HYDROGEN IN TRANSPORT

Hydrogen cars, vans and buses

Overview of flagship demonstration initiatives in the transport sector

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• Introduction
  • H2ME project
  • JIVE project
  • H2Haul project
  • Additional information
Why is hydrogen mobility important? ... perspectives for society and policy makers

Local Air Quality improvements

❖ A solution today for Zero Emission transportation
  ▪ Vehicle operation producing zero tailpipe emissions.
  ▪ ... while offering fast refueling and long driving range.

❖ A solution making the energy transition feasible
  ▪ The technology is needed to meet targets for CO₂ reduction and accommodate increases in Renewable Energy (RE) production.
  ▪ FCEVs have significantly lower GHG emissions compared to conventional vehicles, and can be zero-emission when hydrogen is generated from renewable energy.
  ▪ 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.

M1 Wind Hydrogen Station, UK @ITM power

Source: H2ME project, Emerging conclusions
Why go for fuel cell electric vehicles?

FCEVs have the most efficient decarbonisation level for long-distances and heavy payloads

- Airplanes/freight ships – synfuels based on H₂ as only feasible decarbonization option
- Passenger ships
- Medium and heavy truck segments, by attractiveness for FCEV vs. BEV
- Long-haul freight (coast to coast)
- Mining
- International road masters
- Regional distributor (high payload)
- Regional distributor (low payload)
- Local drop and drive
- Medium and large car segments, by attractiveness for FCEV vs. BEV
- Off-road, utility and military vehicles
- Taxis, limousine services
- Service fleets
- SUVs
- D segments for private use
- A-C segment for private use

Source: Hydrogen Roadmap for Europe, 2019

1 H₂-based fuels or fuel cells
What are the remaining barriers towards commercialisation?

Remaining barriers to be overcome include:

- The number of FCEVs on Europe’s roads is 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. In the future, FCEVs are expected to offer a cost-competitive alternative to long range electric vehicles for zero emission driving.

- Today, FCEVs are starting to provide competitive Total Cost of Ownership only for specific fleets which value the advantages of hydrogen fuel, such as taxis in polluted urban centres and urban delivery vehicles.

- Achieving the mass market will require fuel cell vehicles manufacturers to reduce prices through economies of scale (10,000s of vehicles per year).

- This large market for vehicles will then justify commercial deployment of hydrogen stations to expand the network.

Source: H2ME project, Emerging conclusions

HRS: Hydrogen Refuelling Station
FCEV: Fuel Cell Electric Vehicle
RE-EV: Range-Extended Electric Vehicle
Why it makes sense to start in the transport sector

Dates when hydrogen vehicles become available

- Transport applications exist today
- Are inherently scalable (don’t require £bn’s of investment)
- Offer the highest value end user market for hydrogen producers
- There are three main requirements to make hydrogen for transport work:
  1. Technology learning
  2. Scale of demand
  3. Low cost sources of energy

Note: Commercially competitive products refers to hydrogen transport modes which are competitive with other forms of low/zero emission transport. They may still have a small total cost of ownership premium compared to conventional drive trains.
• Introduction

• **H2ME project**
  • JIVE project
  • H2Haul project
  • Additional information
H2ME – a major pan-European effort to support commercialisation

H2ME 1
- 29 stations
- >300 cars and vans
- €70m total cost
- €32m funding
- Started June 2015

H2ME 2
- 20 stations
- >1100 cars, vans and trucks
- €100m total cost
- €35m funding
- Started May 2016

❖ >45 refuelling stations
❖ >1400 cars, and vans
❖ €170m total cost
❖ €67m funding
❖ > 40 organisations

A major European activity!

These activities are part of a much larger vehicle and HRS rollout in Europe
Bringing H2 mobility initiatives into one framework

**Endorsers:**
- Mobilité Hydrogène France
- H₂ Mobility
- UK H₂ Mobility
- Scandinavian Hydrogen Highway Partnership
- Hydrogen mobility grouping in Benelux
- Hydrogen mobility grouping in Austria
- Hydrogen mobility grouping in Italy

**H2ME Project overview (2015 – 2022)**

**Concept:**
- Joint initiative from the most ambitious European hydrogen mobility initiatives
- One ‘working framework’ linking these initiatives, which provide the opportunity to:
  1) identify optimal commercialisation strategies and synergies between countries
  2) develop European strategies for commercialisation

**New hydrogen refuelling stations:**
- 20 - Germany
- 12 - Scandinavia
- 11 - France
- 6 – UK
- 1 - NL

**Fuel cell vehicles:**
- 500 OEM FCEVs
- 900 fuel cell RE-EV vans

**Abbreviations:**
- HRS: Hydrogen Refuelling Station
- FCEV: Fuel Cell Electric Vehicle
- RE-EV: Range-Extended Electric Vehicle
- OEM: Original Equipment Manufacturer
H2ME brings together high level partners in these initiatives in a joint European approach.

