source: data H2ME projects, Element Energy, 2022

Key findings from utilisation of HRS networks
Local insights

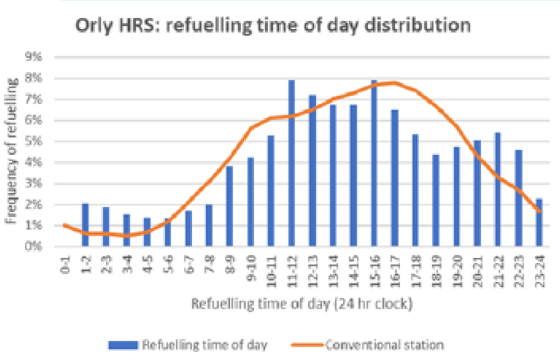
In Denmark, we can observe the influence of the HRS network on distance driven. The map shows the FCEV's refuelling behaviour :

- ~ 2/3rd of its hydrogen was refuelled at two Nel stations in Copenhagen.
- The remaining 3rd was refuelled at 3 other stations in the Danish HRS network.
- The Danish refuelling network allows the vehicle to travel considerably beyond Copenhagen.





In Paris, placing a number of taxis in a network of multiple HRS increases overall network utilisation.



- The load at Orly (H_2 dispensed as a % of its rated capacity of 200 kg/day) rose from 2% in Sep. 2017 to ~45% in Aug. 2019 but then fell back as less travel occurs in the COVID pandemic.
- Taxis in Paris refuel 24/7, which also spreads the load throughout the time period, resulting in a similar overall refuelling profile to conventional fuelling stations.

Source: Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), D4.12, Cenex

HRS availability is generally improving over time, but sustained efforts are needed to ensure this continues as more new suppliers enter the market

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Overview of availability issues

- To ensure that customers can fully utilise the capabilities of FCEVs, the amount of time that each HRS is fully operational and available for customers to refuel (i.e. the **availability**) should be maximised; the H2ME initiative **aims to achieve an average HRS availability of over 98% by 2022** across all the HRS in the project (excluding planned maintenance).
- The availability of the public HRS deployed to date varies, and not all stations currently meet this target. It is **common for HRS to experience a 'teething period'** when various technical issues need to be addressed after the opening of the station, and in some cases after significant upgrades have taken place. Availability tends to improve as the total volume of dispensed hydrogen increases and issues arising during the 'teething period' have been addressed.
- Some HRS operators with experience of operating multiple HRS for several years have started to observe improvements in station availability for new stations (compared to previous models from the same supplier), suggesting that design and operational improvements are being implemented as a result of the experiences of early stations. Best practices should be shared widely wherever possible to ensure that HRS from new suppliers and operators also have high availability.
- **Some components (compressors and dispensers) are particularly unreliable or prone to damage** (including damage by mishandling by users), and further development of the supply chain is needed to produce more reliable and robust components.
- Vehicle manufacturers have identified **improvements to station availability as a high priority** and critical to the commercialisation of hydrogen mobility. Problems with isolated stations could cause disruption to customers and reputational risks, particularly as in the early stages of HRS network development there may be limited alternative locations for customers to refuel nearby should issues arise.




Clean Hydrogen Partnership

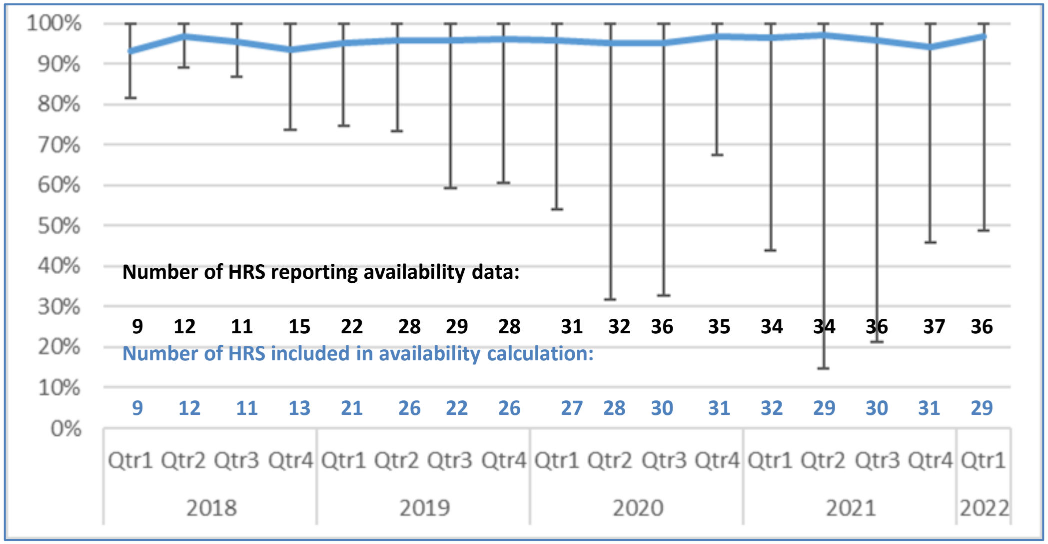
Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

Data from the selection of HRS monitored in the project shows that while many HRS are performing well, some still have relatively low availability

HRS availability data

- 24 HRS are currently reporting availability data to the H2ME and ZEFER projects. Quarterly availability is defined here by the percentage of time that the HRS can dispense hydrogen, excluding planned maintenance.
- The project average HRS availability is currently 96% across the 24 HRS. By Q4 2021, one third of HRS had 98% availability.
- However, as shown by the range bars on the chart, the availability of some HRS is as low as 75%. This is partly a result of several new HRS coming online in recent months and beginning to provide availability data during the 'teething phase'.

HRS availability across the H2ME and ZEFER projects[1]



- Average availability across HRS is shown by the blue line. This average excludes stations with lower than 80% availability in the quarter, as this is generally due to one-off issues.
- In Q2 2020 onwards, the availability of some stations was affected by the impacts COVID-19 (e.g., from restrictions to maintenance activities), with availability still lower than that seen in 2018.

[1] Cenex analysis of data reported by refuelling stations across H2ME, H2ME2, and ZEFER projects. Note that only 2 of the stations are within the ZEFER project.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

HRS with low utilisation after opening are prone to lower availability than HRS with high utilisation

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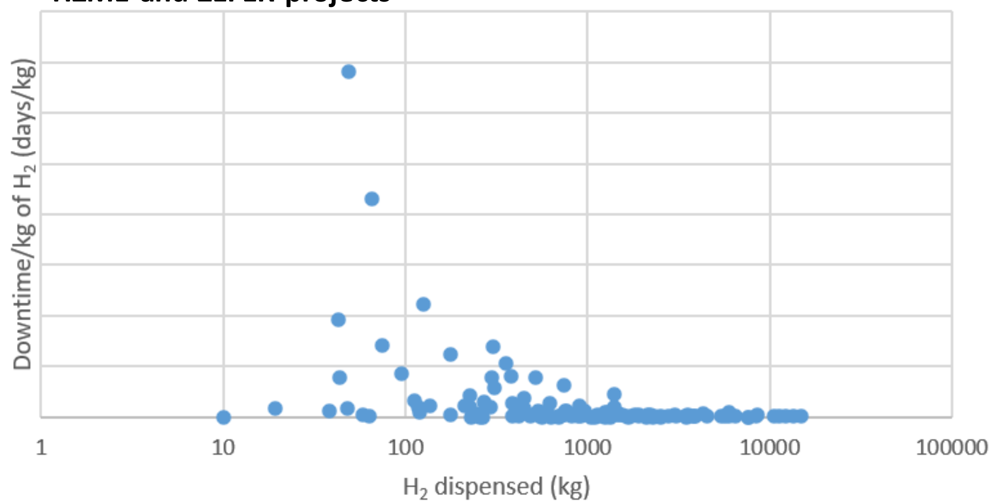
Utilisation and availability

- Many of the HRS providing data to the project have seen relatively low levels of utilisation, which can lead to lower availability. The reduced frequency of problems as utilisation of equipment increases is a well-established effect, known as the ***bathtub curve***. Low levels of utilisation can be detrimental to some HRS components which function best when highly utilised; furthermore, if there is a bottleneck for supply of maintenance or spare parts, stations with lower utilisation may be less of a priority in terms of maintenance and addressing issues, compared to very busy stations.

Downtime per kg hydrogen dispensed for specific HRS across the H2ME and ZEFER projects[1]



- The chart (above right) shows, for each HRS in the project, the downtime days (adjusted for total dispensed hydrogen) against the total hydrogen dispended by the HRS, showing that as the total utilisation of an HRS increases beyond 100 kg, the downtime per kg dispensed reduces dramatically: i.e. the availability increases.
- The H2.LIVE map specifies when HRS are in the 'optimisation phase' (i.e., when the HRS has just opened and the volume of H_2 dispensed is very low, and issues are more likely to occur). When HRS are in this phase, the map displays the following message: *"Almost there! This station is in optimization phase – a standard procedure that we carry out at all stations in order to give the plant the final polish. The station is available for refueling. We are looking forward to your feedback."*

[1] Cenex analysis of data reported by refuelling stations across H2ME, H2ME2, and ZEFER projects

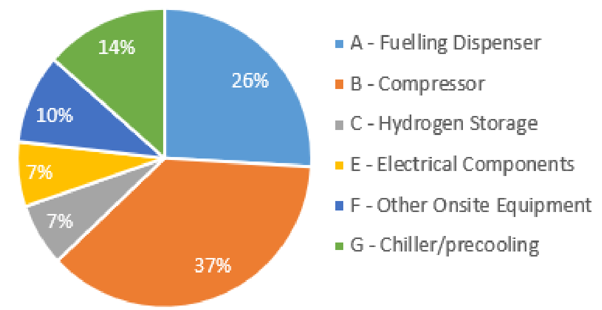
Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

Problems with compressors and dispensers cause the majority of downtime; HRS suppliers should consider including redundant components for future large HRS

Causes of downtime and potential solutions

- Data has been collected on the causes of downtime for the HRS in the project and is summarised in the chart (right). Note that electrolyser downtime is not included, to preserve anonymity for the HRS suppliers in the project. Problems with compressors and dispensers cause the largest share of total downtime, accounting for >60% of total HRS downtime combined. This suggests that **significant improvement in reliability and supply of these components is needed to improve the overall availability of refuelling stations**.
- For fleet users, high HRS reliability and availability is critical to ensure that fleets can carry out their operations as normal.

HRS downtime hours by reported category (H2ME and ZEFER projects, 2018-2020)[1]



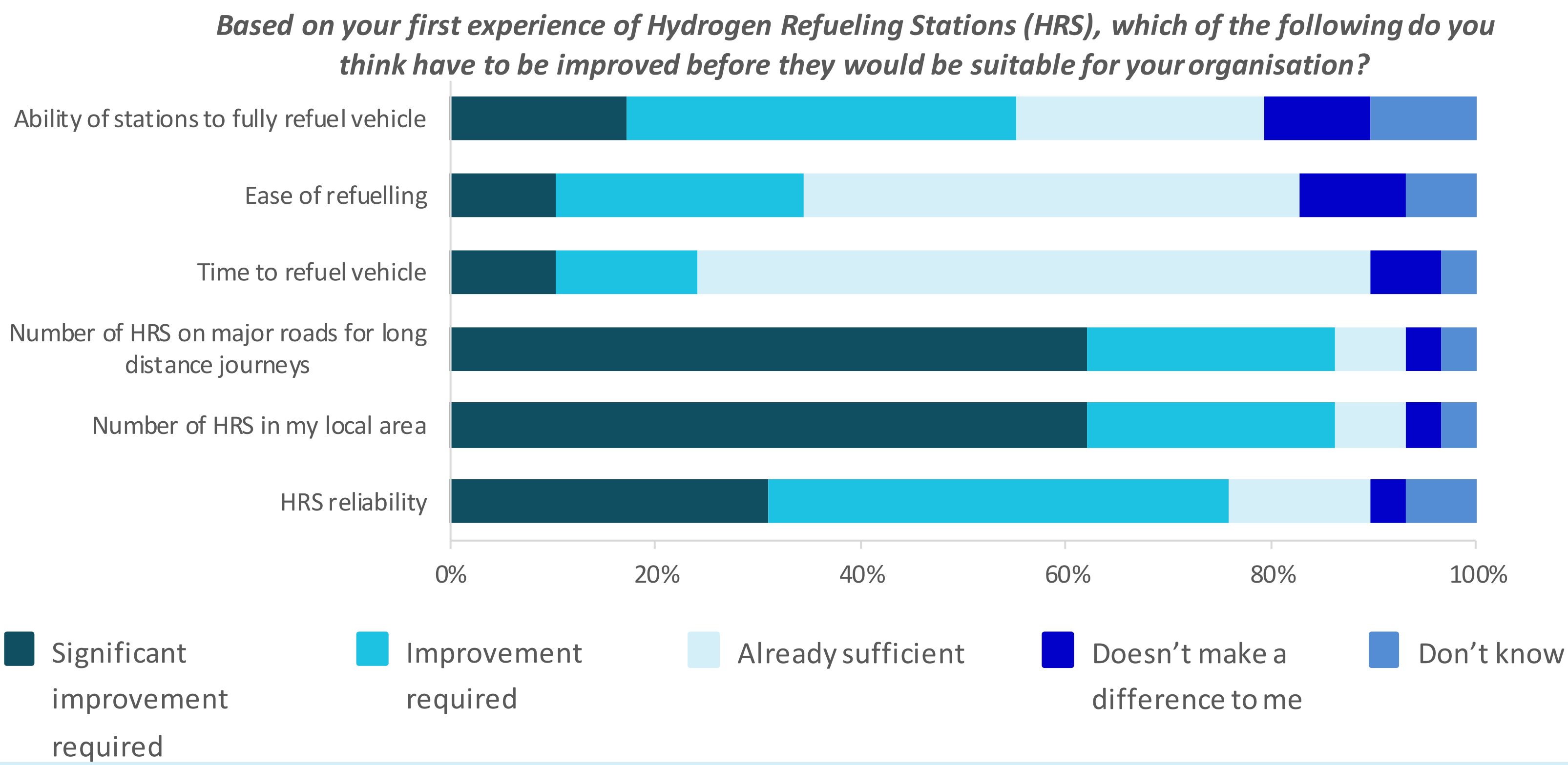
- Refuelling needs vary; buses, refuse trucks and other 'back-to-base' truck applications are likely to have predictable refuelling times, often refuelling in the early morning or late at night. Taxis and long-haul trucks are more likely to refuel throughout the day, although certain times will be more popular. **HRS operators need to ensure that HRS availability is high during the typical refuelling period and should schedule any preventative maintenance or repairs around this.**
- Options for deploying several HRS not too distant to provide redundancy at the network level can be a solution but this requires additional investments. Short-term redundancy while maintenance is underway can be facilitated by fitting larger H_2 pressure arrays.
- In some cases, issues may be caused by a low user's experience with refuelling procedure and wrong manipulation or connection.
- The NewBusFuel project (2015-2017) identified several recommendations for bus refuelling infrastructure that will be relevant in providing solutions to HRS availability for fleets[2]:
  - **Reliability can be improved by including additional (redundant) components**, but this increases capex and footprint. Integrating redundant components is more cost-effective for larger HRS, and HRS designs based on smaller modules.
  - **Standardisation of designs** can help to make maintenance and repairs more efficient.
  - For a small fleet of H_2 vehicles, using fossil fuel vehicles as a back-up option may be a more cost-effective alternative to installing and operating an HRS with very high availability.