The results generated by the project are shared with industry, policy makers, and the wider public to support the commercialisation of hydrogen mobility.
H2ME is well underway but activities are planned until 2022

### Deployment status and timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Daimler FCEVs</th>
<th>Honda FCEVs</th>
<th>Toyota FCEVs</th>
<th>Procurement of other FCEVs</th>
<th>FC range-extended electric vans</th>
<th>HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
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<td>1</td>
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<tr>
<td>2016</td>
<td></td>
<td>Honda Clarity from 2017Q1</td>
<td>Toyota Mirai from 2017Q3</td>
<td></td>
<td>Renault Kangoo Z.E from 2015Q3</td>
<td>1</td>
</tr>
<tr>
<td>2017</td>
<td>B-Class F-Cell from 2015Q2</td>
<td>10 in operation in the project</td>
<td></td>
<td>other vehicle types procured and deployed from 2017Q2</td>
<td></td>
<td>2</td>
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<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>3</td>
</tr>
<tr>
<td>2019</td>
<td></td>
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<td>4</td>
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<td>2020</td>
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<td>5</td>
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<tr>
<td>2021</td>
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<td>4</td>
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<tr>
<td>2022</td>
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<td>1</td>
</tr>
</tbody>
</table>

**Legend:**
- **Deployment phase**
  - All in operation

**Project snapshot:**
- 32 HRS and >550 vehicles have been deployed to date:
  - 194 Renault Kangoo vans
  - 40 Daimler B Class F-CELL and 60 Daimler GLC F-CELL
  - 107 Toyota Mirai
  - 10 Honda Clarity
  - 106 vehicles procured by project partners

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Significant HRS and Vehicle deployment outside H2ME projects
The H2ME project is supporting advancements on the state of the art for the sector

Fleet validation for Fuel Cell Electric Vehicles

- Vehicles have reported a total of **11.59 M km driven since the first vehicles were deployed** in Q3 2015.
- The **furthest distance travelled** by one vehicle was **120 000 km**, accumulated since August 2017.
- **Daily distance** covered for **500-550 km** reported.
- **Average availability** for the vehicle is **effectively 99%+** for all FCEVs.
- **No major safety incidents reported.**

Network validation for Hydrogen Refueling Stations

- All H2ME HRS have dispensed **72 132 kg of H2 in 35 518 refuelling events** since March 2016.
- The most utilised HRS in the project alone has dispensed **32 464 kg H2 since Q3 2017** due to usage from STEP/Hype taxis.
- **Average availability** HRS for best performing HRS reached **99.9%**.
- **No major safety incidents have been reported.**
Large fleets of high utilisation cars and vans

Taxis offer the highest utilisation of hydrogen amongst passenger cars

Heavily regulated which allows the state to regulate in favour of zero emission options

Taxis can be scheduled to fuel at a limited number of stations

Interesting projects emerging across Europe

• Paris – STEP - 600 taxis by 2020
• London – 50 Green Tomato taxis
• Brussels, Copenhagen, The Hague etc

Source: ZEFER project.
*Fuel Cell Electric Vehicles
• Introduction
• H2ME project
• **JIVE project**
• H2Haul project
• Additional information
Together, the *JIVE* projects will demonstrate nearly 300 fuel cell buses in over 20 different cities across Europe.

### Joint Initiative for hydrogen Vehicles across Europe

**Objectives**

Deploy large fleets of FC buses and associated refuelling infrastructure

Achieve a maximum price of €625k for a standard fuel cell bus (JIVE 2)

Enable new entrants to trial the technology

Stimulate further large scale uptake

Validate large scale fleets in operation

Demonstrate routes to low cost renewable H₂

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The JIVE project began in 2017; JIVE 2 began in 2018. Both projects are funded by the FCH 2 JU.
JIVE vehicles are starting to be delivered – 130 ordered, deadline for all 290 to be ordered by end of the year
European bus OEMs with fuel cell programs
JIVE has now ordered from 5 of these suppliers, with at least 2 others expected soon - <€650k target price
The H2Bus project aims to deliver “the lowest cost truly zero emission bus” to the European bus market.