[1] Cenex analysis of data reported by refuelling stations across H2ME, H2ME2, and ZEFER projects

[2] Adapted from NewBusFuel High-Level Techno-Economic Project Summary Report, Thinkstep, 2017 – Available here

Improvements to HRS required for future use

Fleet operators interviews



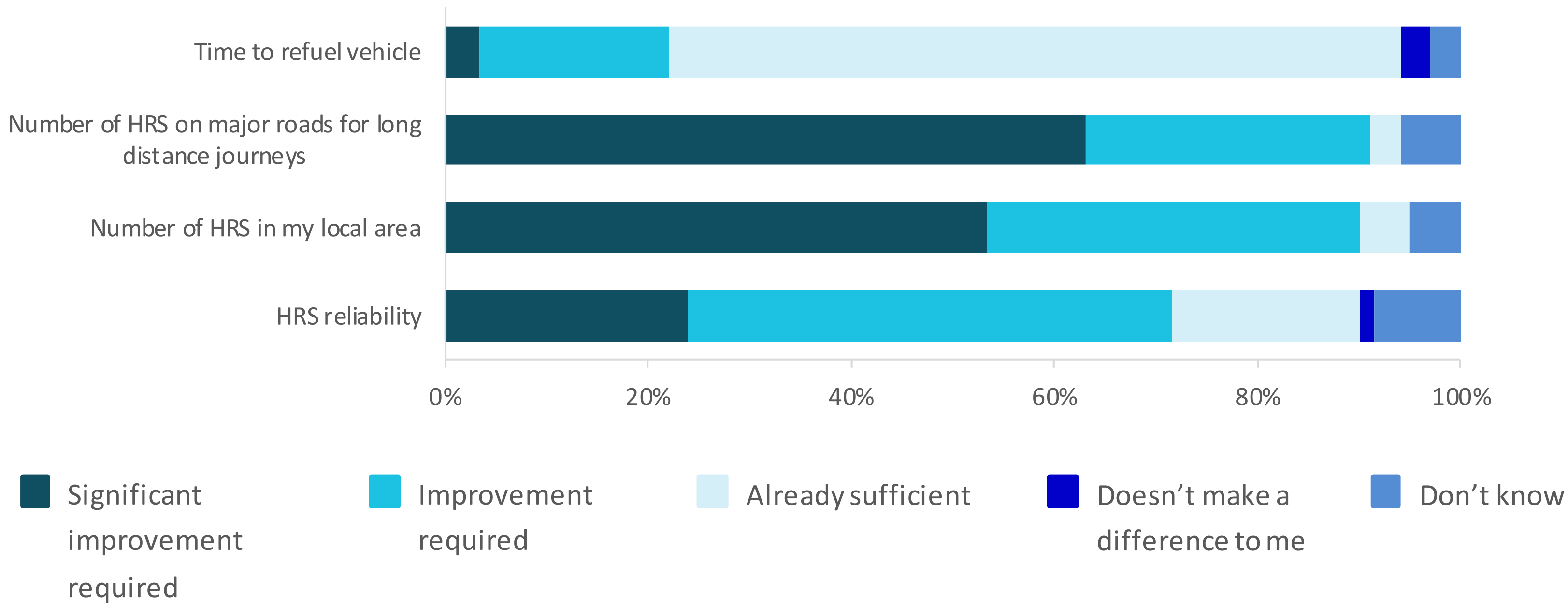
- **Numbers of stations in local areas and along major roads** were identified as the two areas **requiring most improvement** amongst fleet operators, with over 86% of operators stating these aspects need to improve. It is notable that va**n operators disproportionately felt that significant improvements to numbers of HRS were required; this suggests that, due to the fact that the operating area is typically more dispersed, a more comprehensive level of HRS coverage is needed for van fleet operators, compared to e.g., taxi operators in city centres.**
- **HRS reliability was also frequently considered to be an area where improvement is needed, although to a lesser extent compared to number of HRS.**

Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME (2) Deliverable 6.21. Element Energy

Improvements to HRS required for future use

Fleet drivers interviews

Based on your first experience of Hydrogen Refueling Stations (HRS), which of the following do you think have to be improved before they would be suitable for your organisation?



- Similarly to fleet operators, fleet drivers identify **number of HRS in the local area and on major roads** as the two characteristics requiring the biggest improvements with regards to HRS network development and the refuelling process.
- 72% of drivers felt that the **reliability of HRS required improvement** for them to be suitable – a higher proportion than for fleet operators. This could be because fleet operators are less likely to personally experience the impact of reliability issues.

Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME (2) Deliverable 6.21. Element Energy

To create sustainable networks, growth and performance criteria must be balanced with the need to operate cost-effectively

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Overview of issues for HRS business cases

- To support the continued commercialization of hydrogen mobility in Europe, HRS operators need to balance the following key objectives for refuelling stations:
  - Installing enough HRS to provide sufficient **coverage** of the operating area for their target market;
  - Providing a high quality service to customers: crucially, this means providing high HRS **availability** to ensure that customers have access to hydrogen when required, and communicating HRS availability to customers;
  - Ensuring that **fixed and variable operating costs are not prohibitive** to the long-term business case, e.g., by JVs between equipment suppliers and operators, growing the network and demand in parallel, and growing demand from HDV fleets).
- The business case for public HRS operators can be challenging for several reasons:
  - **In the absence of demand commitments from customers, investment in new HRS is risky** due to the uncertainty of future demand growth and the high costs of current HRS capex and opex; consequently, many HRS operators take a 'demand-led' approach to network growth. Uncertainty over the **future supply of vehicles, and value of H_2** (low carbon H_2 in particular) contributes to the risk; policy setting out **clearly defined cost support for low carbon H_2 and vehicles** can help to address this.
  - **Overall utilisation of public refuelling networks is low** compared to installed capacity during the early years of deployment: even in areas of relatively high FCEV deployment (e.g. Paris, London, Hamburg) average levels of HRS utilisation only recently exceeded ~30% of capacity. As overall FCEV deployment starts to ramp up, the need for high availability and customer support increases, and so do the associated HRS operator costs. Initially these costs may be high relative to the overall revenue, but as the total number of customers and HRS increases, these processes become more efficient and the associated operating costs become less significant to the overall cashflow. However, the **costs of high HRS availability and customer support should be minimised** going forwards.
  - **Access to low cost, low carbon, fuel-cell quality H_2 is currently limited**. Some HRS operators and suppliers focus on the provision of electrolytic H_2 from renewable electricity; this is generally more costly than H_2 produced as a by-product of chemical processes, or from reformation of methane, due to the relatively high cost of electricity compared to methane. However, new approaches to cost-effectively supply low carbon hydrogen are now starting to be demonstrated in Europe.

The following pages set out emerging business case approaches and remaining issues to be addressed.

Two emerging trends for business case: emphasis on larger HRS that can refuel heavy vehicles and on renewable hydrogen

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Emerging trends

The following trends will have implications for future HRS business cases:

- **Shift towards higher capacity refuelling stations serving heavy-duty vehicles**
  - The Hydrogen Mobility Europe partners have refined their business cases for HRS deployment based on the lessons learned over the course of the project, and on the development of the FCEV market in Europe. For many of the national hydrogen mobility initiatives, the focus in the past decade has been on installing as many individual public HRS as possible. However, the next phase of European HRS deployment in the early 2020s is shifting to the development of **fewer, higher capacity HRS** (as opposed to a large number of smaller stations focused on LDVs), targeting HDVs as the main users of these stations. Larger stations can offer economies of scale compared to smaller stations and therefore can provide a stronger business case to the HRS operators[1]. However, gathering sufficient demand for such stations is critical.
- **Increased ambitions for supply of renewable hydrogen**
  - In parallel, national governments in Europe increasingly see a key role for hydrogen technologies as part of a net-zero future. Many have published hydrogen strategies emphasising their ambitions to increase the capacity of renewable hydrogen production, and its use for transport. Currently, hydrogen from low-carbon production routes (including renewable hydrogen) is more costly than hydrogen produced from fossil fuels, and many refuelling stations in Europe still dispense fossil hydrogen.
  - To maximise the potential benefits of hydrogen mobility there is therefore a **need for a stronger business case for refuelling stations to supply renewable hydrogen**; in the short term, national policy support is needed to help achieve this.

[1] Further details can be found in: H2ME D5.13 – Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020. Available at: https://cordis.europa.eu/project/id/671438/results and https://h2me.eu/reports/

High capacity stations have the potential to be more profitable, but confidence in future demand is critical

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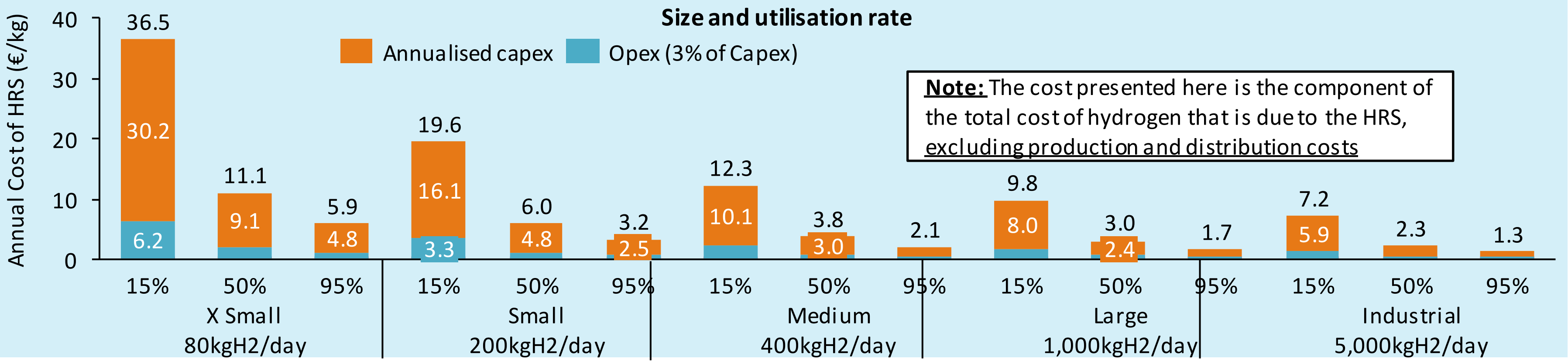
Business case impacts of HRS capacity and utilisation

- Refuelling station costs do not scale with hydrogen output when the costs of hydrogen production and distribution are excluded. The implications of this on the cost of dispensed hydrogen are illustrated by the graph below (adapted from the Hydrogen Mobility Ireland public report), which shows the cost added to the price of hydrogen at the refueling station, for different station sizes and utilisation rates. It demonstrates that spreading the costs of a larger HRS over its far higher hydrogen throughput significantly reduces the costs that must be recovered from each kilogram sold, compared to a smaller HRS: i.e. **larger hydrogen refueling stations with high utilization have significantly lower costs per kilogram of hydrogen.** This is well-recognised across the industry (e.g., as discussed in the New Bus Fuel final report, p25 and in previous H2ME reports); combined with the relatively slow roll-out of hydrogen cars and vans in Europe, this has led to hydrogen mobility strategies seeking to focus more on heavy-duty fleets (trucks and buses) to provide the anchor demand for new HRS.

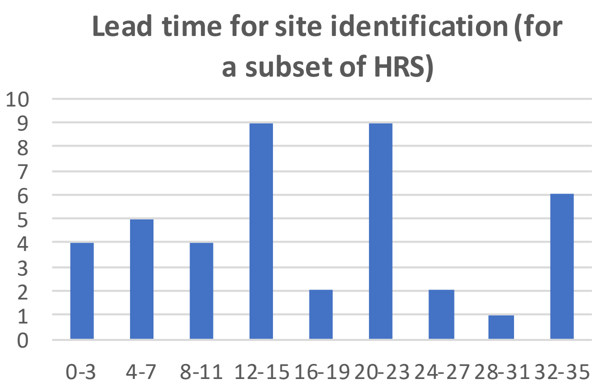


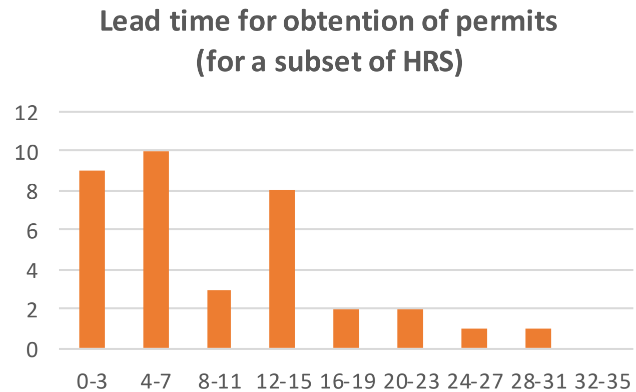
- For stations used by fleets, very high availability is essential; one way to achieve this is through redundancy of key components such as compressors and dispensers[1]. Combined with the higher capacity, this means that the capital investment needed for such HRS will be much higher than for many existing public HRS. **Confidence in sufficiently high HRS utilisation and revenues will be essential to attract investment**; some possible approaches are explored on the next page.