In June 2019, the establishment of the “H2Bus Consortium” was announced.

Initial wave of deployment of 600 fuel cell buses

Focused in three clusters

Supported by €40m of funding from the Connecting Europe Facility (CEF).

The volume enables:

• FC bus priced at <€375k (single deck)
• Hydrogen price of €5–7/kg³ (for parity with diesel on a per kilometre basis)
• Bus maintenance cost of €0.30/km
• Introduction
• H2ME project
• JIVE project
• H2Haul project
• Additional information
Objectives

• Develop long-haul heavy-duty (26-44t) fuel cell trucks in a range of operating environments and homologate three truck types

• Install hydrogen refuelling infrastructure at each of the demonstration sites and put in place arrangements for high reliability hydrogen supplies that maximise environmental benefits

• Achieve >2 million kilometres, proving the viability of the technology and demonstrating high reliability compatible with mainstream trucking operations under normal operation conditions

• Prepare the European market for further roll-out of fuel cell trucks through development of innovative commercial models and disseminating information from the project to a wide audience of relevant stakeholders

The H2Haul project began in 2019 and is funded by the FCH 2 JU.
Selection of fuel cell heavy-duty vehicles in Europe (non-exhaustive):

<table>
<thead>
<tr>
<th>Project / product</th>
<th>Coop FC truck demo</th>
<th>ASKO FC truck demo</th>
<th>H2-Share</th>
<th>Hydrogen region 2.0</th>
<th>REVIVE</th>
<th>GOH! (Generation of Hydrogen)</th>
<th>Man &amp; Shell demo</th>
<th>HVSystems</th>
<th>Hyundai</th>
<th>Nikola</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle supplier</td>
<td>MAN (ESORO)</td>
<td>Scania</td>
<td>VDL</td>
<td>VDL</td>
<td>E Trucks Europe</td>
<td>GreenGT/(Kamaz)</td>
<td>MAN</td>
<td>HVSystems</td>
<td>Hyundai</td>
<td>Nikola</td>
</tr>
<tr>
<td>GVW</td>
<td>34t</td>
<td>27t</td>
<td>28t</td>
<td>40t</td>
<td>Refuse trucks</td>
<td>40t</td>
<td>44t</td>
<td>18t (34t with trailer)</td>
<td>40t</td>
<td></td>
</tr>
<tr>
<td>No. of trucks</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>TBC</td>
<td>1,600</td>
<td>TBC</td>
</tr>
<tr>
<td>Demo location (s)</td>
<td>Switzerland</td>
<td>Norway</td>
<td>BE, DE, FR, NL</td>
<td>Belgium</td>
<td>7 sites</td>
<td>Geneva</td>
<td>Germany</td>
<td>TBC</td>
<td>Switzerland – others potentially</td>
<td>TBC</td>
</tr>
</tbody>
</table>

Source: [www.netinfom.eu/h2/2/2/2/Mobilizing-truck-transport-ages/H2/2/2/2/2](https://www.netinfom.eu/h2/2/2/2/Mobilizing-truck-transport-ages/H2/2/2/2/2)


Source: [https://www.bmv.gov.de/de/Pressemitteilungen2019/079-scheuer-rundwaertest.html](https://www.bmv.gov.de/de/Pressemitteilungen2019/079-scheuer-rundwaertest.html)

Source: [https://www.linkedin.com/pulse/shell-man-project-receives-federal-funding-paul-barzel](https://www.linkedin.com/pulse/shell-man-project-receives-federal-funding-paul-barzel/)


Source: [https://nikolareto.com/trc]
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Experience shows increasing convergence with strategies and focus on higher utilisation rates and joint initiatives

**H₂ mobility rollout strategies**
- Colocation of vehicles and HRS. The low number of HRS remains a barrier to adoption; each fleet has their own requirements for HRS locations depending on their operations.
- Using mixed vehicle types and high demand applications to help sustain the early network.
- Developing viable clusters of stations in key locations. A min. of 2 HRS is required to establish demand from light fleet applications.
- Increasing number of joint initiatives. Such partnerships can help to unlock benefits of scale for FCEV and/or HRS business cases.