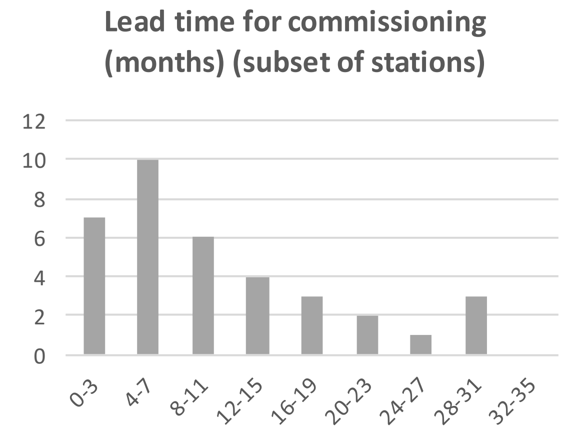
[1] Ref: New Bus Fuel D4.2, High-level technoeconomic summary report, 2017. Available here: fuelcellbuses.eu/sites/default/files/documents/NewBusFuel_D4.2_High-level-techno-economic-summary-report_final.pdf

Sitting, permitting and building
Analysis of H2ME stations deployment

HRS sitting and permitting remains time consuming, while commissioning is a more streamlined process







- Finding a suitable site can be complex. The main cited reasons for long lead time for confirming sites are: contractual discussions for land usage, discussion with DNO for grid connection upgrade (electrolyzer), additional studies required due to surroundings, change of sites after initial selection due to unforeseen complications (e.g. change of plan for land usage, issues with permits etc.)

- Lead time for permits can vary significantly. On average, permits are obtained following after 8 months in most locations with the exception of France with average lead time of 12 months for obtaining permits.
- While it is expected lead time for permitting might decrease as the technology is more widely understood by authorities providing the permits, sites might require increasingly complex applications as options for easier sites are reduced and while the footprint of stations is increasing to support mixed usage.

- Building and commissioning of the HRS is generally the faster phase of the installation process. On site electrolyzer HRS typically require 25 to 50% more time to be built compared to HRS with H2 supplied by trucks. This is due to more complex equipment and civil works.

Source: data H2ME projects, Element Energy, 2022

Case study: Experiences and lessons learnt from a national HRS network implementation in Germany (H_2 Mobility Deutschland)

Hydrogen refuelling station installation process

- Since its inception in 2015, H_2 Mobility Deutschland has decreased the total period of time to deliver an HRS from 24 down to 16 months, with an end target of 12 months

- A number of challenges makes reducing lead time difficult:
  - **Location**: various criteria for network planning ; the number of different stakeholders involved; constructional constraints (space, noise, etc.)
  - **Permitting**: lack of standardised permitting process with authorities - regional differences in Germany lead to unpredictable lead times
  - **Delivery time of HRS**: immaturity in the supply chain results in delivery time of 9-10 months from HRS suppliers as well as limited capacities
  - **Resource bottlenecks**: Requirement for OEM approval and vehicle testing at each station can delay commissioning process

Lessons learnt have been recorded and guidance documents (DE)| (EN)| (FR) developed to help new-comers to the HRS installation process. Work is on-going in addressing the challenges identified.
Sources: H_2 Mobility Deutschland, Element Energy, France Hydrogène

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project interim 2020, H2ME (1) Deliverable 5.12, CONFIDENTIAL, Element Energy

Case study: Preparing for a national infrastructure network (Germany)

- A 2017 Study by Shell found that the **number of FCEVs in selected markets could exceed 100 million by 2050** and would reach the **20 million threshold in the 2030s**.
- As the market for vehicles increases, this will justify commercial deployment of hydrogen stations to expand the network.
- Despite high initial rollout costs due to low utilisation which harms their economics, **analysis suggests that an hydrogen infrastructure scales better than competing zero emission technologies**, both in terms of infrastructure costs and logistics (e.g. additional load on the grid).

2018 study from Jülich – Infrastructure costs comparison for battery and hydrogen vehicles

- It found that the **hydrogen infrastructure works out cheaper as of 1 million vehicles** and that a battery charging network is more cost intensive than hydrogen in the long term.

Infrastructure cost / national fleet size	up to 100,000 vehicles	From 1 million vehicles	From 20 million vehicles
For Battery vehicles	~ EUR 310 million	~ EUR 2.8 billion	~ EUR 51 billion
For Hydrogen vehicles	~ EUR 450 million	~ EUR 1.9 billion	~ EUR 40 billion

Sources: Shell, Jülich.
https://www.shell.de/medien/shell-publikationen/shell-hydrogen-study.html#vanity-aHR0cHM6Ly93d3cuc2hlbGwuZGUvaDJzdHVkaWUuaHRtbA
http://h2-mobility.de/wp-content/uploads/2018/01/Energie-und-Umwelt_408_Robinius-final.pdf

Minimising the frequency and impact of safety incidents at HRS is vital for the successful commercialisation of hydrogen mobility

Overview of HRS safety

- The successful commercialisation of hydrogen mobility will rely on achieving a certain level of **public confidence** in the technology, including safety aspects.
- As such, the **frequency of incidents should be minimised**, and when they do occur (however rare), it is important that HRS operators and suppliers are prepared, both in terms of taking all necessary steps to contain and address issues, and also in terms of how incident (and the measures taken) are **communicated externally**.
- Currently, at the European regulatory level, only sites with over 5 tonnes of hydrogen are required to report safety incidents. Incidents (including 'near misses' and cases where no hydrogen is released) can also be reported to the Hydrogen Incidents and Accidents Database (HIAD) on a voluntary basis.
  - According to the European Hydrogen Safety Panel (EHSP), the total number of events reported in HIAD in 2018 was 272 (155 of which were in Europe). Of these, 7 incidents related to HRS.
- The EHSP extracted the following findings based on incidents reported to HIAD:
  - Overall, the overarching lesson learnt is that accidents might consist of several causal events that, if occurring separately, might have little consequences; but if these minor events occurred simultaneously, they could still result in extremely serious consequences. Fault analysis allows for safe designs.
  - Accidents are often initiated under special conditions, like maintenance, revision or restart after changing the system. Most cases are attributed to the human factor (wrong design, wrong operation). By recording and conveying lessons learned, the industry can adapt its processes.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

Nordic region: experiences following the incident at Kjörbo emphasise the importance of safety processes and redundancy

Reasons for HRS shutdown in Nordic regions

- The majority of Scandinavian HRS have been operated by two companies: Uno-X (whose stations are supplied by NEL) and previously HYOP.
- In September 2018 HYOP closed its network of refuelling stations in Norway (following their bankruptcy), meaning that all the open HRS were supplied by NEL.
- In June 2019 a NEL station in Kjörbo, Norway experienced a hydrogen leak which led to a fire. NEL responded rapidly to ensure that all appropriate measures were taken to avoid escalation or further safety incidents. Following the incident, all HRS with the same design were closed so that inspections and verifications could be carried out. This included the only three stations in Iceland, leaving the island with no way to refuel its FCEVs.

Lessons learned

- The impact of the HRS closure on the overall networks in Nordic regions shows the importance of redundancy in station design in HRS networks. This will minimise the impact of financial or technical issues on network availability, and the resulting damage to the reputation of H_2 in these regions. By having different HRS suppliers, systemic errors are less likely.
- In addition, this emphasises the need for vigorous training and safety processes that encompass the design, assembly, and operation of HRS, as well as well-established procedures for responding in the event of a safety incident.

Uno-X and NEL station in Norway
Source: adressa.no

HYOP station in Norway
Source: hyop.no

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Implementation of rigorous safety processes and checks is an essential part of HRS installation and operation

Summary of recommended best practices on HRS safety

HRS and component design

- Avoid 'overdesign'. Equipment should be designed so that any **failures can be detected at the testing stage**.
- One cause of leakages in Japan and the USA is **poorly planned fatigue**. Considering the incidents in EU, Japan and the USA, it is very important to adequately consider operational conditions in the design; compressor induced vibrations are a key example that should be accounted for.
- Some leakage events are caused by **screw joints and inappropriate sealings**. If welded joints are to be used instead, do careful statistical checks of weldings and control certificates and capabilities of suppliers. Obtain data on the strength of welded parts and develop technology and techniques for improving quality of welding of hydrogen compatible material and reducing the pipe thickness.
- Be aware of differences between specifications and standards between different markets (e.g. North America / Europe) – this can cause issues if not identified early.

HRS installation and operation

- Insist on fully documented quality control, appropriate checks and prompt documentation of installation (and upgrade) procedures.
- Develop and implement thorough quality control processes and checks (e.g. regular leak tests). Training procedures should include appropriate testing to ensure capability.
- Implement a Safety Alarm Plan in response to sensor conditions and ensure that this is kept up to date following any changes.
- Carry out Emergency Response training for first responders (both internally and with local Emergency Services).
- Ensure that contingency plans are in place setting out clear actions in the event of an incident.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

While progress has been made on HRS commercialisation, there is a clear need for further development of the supply chain and harmonisation across the network

Conclusions on HRS issues (1/2)

Based on the information in this report, initial high-level conclusions on HRS issues are summarised below. These conclusions will continue to be refined in future iterations of this report as part of the H2ME2 project.

Siting and permitting

Continued efforts are needed to identify sites and gain planning approvals. Future HRS may require more space, to enable higher capacities, meaning that partnerships with existing fuel providers will have increasing strategic importance.

Communication with customers

Widespread provision of data to consistent maps and apps will be the key to providing network visibility; alongside this, harmonisation of access, billing and services such as 24/7 helplines at HRS help to optimise the customer experience.

Technical performance

Following significant efforts by HRS operators to optimise maintenance and functionality, further work is needed to ensure wider adoption of best practices and to ensure that components are reliable, user-friendly and cost-effective. Vehicle tanks are often fuelled fully to limit range anxiety. Whilst the percentage of successful refuelling events (where the tank is filled to >92% of capacity) is increasing over time, continued work is needed to understand fully the causes and potential solutions of station downtime and incomplete refuelling events.

Safety

Best practices on HRS safety (including quality assurance processes and contingency measures) must be widely disseminated and adopted to minimise the risks associated with hydrogen as a transport technology.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

As business cases shift towards targeting fleet vehicles & heavy duty applications, there are further opportunities to learn from the experiences of HRS operation for buses

Conclusions on HRS issues (2/2)

Business cases

The next phase of European HRS deployment is shifting to the development of fewer, higher capacity refuelling stations targeting heavy-duty vehicles as the main users. Larger stations can offer economies of scale and therefore can provide a stronger business case to HRS operators. However, gathering sufficient demand for such stations is critical. HRS deployments based on local demand aggregation will be needed to support the continued roll-out (and operation) of public HRS networks. In addition, improvements to component supply and reliability could help to reduce the costs associated with HRS operation (with high technical performance) at low demand.

The role of policy

Future HRS business cases will rely on the accelerated scale-up of fuel cell vehicle fleets, especially in heavy-duty applications. This will require national subsidies and incentives for all vehicle types alongside incentives for low carbon hydrogen and disincentives for fossil fuel vehicles. Local governments and transport authorities can play a role in reducing risk, especially for public fleets such as buses and refuse trucks, by acting as a financial intermediary between the fleet operator and the hydrogen retailer.

Cross-cutting considerations for future HRS

Some of the refuelling requirements of heavy-duty fleets will reflect the aims of the public HRS deployed to date, but there are some differences (e.g. refuelling schedules, user groups, use cases) that will impact the specifications and design for HRS focusing on these fleets. Comparisons of light vehicles with bus fleets can provide examples of some key similarities and differences. As such, HRS suppliers and operators for future stations can draw from experiences of hydrogen bus projects such as NewBusFuel, JIVE and H2Bus Europe, combined with the solutions adopted in H2ME, to ensure that the most relevant best practices and insights are applied to future HRS.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

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Commercialisation status for green H2

- Potential for green hydrogen
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- National subsidies or fuel credits

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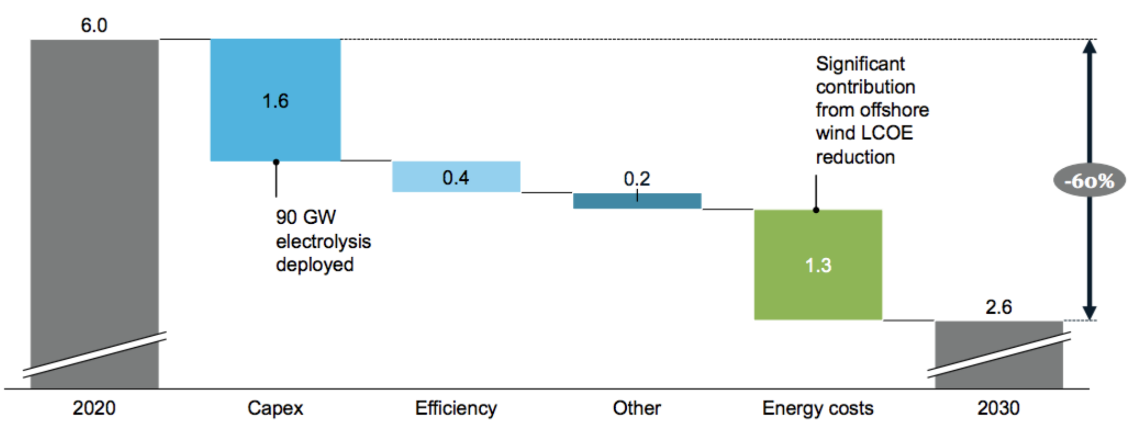
- Source of H2 production for H2ME HRS
- FCEV Well to Wheel emissions
- Perceived FCEV Well to Wheel emissions before and after use
- Benefits of electrolyzers in grid operation

Potential for green hydrogen production in Europe

Renewable hydrogen is expected to benefit from low electricity price in Europe with competitive costs for green hydrogen production by 2030. The green transition may speed-up due to the Russian invasion of Ukraine.

- **Today, 5% of the H2 produced globally comes from renewables sources** (either electrolysis using low-carbon power or natural gas reforming and coal gasification combined with Carbon Capture Storage (CCS) technologies).
- However, recent cost reductions in low-carbon technologies **have significantly reduced the cost of green hydrogen production**. In parallel, **grey hydrogen** by natural gas reforming or coal gasification is expected to become increasingly **less competitive** over time as the cost of CO_2 emissions increases.
- Since 2010, the **cost of electrolysis has fallen by 60%,** from USD 10-15/kg of H_2 to as low as **USD 4-6** today. Offshore wind-based electrolysis shows another **60% cost reduction between now and 2030**, mainly due to larger-scale manufacturing of electrolysers and expected offshore wind prices reduction.
- Green hydrogen production costs varies significantly across regions. **Northern Europe is likely to benefit from very low electricity prices that could enable production of renewable hydrogen at USD 2.6/kg in 2030**.

Cost reduction lever for hydrogen for electrolysis[1] connected to dedicated offshore wind in Europe (average case)
USD/kg hydrogen



1. Assume 4,000 Nm3/h (~20 MW) PEM electrolysers connected to offshore wind, excludes compression and storage
2. Germany assumed

SOURCE: H21; McKinsey; Expert interview

Source: Path-to-Hydrogen-Competitiveness, Hydrogen Council, 2020

Key barrier to the increased supply of low carbon hydrogen at refuelling stations

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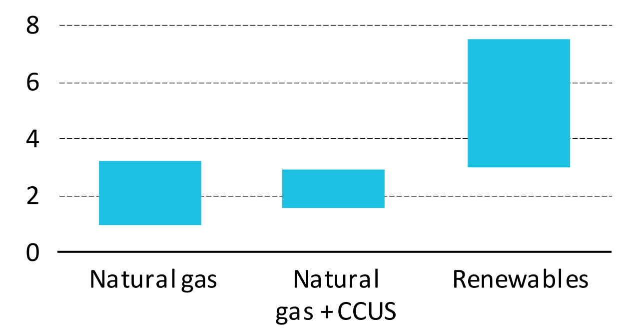
Renewable hydrogen is currently expensive, presenting a further challenge for the HRS business case

- Many existing HRS in Europe dispense hydrogen produced via industrial-scale reforming of fossil fuels. This production route is currently the most cost-effective way of producing hydrogen, and accounts for most of the existing hydrogen consumption today. However, hydrogen can be produced via several routes resulting in a low emissions intensity. The following low-emission production routes are already used to supply some HRS across Europe, to varying extents:
  - Electrolysis using electricity with a low emissions intensity (e.g., from renewables or nuclear power)
  - Reforming of biomethane (where the biomethane has a certified overall emissions intensity)
  - Reforming of natural gas with carbon capture and storage or carbon capture & utilisation, though NG prices have risen hugely since 2022.
- However, some fleet operators that have trialled low emission routes have expressed reservations about H_2 vehicles in the past, due to the limited availability of renewable H_2; in the context of recent net-zero commitments, fleets are increasingly likely to seek options which are fully aligned with global decarbonisation aims.

Hydrogen production costs in 2018 (USD/kg)

IEA, The Future of Hydrogen, 2019



- The CertifHy project has established a framework for providing Guarantees of Origin (GOs) which document the CO_2 intensity of different hydrogen pathways. This is a necessary first step in addressing the demand for green hydrogen and, when fully implemented, will enable end users to consume certified Green or Low-Carbon Hydrogen all over the European Union.
- However, as shown in the chart above, renewable H_2 production is currently a more expensive option, due to a) the price of electricity and b) the cost of electrolysers (note that purification costs for fuel cell applications are not accounted for here). As renewable generation capacity increases, significantly lower cost electricity is likely to become available, including the potential for direct connections, eliminating grid costs. The cost of electrolysers has reduced significantly in the last few years and will continue to do so with increasing production volumes. **However, there is a need for policy to address the current cost gap by incentivising HRS operators to sell hydrogen from renewable or low carbon sources.**

Ref: https://www.certifhy.eu/; https://www.iea.org/reports/the-future-of-hydrogen

National subsidies or fuel credits for hydrogen can support renewable production of hydrogen mobility as a whole

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Hydrogen Mobility Europe

Policy incentives are needed to scale up demand and unlock the short term HRS business case

- **Fuel credits for renewable hydrogen are needed to stimulate demand and production**
  - The wording of the second Renewable Energy Directive (RED II) gives member states the freedom to support hydrogen produced from renewable sources (biomass and renewable electricity) with higher credit values, either through multiple counting of credits or by including hydrogen as an advanced biofuel. However, currently there are no specific targets for the percentage of hydrogen within transport fuels.
  - Hydrogen Europe (which represents European industry, national associations and research centers active in the hydrogen and fuel cell sector) recommends setting **specific targets for renewable and low carbon hydrogen within transport fuels** and setting **incentives to enable these targets to be met** (e.g. as part of RED II implementation at national level)[1].
  - Policies implemented at national level should aim to ensure that the **dispensed cost of low carbon hydrogen is competitive for vehicle operators,** and **provide visibility on how long subsidies will be available.** Based on the current cost premium of renewable hydrogen (relative to fossil hydrogen and fossil fuels), **fuel credits with a value of around €3-4 per kg of renewable hydrogen** would enable retailers to make it available at a price attractive to operators of heavy vehicle fleets.
- **Future HRS business cases will rely on the rapid scale-up of fuel cell vehicle fleets. Alongside incentives for low carbon hydrogen, this will require national subsidies and incentives for all vehicle types.**
  - Support for low carbon hydrogen can address the fuel cost premiums, but vehicle costs are also a barrier to wider uptake (currently, these have been addressed through provision funding on a project-by-project basis). National purchase incentives that **bring the on-the-road costs of hydrogen vehicles in line with fossil fuel options** are needed to unlock demand from vehicle operators. **Visibility on the planned duration of vehicle subsidies** will help to bring vehicle suppliers the confidence to bring FCEVs to the European market. But specific government-set targets (as in South Korea) are also important to wider growth.
  - Incentives to be applied at the national level could include purchase grants and various tax exemptions; policies similar to those applied to Battery Electric Vehicles are likely to be appropriate, but subsidy levels should account for the current lower maturity of the FCEV market compared to BEVs.

Source: Summary of solutions adopted to resolve outstanding network and precommercial issues around hydrogen fuel retailing, 2020, H2ME (1) Deliverable 2.6, Element Energy

[1] The EU Hydrogen Strategy: Hydrogen Europe's Top 10 Key Recommendations, June 2020 (available here)

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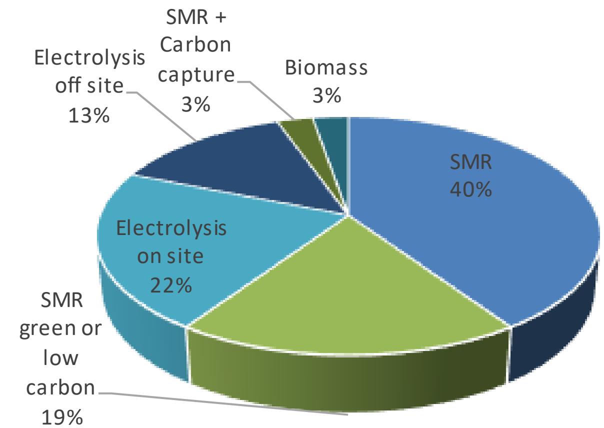
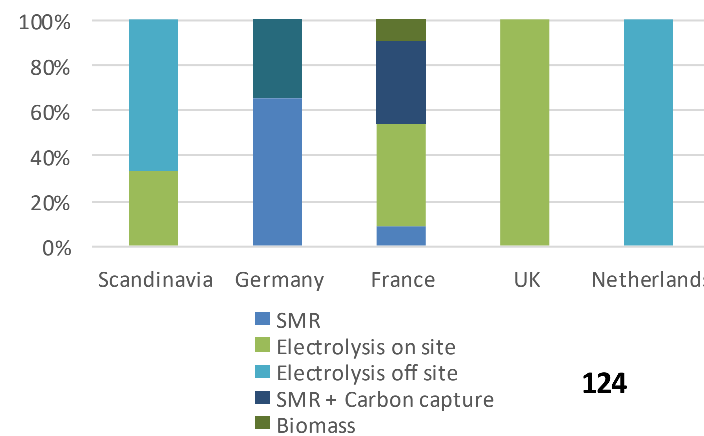
Green H_2 in the project

- **60% of the HRS to be deployed as part of the H2ME initiative are foreseen to be delivering green hydrogen at the pump**.
- In most cases, green H_2 is produced via **electrolysis on site** with an electrolyzer installed at the HRS site. Other options for green or low carbon H_2 is off-site production with decentralised electrolyzers, production via biomass, reforming of biomethane and production by SMR with capture of carbon.
- The H_2 production sources tend to differ for each coalition, as a result of national strategies and CO_2 intensity for the electricity grid.
- **In Scandinavia and the Netherlands, electrolysis off-site is currently preferred**, whereas **electrolysis on-site** is preferred in **the UK and France**. Both presents advantages and disadvantages and may be preferable based on the local context. In more concentrated countries, H_2 may be transported economically to HRS locations while centralised production allows economies of scale as well as can make the permitting process more straightforward at the HRS site. In larger countries, production at the site means transportation is not necessary and can enable stations to provide grid balancing services.
    - The **German HRS** in the project use H_2 made from Steam Methane Reforming (SMR). **Options for green or low carbon H_2 are being rolled out.** This is due to a high percentage of coal-fired electricity in the country compared to other European countries, which makes electrolysis less attractive to achieve environmental goals.
- The proportion of green H_2 dispensed at H2ME HRS has grown over the project execution, demonstrating a motivation and an ability to move towards greener production methods.

Source of hydrogen at the H2ME stations – by production



Source of hydrogen at the H2ME stations – per coalition

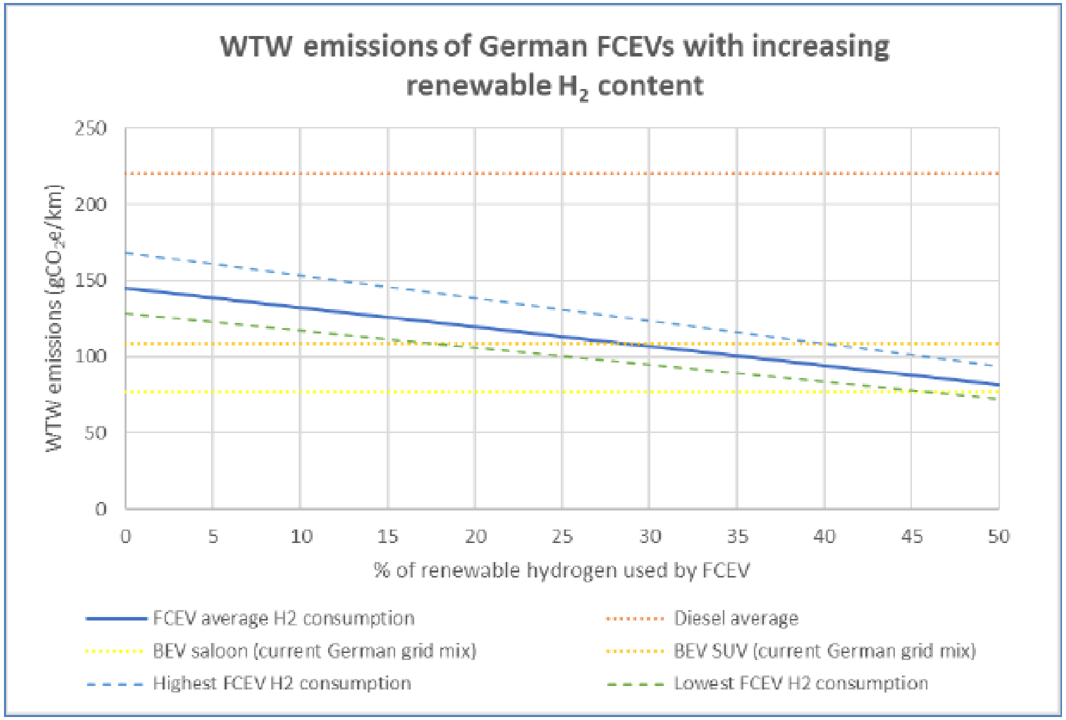


Source: data H2ME projects, Element Energy, 2022

Well-to-Wheels emissions for FCEVs
General considerations

The analysis of Well-to-Wheels (WTW) emissions for FCEVs show the importance of using green hydrogen as well as the benefit of rolling out FCEVs today

- The analysis has shown that **FCEVs achieve significantly lower WTW emissions than diesel or gasoline vehicles even if using fossil (SMR)-derived hydrogen.**
- **Emission savings** compared to diesel or gasoline vehicles **are increased even more significantly when using low carbon or green hydrogen** (e.g., wind- or nuclear-electrolysis-derived).
- Significant low carbon hydrogen content is essential to achieve WTW emissions that are comparable to, or better than, those from battery electric vehicles.
- As emissions from BEVs fall in line with electricity grid decarbonisation plans across Europe, so will the ease and importance of using renewable hydrogen in transport.
- Note that WTW analysis simply considers fuel production, delivery and use. Emissions linked with the production and disposal of vehicles are not taken into account.



- A Life Cycle Assessment (LCA) from concluded that FCEV can have lower CO_2 emissions than any other vehicles, including BEV, if both vehicles use renewable electricity[1].