**Identification of sweet spots for early adoption of FCEVs**
- Through loading of stations with mixed vehicle types, with a focus on heavy duty vehicles e.g. buses and trucks
- Via high mileage applications and operational advantage e.g. taxi fleets and long range with fast charging

Conclusions: Demand for FCEVs and associated HRS is growing, driven by increasingly ambitious emissions targets and policy at European, national and local scale
And that further efforts are required to prepare for the commercial roll-out

**HRS network implementation**

- HRS deployment times are still subject to delays at the permitting stage due to the lack of standardised permitting process with authorities.
- Access to utilities and land can be problematic.
- Guidance have been developed for most countries and commissioning time is decreasing.

**Costs reduction**

- At low levels of demand (<200kg/day) the cost of producing and supplying hydrogen at an HRS can be high;
- FCEVs also still have a significant cost premium compared to diesel vehicles.
- Economies of scale and technology learning curves could enable vehicles and hydrogen to be cost-competitive with counterfactuals; this is starting to be achieved in specific cases.

**Public sector support**

- Business cases can be improved by combining public sector support with partnerships and JV.
- Success stories linked to financial incentives/tax exemptions for zero emission vehicles, as well as restrictions on diesel vehicles.

**Conclusions:** To achieve further scale-up, effective short term solutions and public funding are needed to ensure that prices for hydrogen and vehicles are sufficiently low to stimulate demand.
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.

<table>
<thead>
<tr>
<th>Infrastructure cost / national fleet size</th>
<th>up to 100,000 vehicles</th>
<th>From 1 million vehicles</th>
<th>From 20 million vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>For Battery vehicles</td>
<td>~ EUR 310 million</td>
<td>~ EUR 2.8 billion</td>
<td>~ EUR 51 billion</td>
</tr>
<tr>
<td>For Hydrogen vehicles</td>
<td>~ EUR 450 million</td>
<td>~ EUR 1.9 billion</td>
<td>~ EUR 40 billion</td>
</tr>
</tbody>
</table>

Sources: Shell, Jülich.
https://www.shell.de/medien/shell-publikationen/shell-hydrogen-study.html#vanity-aHR0cHM6Ly93d3cuc2hlbGwuZGUvaDJzdHVkaWVuAHRtBA
**Attractive ownership models are starting to emerge** for example:

- **long distance captive fleets with high utilisation mode or ‘first responders’**
- **taxis or private hire vehicles in cities with strict environmental targets**

### Motivation for operator(s)

**Operational flexibility:**
- Green operation
- No idle time
- Ability for fast response

**Preparing for the future:**
- Tool / long term strategy to comply with national and local regulations (emissions, noise)
- Engaging early with the technology helps prepare and can provide a competitive advantage

### Incentives

**Pioneer locations:**
- Large metropolitan cities (London, Paris, etc.)
- Airports
- Etc.

**Tool-box:**
- Local grants for green vehicles
- National grants / tax relief for green vehicles
- Low emissions zones
- Access to bus lanes/ priority lane/ pedestrianised city centers

**Total cost of ownership (TCO)**

- Analysis based on 70,000 km/yr (average for a London taxi)

**FCEV taxis could be cost effective with incentives in a city like London**

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1- Based on 12EUR/day, 250 days per year for 4 years, and 5000 EUR purchase incentive
Emerging themes

- A clear **acceleration of activity** on fuel cell buses.
- Deployments focussing on **commercial aspects** instead of “demonstration”
- Activity in **China and across Asia** is the most aggressive
- **Many OEMs** are now coming forwards with first plausible product
- Prices starting to look competitive (when linked to **high volume plans** – 100+ buses per OEM)
- **Scale within depots also helps drive down** maintenance and hydrogen prices
- Marketing for the “**genuinely zero emission bus, without compromise**”
The sales proposition for these new fuel cell bus products

- **Long ranges** (>400km if required)
- **Low fuel consumption** (7-8kg/100km) - a 20-30% improvement over the current generation
- **Fast fuelling** (as low as 5 mins)
- **Reliable fuelling**
- **Minimal infrastructure** in depot or ex-depot grid upgrades
- **Small footprint**
- **Direct coupling to renewables**
- **No need for auxiliary heaters** in cold climates
- **Next generation fuel cells have full freeze start**
- **First plausible maintenance arrangements** – still work to do!
H2Bus Consortium cost reduction projections

Single-deck urban bus annuitised total cost of ownership
‘000€/bus/year