Source: Well-to-Wheels analysis, 2020, H2ME (1) Deliverable 4.18, Cenex

[1] https://www.ise.fraunhofer.de/content/dam/ise/en/documents/News/190815_LCA-BEV-FCEV_Results_EnglishVersion.pdf

Well-to-Wheels emissions for FCEVs
Country by country analysis – Germany

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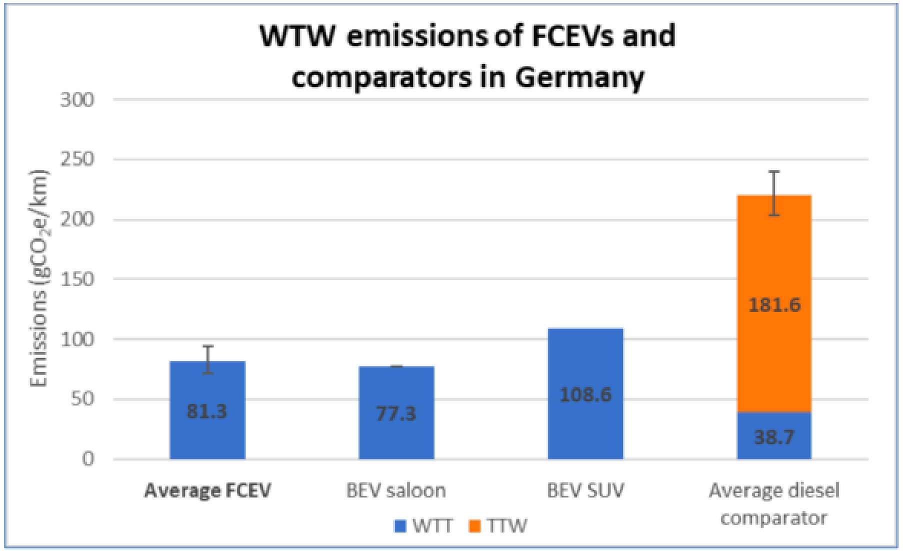
The analysis of Well-to-Wheels (WTW) emissions for FCEVs was conducted for Germany, Denmark and France with BEV and Diesel vehicles

- The countries have different electricity generating mixes with **CO_2 emissions resulting from the amount of renewables/low carbon generation** employed: 474 gCO2e/kWh for Germany.
- For the **FCEVs in Germany, a mix of 50% SMR and 50% wind electrolysis-derived H2 was assumed**, which is H2Mobility Germany's ambition for the H_2 mix at its stations.
- WTW emissions from the FCEVs in Germany were found to be 81 gCO2e/km, compared to 77 gCO2e/km for a battery electric saloon, 108 gCO2e/km for a battery electric sport utility vehicle (SUV) and 220 gCO2e/km for a diesel-fuelled comparator.
- The analysis shows the importance of renewable H2 in Germany in achieving comparable or lower WTW emissions than battery electric vehicles (BEVs).



- **FCEVs provide significant benefits today compared to the average diesel vehicle in Germany.**
- **They also provide comparable benefits to BEV today in Germany and higher benefits for larger vehicles such as SUVs.**

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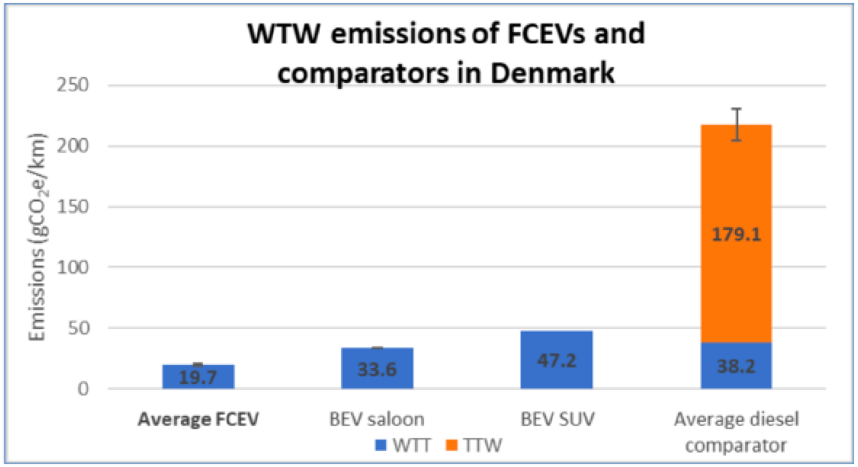
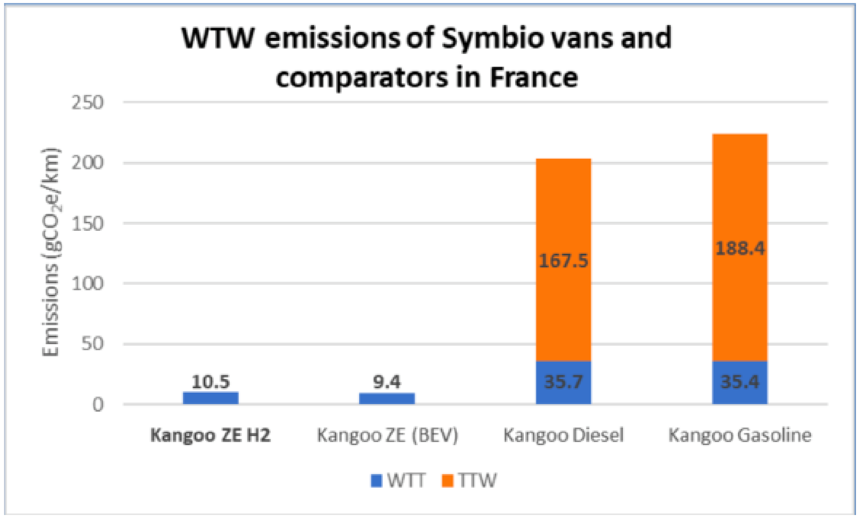
Source: Well-to-Wheels analysis, 2020, H2ME (1) Deliverable 4.18, Cenex

Well-to-Wheels emissions for FCEVs

Country by country analysis – Denmark and France

- The countries have different electricity generating mixes with **CO_2 emissions resulting from the amount of renewables/low carbon generation** employed: 206 gCO2e/kWh for Denmark and 60 gCO2e/kWh for France.
- **FCEVs provide significant benefits today compared to the average diesel vehicle in Denmark and achieved greater CO_2 emissions reduction than BEVs.**
- WTW emissions from the FCEVs in Denmark were found to be 20 gCO2e/km, compared to 34 gCO2e/km for a BEV, 47 gCO2e/km for a battery electric SUV and 217 gCO2e/km for a diesel comparator.
- The use of 100% green certified electrolytic hydrogen is key to the low WTW FCEV emissions in Denmark.
- **FCEVs provide significant benefits today compared to the average diesel or gasoline vehicle in France and achieved comparable reduction than BEVs.**
- WTW emissions from the Symbio FC range extended vans in France were found to be 11 gCO2e/km, compared to 9 gCO2e/km and 203 gCO2e/km respectively for a BEV and diesel equivalent. The low carbon footprint of electrolytic H_2 in France means the FC vans achieve much lower emissions than conventional vehicles whether driven on H_2, or electricity, or both.
- **In addition to the reduction of CO_2 emissions, FCEVs also provide operational advantages and can enable fleets to transition to zero emissions options that overcome the range and recharge time limitations of BEV alternatives.**





Source: Well-to-Wheels analysis, 2020, H2ME (1) Deliverable 4.18, Cenex

Perceived FCEV Well to Wheel emissions before and after use

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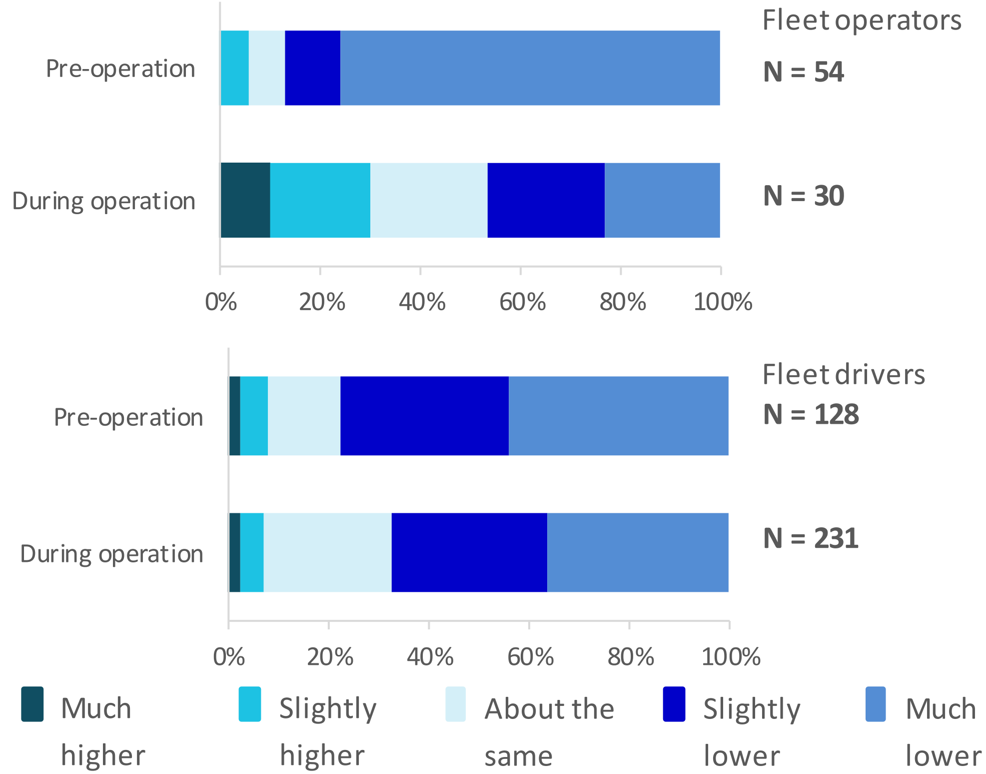
After using the vehicles, fewer fleet operators expected their Well to Wheel emissions to be much lower than petrol/diesel vehicles (compared to before using the vehicles)

- Most fleet operators and drivers expected the Well to Wheel emissions of the FCEV to be either **slightly lower or much lower than petrol/diesel** vehicles, both before and after using the vehicles.
- Prior to operation, 87% of fleet operators said they believed that FCEVs have lower Well to Wheel emissions than FCEVs. However, following the use of the vehicles, this reduced to 47%.
- A decrease in perceptions may reflect **increased customer awareness** on hydrogen supply and production following more exposure to the technology. Although many HRS operators are aiming to transition to zero-emission hydrogen, to date, some are still supplied with grey hydrogen and hence have emissions associated with their lifecycle
- As the supply of green hydrogen to European HRS increases, it will be important to ensure this is communicated to potential customers.

Do you expect the Well to Wheel emission of the FCEV (which takes account of the production, transport and storage of the hydrogen) to be higher or lower than for a petrol/diesel vehicle?



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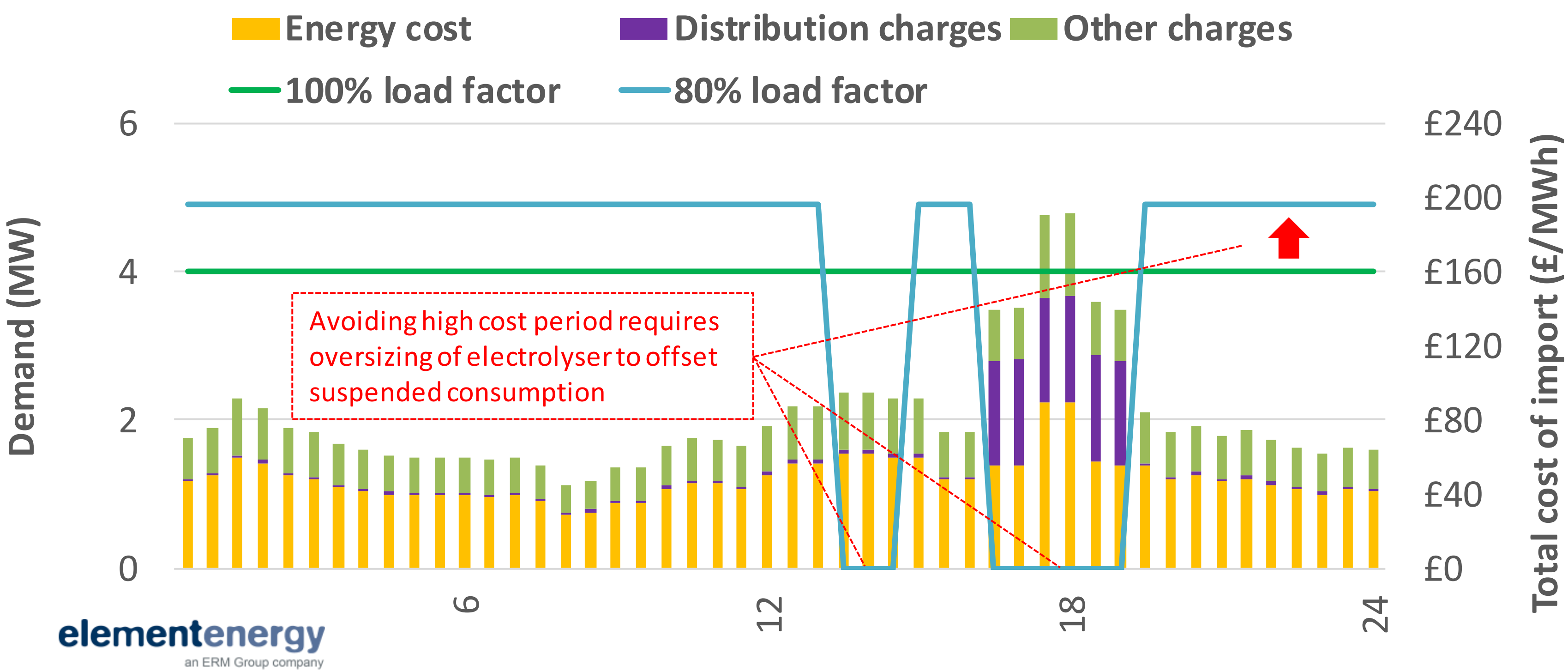
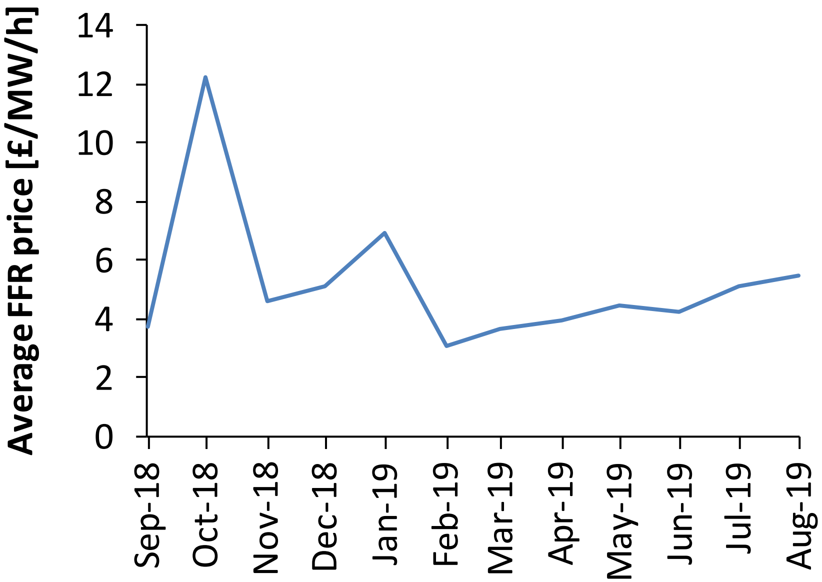
Source: Status and advancements in the customer value proposition offered by the fuel cell vehicle technology, 2022, H2ME (2) Deliverable 6.21, Element Energy

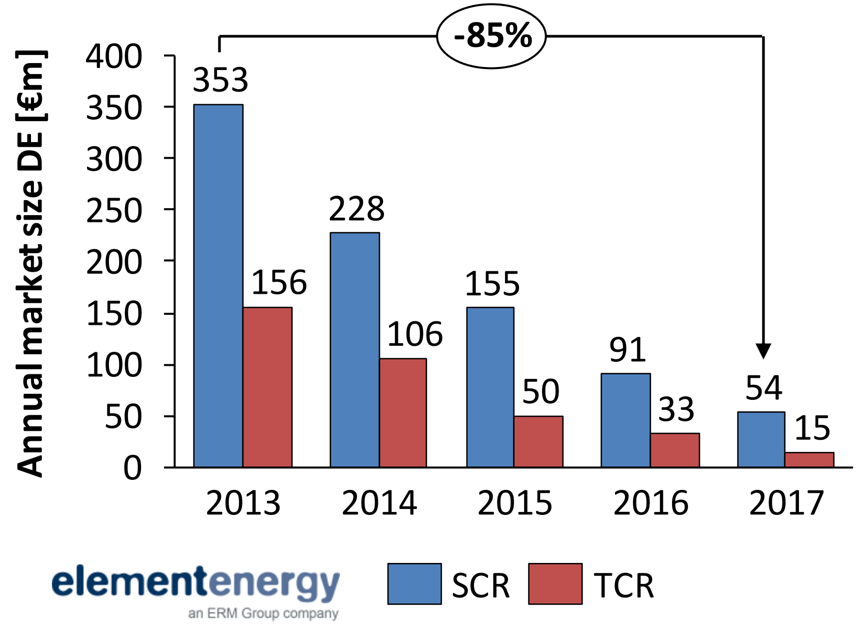
Excess electrolyser capacity and H_2 storage used to offset high import cost during peak hours



- Excess electrolyser capacity allows the avoidance of peak network and energy import costs.
- H_2 storage is discharged during times of high energy and network costs and charged using excess electrolyser capacity during times of low import cost.

Balancing services contracted by the Transmission System Operators TSO – an attractive but quickly changing market

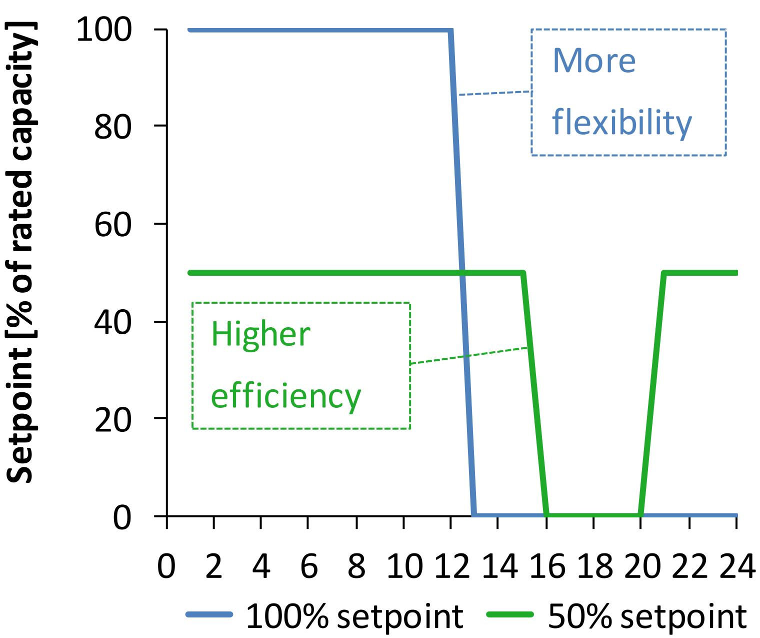


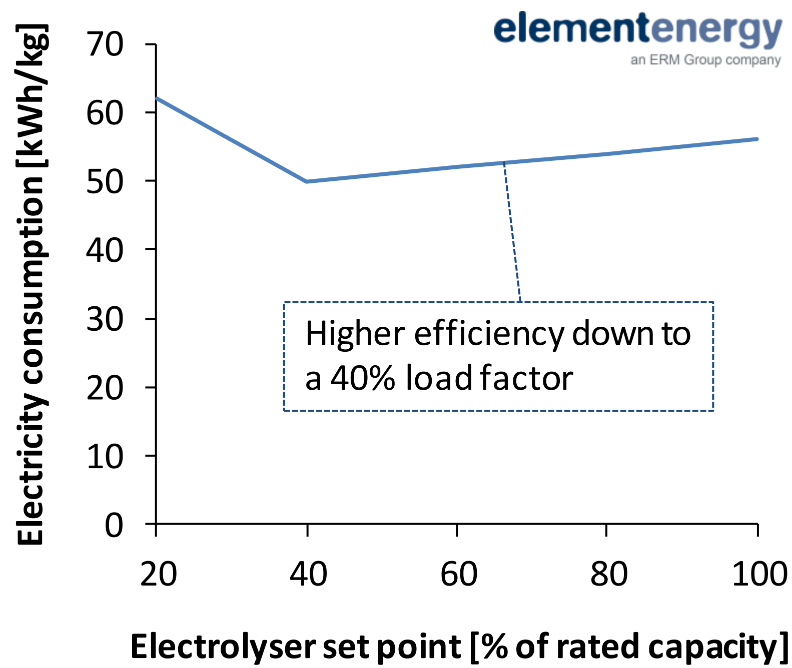


- Contracted services have to be committed ahead of delivery for fixed time windows set by the TSO. The service provision is rewarded with availability payments (in £/MW/h) that are also paid, if the service not utilised. The utilisation rate is relatively low (below 10%[1]).
- While an attractive market, emergence of new technologies, mainly batteries, and increased TSO cooperation have led to lower prices and shrinking market size. In the UK, prices for Frequency Response have halved since 2017. In 2019 Firm Frequency Response (FFR) prices averaged around £5/MW/h (graph above).
- Similar prices and price development can be observed in France and Germany.
- In Germany, the market size of secondary control reserve (SCR) has been reduced by 85% since 2013.

[1] For Frequency Response in the UK and Secondary and Tertiary Control Reserve in Germany (SCR and TCR)

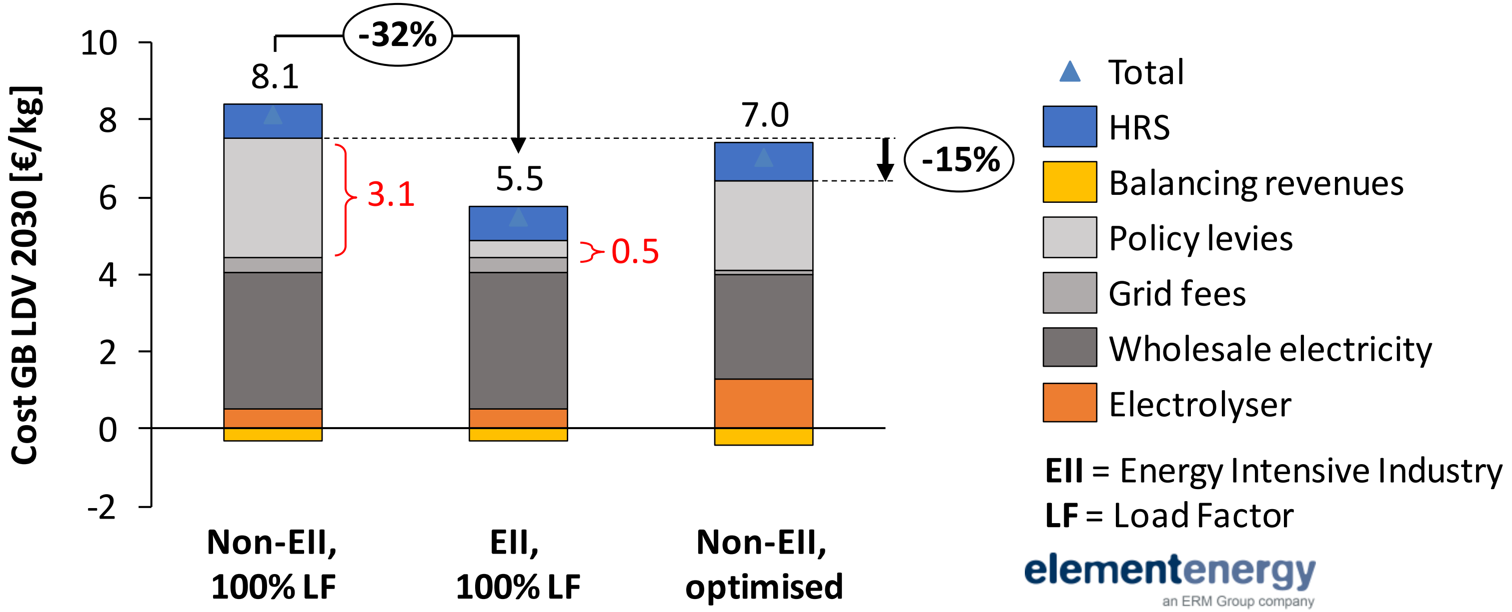
Key characteristics of operational strategies of electrolysers: when to run and at which set point





- Once a given size of the electrolyser for a given daily demand is chosen, operational strategies to run the unit will differ in terms of 1) the hours **when** the electrolyser is run and 2) the **set point** at which the electrolyser is run
- The electrolyser could either be utilised at a **high set point** for a **small number of hours** or at a **low set point** for a **large number of hours**, compare the upper left graph showing two ways how to operate at a 50% load factor.
- The **efficiency** of the electrolyser **improves at lower set points** (down to 40%, right graph above).
- Running the electrolyser at a low set point therefore reduces the electricity consumption per kg H_2 produced but it also reduces the flexibility to shift consumption to low price periods. This can offset by siting two electrolysers for future capacity expansion but at a higher capital cost.

Grid fees and green levies are a significant component of the cost of green hydrogen



- Policy levies comprise more than 40% of industrial electricity prices in GB.
- 80% of these levies are for green policies such as the Renewable Obligation and Contracts for Difference.
- Reduction of levies by up to 85% available to **energy intensive industry** (EII), similar reductions available in DE. In FR, electrolysis already exempted from levies; EII status only reduces grid fees and the difference between EII and Non-EII costs are not as high as in GB and DE.
- In 2030, such a reduction would have a **higher impact** on the hydrogen cost **than operational optimisation** of the electrolyser to utilise low price periods.
- Operational optimisation: 12% reduction; EII status: 32% reduction
- In terms of **realistic policy**, it may be problematic if grid connected electrolysers are economically viable only through being exempted from contributing to decarbonisation of electricity

Role of grid services in improving the business models for electrolysers

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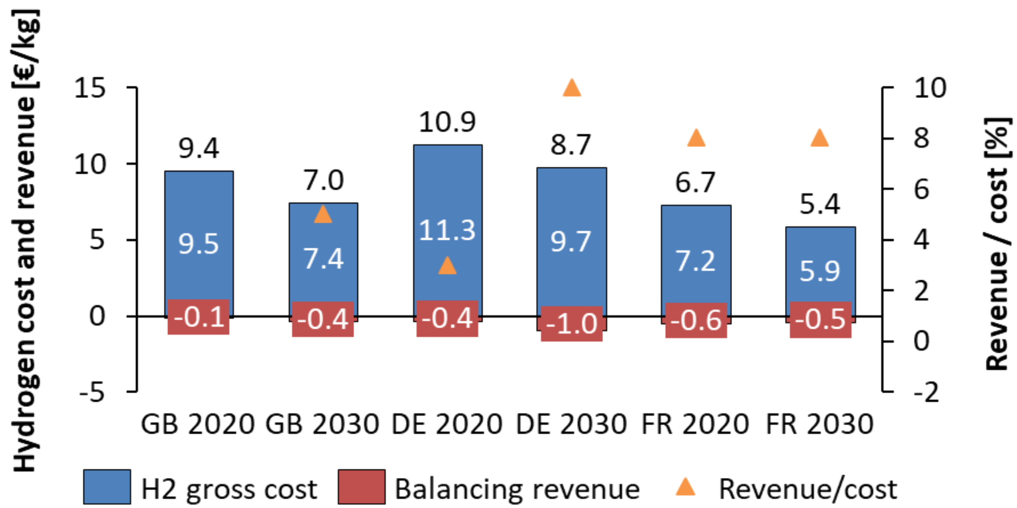
Electrolyzer can support the integration of renewable electricity as well as provide green H2 for mobility

- Production of H_2 by electrolysis can **help the energy transition to Variable Renewable Energy (VRE)** such as wind and solar power by balancing the grid in hours of low electricity demand and high VRE production.
- Contracts with Transmission System Operators (TSOs) are rewarded with **availability payments** (in £/MW/h), which are also paid if the service is not utilised.
- Contracted Balancing services have to be committed ahead of delivery for fixed time windows set by the TSO.



- Balancing revenues **reduce** the **cost** of hydrogen by **1-10%** across countries. Revenues increase if a lower load factor is used, which offers more capacity for balancing services. This is likely to be the case **in GB and DE** in 2030, as marginal electricity costs will become more volatile.
- The Balancing Services market by electrolysis is in strong competition with other storage technologies (mainly batteries). They can help to **improve the business case** but they should not be a main pillar of it.

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Source: Desirable design changes and operating regimes for electrolyser-HRS for 2020-2030, 2020, H2ME 2 Deliverable 4.17, Element Energy

Contents

Although significant progress has been made, the number of refuelling stations is still a major barrier to further adoption of FCEVs

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HRS deployment barriers to FCEV adoption

- **Number of local HRS (i.e. in hydrogen demand "clusters")**
  - A minimum of two HRS per cluster is required to establish demand from light fleet applications; this provides redundancy (allowing HRS maintenance to take place) as well as additional geographic coverage.
  - Some high-mileage light duty fleets need more operational flexibility; to support a higher replacement rate in these fleets, more local HRS are required to provide a greater degree of city-wide coverage.

- **Wider HRS coverage (to enable long distance journeys)**
  - Many business customers (as well as private customers, and some fleets) rely on the ability to make long journeys. In addition, some fleets frequently operate in suburban or rural areas which are not covered by current HRS locations, which tend to be closer to urban centres. In practice, in the initial stages of HRS deployment, this trend is likely to restrict the accessible market for cars and vans to those that are "captive" operating within a region well served by HRS.

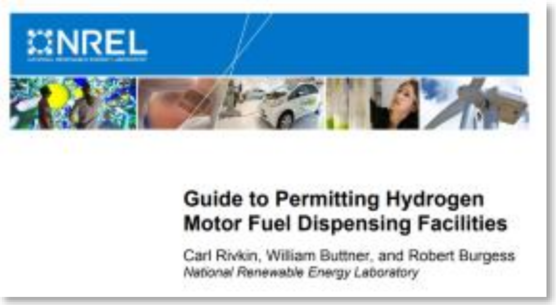
- **Some HRS have limited capacity, performance or interoperability**
  - Some HRS deployed several years ago are not designed to meet the level of demand from recently deployed local fleets, and need to be replaced or upgraded; in addition some relatively recent HRS can only refuel at 350 bar. This means that for some vehicles, the available public infrastructure does not enable the full capabilities of the technology to be realized (either due to refuelling demand exceeding HRS capacity, or due to vehicles that can refuel up to 700 bar only obtaining a partial refuel, or in some cases being unable to use 350 bar HRS). This further restricts the locations where FCEVs can be deployed with an optimal user experience, and risks lowering user confidence in hydrogen as a fuel.

Siting and permitting is a bottleneck in the HRS installation process, and the high risk associated with investment also needs to be addressed

Issues to be addressed to accelerate HRS deployment

- **Siting and permitting challenges**
  - The time taken to identify sites for HRS and delays at the permitting stage are major factors that have contributed to the deployment of new HRS being slower than envisaged by national strategies. Work is required to educate and improve sharing of best practice between authorities responsible for consenting and approving new HRS.
- **High investment risk for HRS operators and green hydrogen producers**
  - Uncertainty around long-term demand creates risk for investors in new HRS and green hydrogen production.
  - For existing sites, when utilisation is low, the high cost of maintaining and operating HRS creates a risk that stations will close if there is no ongoing support.
  - Uncertainty around the timings of centralised large-scale low carbon hydrogen production (e.g. at the scale envisaged for the use of hydrogen in heat and industrial applications) also creates a demand risk for short-term, smaller scale green hydrogen production routes: if there is a possibility of larger scale lower cost hydrogen production arriving, the business case for smaller scale (often higher cost) production options becomes challenging.
  - For trucks, lack of certainty around refueling technology choices (refueling pressure at 350bar vs 700bar, and gaseous vs liquid) is also holding up progress.

HRS permitting guidance document from the US National Renewable Energy Laboratory (2016) and a blueprint for approvals from the Carbon Neutral Cities Alliance (2016)



Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Limited vehicle availability and high ownership costs are also barriers to wider adoption of FCEVs

Cost and availability barriers to FCEV adoption

- **Model choice is limited and suitable hydrogen vehicles are not available for all potential customers**
  - To enable wider adoption in different markets, significant increases to the available model choices are needed, including more options for cars and in particular vans, as well as heavy trucks (note that fuel cell trucks are not yet readily available in Europe outside of specific demonstration project initiatives).

- **The cost of FCEVs and hydrogen can be prohibitively high for many potential end users**
  - Current cost premiums for FCEVs (relative to the cost of petrol and diesel vehicles) are prohibitively high in the absence of funding (although in specific use cases the total cost of ownership can be close to that of petrol or diesel, after subsidies).
  - If the fuel cost per km *as seen by the end user* is comparable to fossil fuel equivalent, the cost of hydrogen does not present a barrier to adoption. However, at the low levels of demand currently seen at public HRS in Europe (<200 kg/day) the cost of producing and supplying hydrogen at an HRS can be very high; if this cost is passed on to end users, this leads to a significant fuel cost premium compared to fossil fuels, which could be a barrier to adoption. In addition, the "per kg" costs of maintenance for HRS to achieve high availability are significant at low levels of demand. Together with the vehicle cost, the fuel price acts as a drag on scale-up of FCEV production and HRS rollout.

Examples of some popular petrol and diesel vans and trucks used across Europe; a wider range of hydrogen models would increase the accessible market size.

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Demand uncertainty contributes to the lack of model choices and high costs; national policy-makers can provide clear market signals to help address this

Issues to be addressed to bring costs down and improve availability

- **Manufacturers have insufficient certainty around demand volumes needed to produce attractively priced vehicles for some market segments**
  - Production volumes in the low tens of thousands are needed to bring fuel cell car prices nearer to those of ICEVs [1]. The 2nd generation Mirai has shown a fall in unsubsidized price from €74,000 to €64,000. The Hyundai Nexo car (with 60 trialled in H2ME, and shipped mostly to South Korea) is approaching these volumes of production.
  - Particularly in the heavy vehicle market, vehicle costs with low production volumes are too high to justify making hydrogen models available at attractive prices, and OEMs are reluctant to produce more vehicles at risk. Demand aggregation (e.g. supported by pre-orders) for each model / type is needed to demonstrate the demand and unlock economies of scale.
  - This type of demand-based business case can be combined with market conditions that make FCEVs more attractive e.g., high taxes or restrictions for diesel. Long-term policy mechanisms (e.g., per vehicle subsidies maintained over a certain time period) are needed to increase market confidence (for manufacturers and customers) and reduce risk. This also applies to H_2 production & HRS operation; H_2 subsidies or other mechanisms that can provide more certainty around long-term demand and revenues will make the investment case much more attractive for HRS operators.

Hyundai is not currently a major supplier to the European truck market but has responded to the demand for zero emission trucks in Switzerland and other European countries: the Hyundai Hydrogen Mobility project plans to deploy over 1,600 fuel cell trucks in Europe by 2025. This project has been made possible by aggregating demand from numerous transport and logistics fleets in Switzerland, combined with high taxes for fossil fuel Heavy Good Vehicles (HGVs).

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

[1] 2018 –US Department of Energy, doi.org/10.1016/j.trc.2018.01.005

A fully integrated regulatory framework that reflects the safety of hydrogen in mobility applications is needed to avoid restrictions to future adoption of the technology

Safety-related issues for FCEV adoption

- **FCEV users across several countries have experienced access restrictions for hydrogen vehicles**
  - Several users in the H2ME project reported that they were prevented from using underground parking, tunnels or ferries with their FCEV. If this continues to be an issue, this could become a significant barrier for the wider adoption of the technology. Further evidence and understanding of FCEV safety in enclosed spaces is needed.
- **Some users have expressed concerns around the safety of the technology**
  - Whilst the majority of FCEV users in the H2ME project did not express concerns about the safety of the vehicles, some did, most commonly relating to the high-pressure systems in the vehicles and the risk of potential explosions.
- **Safety incidents at hydrogen stations could impact availability of hydrogen for customers**
  - In June 2019, there was a fire and a pressure wave at an HRS in Norway due to a hydrogen leakage. The immediate incident was managed quickly. However, the investigation of the root causes took several months and during this time, all HRS with the same design were closed to ensure that no similar incidents would occur. The risk of reduced utility for hydrogen vehicles as a result of this could be a barrier to wider adoption, if not successfully mitigated.

Regulatory issues for FCEV adoption

- **New research leading to guidance and/or regulations relating specifically to hydrogen mobility still needs to be developed or revisited for several key areas:**
  - Using FCEVs in enclosed spaces such as underground parking, tunnels and ferries
  - Onsite storage of hydrogen at refuelling stations (safety requirements currently relate mainly to industrial sites)
  - Transport of hydrogen by tube trailer
- **There is currently a lack of the knowledge & skills required to ensure that H_2 regulations are implemented appropriately.**
  - There is a need for further research and education within the supply chain and regulatory bodies, to address the lack of understanding around hydrogen safety. The interpretation and implementation of HRS standards by local planning authorities is just one example of where this is required.

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

The following slides set out recommendations to support the further commercialisation of hydrogen mobility from three different perspectives

Overview of recommendations

The following slides set out recommendations to address the issues identified above in terms of three key aspects of deliveri ng hydrogen mobility:

1) Recommendations for hydrogen mobility initiatives

- Recommended strategies and actions for coordinating the delivery of future hydrogen vehicles and refuelling stations

2) Recommendations for maturing the supply chain

- Recommended approaches needed within the FCEV and HRS supply chain and the related wider infrastructure

3) Recommendations for policy and funding

- Broad policy and funding requirements to address cost barriers and support the wider commercialisation actions

The recommendations are based on lessons learned from hydrogen industry stakeholders and the analysis carried out as part of the H2ME project, including customer surveys, workshops, interviews, and techno-economic analysis (the results of which can be found in various other public reports).

Source: Summary and lessons learnt from the hydrogen mobility strategies tested in this project, 2020, H2ME (1) Deliverable 5.13, Element Energy

Hydrogen mobility initiatives should focus on aggregating local demand from various vehicle applications to identify ways to scale up and de-risk hydrogen infrastructure

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Issues to address

- **Low numbers of HRS**
- **High investment risk for HRS operators and green hydrogen producers**
- **Limited vehicle model choice**
- **The cost of FCEVs can be prohibitively high**

Recommendations for hydrogen mobility initiatives

- Continue to **target high utilisation applications** & **link HRS deployment to emerging demand.**
- Focus on **securing commitment** to a rapid scale-up of **hydrogen demand at a local scale** (e.g. within a city or region). This will involve various **demand aggregation** activities:
  - Identify potential short-term local demand for different applications (i.e. vans, buses, refuse trucks, trains and local logistics applications as well as cars for fleets and business users).
  - For different vehicle types and uses, compare: **vehicle & HRS costs (relative to incumbent fuels), specifications, and local demand, to identify options which can work best in the local area**. Identify specific local factors required to unlock the levels of demand required for high-capacity, high availability HRS to be deployed and then well utilised: e.g. local vehicle purchase incentives/mandates, a local hydrogen demand commitment and/or funding needed for HRS investment. Look to build a suite of local measures which create demand for a range of vehicle types, which collectively create demand at stations of 100s of kg/day.
  - Coordinate potential vehicle demand from different end users, and with adjacent regions, to aggregate demand for vehicle procurement: a) to signal demand for **light vehicles** to OEMs (which are often making allocation decisions between Europe, Asia and North America based on expected sales) and b) to instigate supply of **heavy vehicles** to new markets at affordable prices (in the case of heavy vehicles, procurement in the scale of 100s of buses or HGVs in a region could be sufficient under certain conditions).

Issues to address

- **Siting and permitting challenges**

Recommendations for hydrogen mobility initiatives

- Be aware of the need for **advance planning** for HRS siting, consenting and deployment: total lead time for is likely to be up to two years per HRS based on experiences in Europe to date.
- Explore opportunities to use sites owned by local authorities or existing fuel retailers. Once potential sites are identified, **engage with local stakeholders** (planning authorities, site owners, legal teams) as early as possible to ensure the process is collaborative, and to address any issues.
- Work with national authorities to put in place clear **national guidance for permitting processes** that can be implemented locally, based on experiences of existing HRS.

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While hydrogen mobility initiatives and policy have shifted towards heavy duty applications, refuelling infrastructure for passenger cars can be developed alongside this

Hydrogen passenger cars and light duty vehicles will have a role in delivering net zero

Although the focus for hydrogen mobility has shifted towards heavy duty road transport applications such as buses and trucks, due to the cost benefits that can be achieved at higher levels of demand, the vehicles deployed in the H2ME project have nevertheless demonstrated that hydrogen passenger cars and vans can offer specific operational advantages over other zero emission options. The ability to completely refuel in under 10 minutes offered by FCEVs is valued highly by certain commercial applications (such as taxis, police services, and utility fleets) and is likely to be a preferred option for higher mileage private car and commercial vehicle owners in the future, particularly as the availability of fossil fuel vehicles diminishes in line with net-zero goals. Based on the experiences of the H2ME project, two main approaches to infrastructure deployment can be pursued to ensure that the emissions and operational benefits of hydrogen cars and vans can be realised; a combination of both approaches is recommended.

Issues to address

- **Low numbers of HRS**
- **High investment risk for HRS operators**

Recommendations for hydrogen mobility initiatives

- Where appropriate, ensure that HRS for heavy duty vehicles also have the capability & capacity to refuel passenger cars. This includes consideration of:
  - Location & HRS accessibility
  - Suitable refuelling protocols and dispensers
  - Refuelling capacity
  - Interoperability with other public HRS
  - Develop local clusters of stations for light vehicles where there is a clear demand from local fleets with consistently high mileages, such as taxis:
  - Opportunities are most likely to exist in cities with policies providing strong incentives to zero emission fleet operations, and with fleet operators with a clear business case and plans to expand their zero-emission fleet.
  - Taxi fleets have a particularly clear need for rapid refuelling, making FCEVs a strong choice.
  - Station siting should be decided in close consultation with the vehicle operators; FCEV fleet expansion will be facilitated by minimizing the “dead mileage” needed to refuel.
  - Station & network specifications should include redundancy to ensure high availability.

Hydrogen infrastructure suppliers and operators need to identify priority areas for technology improvement whilst working towards achieving harmonised standards

Issues to address	Recommendations for the hydrogen mobility supply chain
▪ **Some HRS have limited capacity, performance or interoperability**	❑ Ensure that **new stations are future-proofed** wherever possible, e.g. with space and connection points to facilitate upgrades to increase refuelling capacity, updated refuelling protocols, and / or improved monitoring and remote maintenance. **Modular station design** could help to enable this. ❑ Establish an independent **regulatory body** for HRS at the national level to **test and certify new refuelling stations** for safety and performance, and to maximise the interoperability of the growing networks of public HRS. This may require support from vehicle suppliers & existing HRS operators and is likely to require funding either from government, and/or from within the sector. ❑ Continue to **improve the customer experience of existing HRS**: including providing high availability, communicating station status, and improving ease of refuelling (e.g. nozzle design). ▪ **Detailed data analysis is needed** to understand progress made on availability: specifically the impact of faster maintenance vs reliability of specific components. ▪ **Make live data available** to third party mapping providers, to ensure customer have access to data on where stations are open and their ability to refuel vehicles. ▪ The industry should seek funding for projects to bring **improvements to the quality and supply of specific HRS components** that frequently need repairing or replacing. Ease of use should also be considered in aspects such as nozzle design. ❑ **Define protocols for refuelling trucks and other heavy-duty vehicles**, considering lessons learned from light duty vehicle refuelling and buses: protocols and the technologies required to fulfill them can impact HRS cost and reliability, which are both key factors in the rate of FCEV adoption.
▪ **The cost of FCEVs can be prohibitively high**	❑ Continue R&D to **reduce production costs for fuel cell and hydrogen components**. ❑ Ensure **FCEV car and van models** are targeted at fleet markets which can sustain the price points at which the vehicles are sold. ❑ Work with OEMs to increase production volumes and so drive down the cost of different vehicle types. Where possible Governments can help here by signaling that there will be sustained demand for hydrogen vehicles going forwards.

The supply chain stakeholders should develop an improved understanding of hydrogen safety in various contexts and communicate this to inform the regulatory landscape

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Issues to address	Recommendations for the hydrogen mobility supply chain
▪ **Access restrictions for FCEVs** ▪ **User concerns around safety**	❑ If future access issues are to be prevented, **further work is needed to demonstrate the safety of FCEVs in enclosed environments** to infrastructure operators / regulators, and to ensure that regulations and guidelines enable access for FCEVs in such environments. The HyTunnel-CS project is conducting pre-normative research on this topic; the wider sector should engage with and build on the project's findings, including working to address any safety issues identified as part of this work. ❑ Clear **communication and dissemination of the evidence base** for FCEV safety (including in confined spaces as well as in the case of accidents) will be needed: ▪ To ensure that FCEV access restrictions are only imposed when identified when strictly necessary for safety purposes; ▪ To ensure that public awareness of the relative safety of hydrogen mobility improves.
▪ **Safety incidents can lead to temporary closure of multiple similar HRS**	❑ Aim for **increased diversity of technology design within HRS clusters** to ensure that in the event of an incident, local hydrogen availability is not adversely affected by precautionary close-downs. ❑ Minimise the risk and impacts of incidents by **following best practices for safety**, including: ▪ Conducting rigorous risk assessments at the design stage and ensuring designs take account of these assessments, as well as the well-respected hydrogen station design standards. ▪ Implementation and documentation of thorough internal safety processes and checks for HRS assembly, commissioning and maintenance. ▪ Training internal emergency response teams, including defined procedures to be followed in the event of an incident. ▪ Ensuring that risk assessments and mitigation processes at the design stage account for the impacts of temperature variations. ▪ Avoidance of "overdesign" of components: faults in equipment should be identifiable at the testing stage (i.e., early failure rather than late failure). ▪ "Fail-safe" design: designing HRS system so that failure of components do not lead to catastrophic events.

National policy and funding can provide the market certainty and cost support needed to accelerate the next stage of hydrogen transport commercialisation in Europe

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Issues to address

- **Low numbers of HRS**
- **High investment risk for HRS operators and green hydrogen producers**

Recommendations for future policy and funding

- ❑ Implement policy at national level that **de-risks the business case for HRS operators** to produce low cost, low carbon hydrogen and invest in new HRS. This could involve: 1) Continued availability of **grants or cheap finance** for initial infrastructure investments; 2) in the longer term, a move to **support hydrogen on a "per unit sold" basis**. This type of support for biofuels and renewable energy has led to these low carbon energy options becoming mainstream as part of mature markets. **Subsidies or certificate schemes to incentivise green hydrogen sales** over a given time period can provide some degree of revenue certainty to make investment attractive.
  - The implementation of the Renewable Energy Directive II (which includes the use of renewable hydrogen for mobility) offers a pathway for the introduction of support schemes for hydrogen at a member state level. This (or other bespoke hydrogen subsidy schemes) can help unlock the market for hydrogen deployment.
  - Overly restrictive requirements (e.g. stipulating 100% additional "new" electricity) could limit the potential for such schemes to support hydrogen roll-out. The European level **definitions of renewable hydrogen should be designed with sufficient flexibility** to enable support for affordable hydrogen production from a range of renewable resources.
  - National implementation should: a) guarantee access to support for early investors for a reasonable time period; b) consider volume caps on renewable hydrogen to ensure that it does not dominate the RED II targets; c) provide clarity on the inclusion of biomethane reformation and waste gasification, which could compete with efforts to decarbonise heat.
- ❑ Encourage **collaborations between vehicle providers and HRS investors** which can increase the scale of deployment: for example, the taxi initiative in Paris (HysetCo) or the truck deployment project in Switzerland (Hyundai Hydrogen Mobility). Where possible, provide specific incentives which are aimed at catalyzing the progression to such larger scale initiatives.
- ❑ Provide funds to **initiate collaboration and strategy development** between government and industry in countries (and regions) with nascent interest in hydrogen mobility.

Policy and funding for FCEVs will be needed until critical volumes are reached, and approaches can be informed by the success of various policies for electric vehicles

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Issues to address

- **The cost of FCEVs can be prohibitively high**
- **Limited vehicle model choice**
- **Lack of market certainty**

Recommendations for future policy and funding

- In parallel to the above, national and European policy should set clear targets for uptake of zero emission vehicles and introduce further **measures to encourage manufacturers to supply more zero emission options across different vehicle segments**, as well as **ensuring that FCEVs are attractive to customers** (financially and otherwise). Measures such as the examples shown below will increase market confidence for manufacturers, customers and infrastructure investors.
  - Sufficient funding for **subsidies to cover cost premiums for fuel cell vehicles** over petrol / diesel alternatives, until critical volumes and price points are reached. Based on the electric vehicle market, the most effective zero-emission vehicle (ZEV) subsidies are: available close to the point of sale; locked into place for at least several years; relatively simple for consumers and dealers to understand their value, and widely accessible.[1]
  - **Restrictions on fossil fuels**, e.g. within: Zero Emission Zones, public procurement, taxi fleets.
  - The **ZEV credit market** in California has played an important role in development of ZEV technology amongst numerous car manufacturers; to improve on this approach, future credit markets could **target (or provide extra credits) for ZEV sales within specific market segments** where emissions reductions and new vehicle technology development are most needed (including those well-suited for FCEV use).[2]

[1] ICCT, Principles for effective electric vehicle incentive design, 2016.
[2] RFF, California's evolving zero emission vehicle program, 2019.

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Contents

The demand for hydrogen mobility is now evident, but a significant increase in scale of local activities is needed to accelerate cost reductions and supply chain development

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Summary (1/2)

- **The H2ME project has demonstrated the viability and practicality of FCEVs of different sizes in meeting the needs of a range of existing vehicle users; over two thousand hydrogen light-duty vehicles are now in operation in Europe.**
  - Several countries now have hundreds of fuel cell cars and vans (FCEVs) in operation. The largest concentrations are found in taxi and ride-sharing fleets in city centres (with over 100 H_2 FCEV taxis in Paris), as well as an increasing number of business users and company cars used by early adopters, especially in Germany.
  - These applications depend on the ability to refuel rapidly and complete high daily mileages when required; the growth in demand for FCEVs in these applications clearly demonstrates that they can meet these needs and offer an attractive customer proposition in these areas.
- **Localised networks of public refuelling stations have been developed in numerous European cities**
  - Where dense concentrations of high-mileage FCEVs exist, there is an attractive business case for the development and operation of local networks of hydrogen refuelling stations (HRS), and cities such as Paris and Berlin now have city-wide HRS networks, ensuring that FCEV fleets can operate flexibly within these locations.
- **Nationwide networks are in place in Germany and Denmark, but utilisation is currently low relative to capacity**
  - Initial national refuelling networks have been developed to support the adoption of passenger cars, but current levels of demand are not sufficient to support the business case. Future development of these networks will link new HRS deployment locations to emerging demand, to make HRS operation more investible.
- **The further commercialization of hydrogen mobility relies on scaling up demand, including demand from heavy vehicles**
  - The business case for hydrogen production from renewables and operating refuelling stations is currently challenging due to the scale of demand relative to the costs of installing and operating infrastructure. With a higher magnitude of demand, both stations and hydrogen production can become more cost-effective, and the development of the European supply chain will accelerate, bringing improved station reliability and economic opportunities.
  - The focus of many hydrogen mobility initiatives has shifted towards heavy duty applications, where demand per vehicle is much higher and the benefits of hydrogen over other alternatives are more critical. Refuelling infrastructure for passenger cars and vans can be developed alongside this: a) by ensuring that stations primarily used by heavy vehicles are also capable of refuelling light vehicles and b) developing local clusters for applications such as taxis.

To achieve scale, what is now needed is a clear policy push in favour of hydrogen for mobility, with financial support for hydrogen as a fuel as well as for vehicles

Summary (2/2)

- **To enable scale-up of the fuel cell vehicle fleet, national subsidies and incentives are needed for all vehicle types**
  - Although demand is steadily growing, production volumes of fuel cell vehicles are still relatively low, especially for heavy duty vehicles, and vehicle costs will be significantly higher than those of fossil fuel vehicles while the supply chain matures and production volumes continue to ramp up. Purchase incentives that bring the on-the-road costs of hydrogen vehicles in line with fossil fuel options are needed to unlock demand from vehicle operators and bring market confidence to vehicle suppliers.
  - Incentives to be applied at the national level could include purchase grants and various tax exemptions; policies similar to those applied to Battery Electric Vehicles are likely to be appropriate, but subsidy levels should account for the current lower maturity of the FCEV market compared to BEVs.
- **Fuel credits for renewable hydrogen are needed to stimulate demand and production**
  - In the initial phases of scale up, the cost of producing and retailing renewable hydrogen is likely to exceed its value to vehicle operators. Fuel credits for renewable hydrogen would help to strengthen the business case for renewable hydrogen production and retail in the face of uncertainty around future demand.
  - The wording of the second Renewable Energy Directive (RED II) gives member states the freedom to support hydrogen produced from renewable sources (biomass and renewable electricity) with higher credit values, either through multiple counting of credits or by including hydrogen as an advanced biofuel.
  - Fuel credits with a value of around €4/kg of renewable hydrogen would enable retailers to make it available at an attractive price.
- **National governments can remove barriers to hydrogen mobility by ensuring that hydrogen options receive equal treatment to other zero emission alternatives within transport strategies and policies**
  - Specific measures to be adapted will vary for each country, but may include specifying hydrogen as an option for innovation & demonstration projects, updating regulations and zero-emission vehicle to include specifications for hydrogen vehicles, and ensuring that guidance on HRS installation is available to planning authorities.

Frequently used abbreviations

BEV	Battery Electric Vehicles
BeNeLux	Belgium, The Netherlands, Luxembourg
CAPEX	Capital Expenditure
CCS	Carbon Capture Storage
DK	Denmark
EHSP	European Hydrogen Safety Panel
EU	European Union
FCEV	Fuel Cell Electric Vehicle
FCH JU	Fuel Cells & Hydrogen Joint Undertaking
CH2 JU	The Clean Hydrogen Partnership
FCEV	Fuel Cell Electric Vehicle
GTC	Green Tomato Cars
H2	Hydrogen
H2ME	Hydrogen Mobility Europe (project)
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicles
HIAD	Hydrogen Incidents & Accidents Database
HRS	Hydrogen Refuelling Station
IEA	International Energy Agency
ICEV	Internal Combustion Engine Vehicle
LCOE	Levelised Cost Of Energy
NL	The Netherlands
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles (UK)
OPEX	Operational Expenditure
R&D	Research and Development
REEV	Range-Extended Electric Vehicles
RED II	Second Renewable Energy Directive
SMR	Steam Methane Reforming
SOC	State of Charge
UK	The United Kingdom
ZEFER	Zero Emission Fleet Vehicles for European Roll-out
ZEV	Zero-emission vehicle

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