FCH JU
HD activities

Bart Biebuyck
Executive Director,
Fuel Cells and Hydrogen
Joint Undertaking
Demonstration projects
Long haul and urban applications

Long haul
- At least 400 km autonomy;
- Tractor and rigid configurations;
- Integration in the daily operations of end users with different operations (Air Liquide, BMW, Carrefour, Colruyt);
- 2021/2022 deployment of the trucks;

Refuse trucks
- Daily back-to-base missions;
- Design standardization towards mass production;
- Fleet operation: 120,000 hours;
- First truck already deployed in Breda;

Validation of FC and hydrogen technology for heavy-duty applications in real-life conditions.

30 trucks
13 demonstration sites
7 countries
Components & infrastructure
Custom development for HD applications

**Durability-Lifetime of stacks for Heavy Duty trucks**
- Understanding of degradation mechanisms;
- Aim 30,000 hours durability;

**Standard Sized FC module for Heavy Duty applications**
- Joint effort between FC suppliers and OEMs;
- Fostering economies of scale, “plug & play concepts” and competition;

**Scale-up and demonstration of innovative hydrogen compressor technology for full-scale hydrogen refuelling station**
- Upscale and integrate innovative compressor in HRS;
- Demonstration in HRS ≥200kg/d H₂;

**Feasibility of liquid H₂ on-board storage for heavy-duty vehicles**
- Evaluate feasibility through a design study and demonstration test bench;
- No projects in 2021!
Study and protocols

Business models safe and rapid refuelling operations completing the picture

**Safe & rapid refueling operations**

**Protocol for heavy-duty hydrogen refuelling**

- Develop refueling protocol(s) for vehicles with Compressed Hydrogen Storage System >250litre, >10kg;
- Identify factors limiting the refueling rate (120g/s) and propose solutions for larger flow rates;
- Findings and recommendations should be shared with relevant sectors and standardization committees;

**Business models**

1. State of the art;
2. Business cases and market potential;
3. Case studies;
4. Recommendations;
Study on European business cases for fuel cells and hydrogen trucks

EU Hydrogen Week
Yvonne Ruf – Roland Berger GmbH
This presentation introduces the results of a study conducted on fuel cells and hydrogen in heavy duty trucks

**Project objectives**

**Objectives of the project**

- Development of **business cases and market potential analyses for the use of FCH technologies** based on use cases (e.g. different range and load profiles)

- Development of **case studies by fuel cell and hydrogen application** (different composition, freight load, route and range) expressing potential opportunities

- Identification of **technical and not technical barriers** for the implementation of fuel cell and hydrogen technologies

- Identification of **needs in research and innovation (R&I), regulation, and standards**

- **On a higher level:**
  - **Creation of a platform for the collaboration of key stakeholders of commercialising FCH heavy duty road transport applications**
  - **Conduct analytical ground work in support of future R&I funding from EU sources**

Source: Roland Berger
We mobilised a balanced Advisory Board with 56 companies and organisations across 15 European countries.

### Advisory Board Members

<table>
<thead>
<tr>
<th>AB member base</th>
<th>Vehicle OEMs</th>
<th>Technology providers</th>
<th>Infrastructure and H₂ providers</th>
<th>Truck operators / Logistics users</th>
<th>Associations and others</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>13</td>
<td>10</td>
</tr>
</tbody>
</table>

**Geographical distribution**

- 15 countries in Europe

Source: Roland Berger
The road freight sector is an important pillar of the European economy, yet a significant source of CO$_2$ emissions

Road freight sector in the EU

Major transport corridors typically along South-North and West-East

- Trucks drive in the EU (medium- and heavy-duty): 6,6 m
- New heavy-duty trucks are sold in Europe every year: 300 k
- Of total EU CO$_2$ emissions come from heavy-duty road transport: ~5%
- Of specific road transport CO$_2$ emissions in the EU come from lorries, buses and coaches: ~27%

Source: European Commission; EEA; ACEA; Colliers; Savills; desk research; Roland Berger
The EU Green Deal aims for a 90% reduction in transport emissions by 2050 and national regulation prompts the uptake of technologies

Selected examples of emissions and air quality regulation

**European Union**

> Two EU Ambient Air Quality (AAQ) Directives\(^1\) set air quality standards and requirements for Member States (incl. monitoring, obligation to adopt national air quality plans, accountability in court)

> The National Emissions Ceilings (NEC) Directive (2016/2284/EU) sets national emission reduction commitments for 2020 and 2030 targeting six main pollutants\(^2\)

> National Air Pollution Control Programmes (NAPCPs) are required in all EU Member States since 2019

> For HDT, the EURO VI regulation sets stricter type approval standards aimed at improved air quality through
  - Not-to-exceed emission limits
  - Stricter testing cycles
  - Independent market surveillance

1) Directives 2008/50/EC and 2004/107/EC  2) Sulphur dioxide, nitrogen oxides, volatile organic compounds, ammonia, methane and fine particulate matter

**National approaches**

<table>
<thead>
<tr>
<th>Country</th>
<th>Measures</th>
</tr>
</thead>
</table>
| France / Paris | > Low emission zones in place in several cities, excl. access for vehicles below Euro 4  
> Access regulation for delivery trucks in several cities with time restrictions  
> Plan to ban all diesel cars in 2024 in Paris, exemption for delivery trucks |
| UK / London | > Plan to ban new petrol, diesel and hybrid car sales from 2035, trucks not covered  
> Ultra Low Emission Zone (ULEZ) in the City of London since 2019 and complete ban of petrol and diesel cars since March 2020 in selected central parts |
| Germany / Stuttgart | > National framework of low emission zones in place incl. vehicle bans  
> Transit bans in several cities for medium- and heavy-duty vehicles  
> 'Smog alarm' programme in Stuttgart for times of high particulate concentration |
| Spain / Madrid | > Low emission zone in place in several cities with eased restrictions in Madrid (2019)  
> Weight restricted access for trucks during daytime and holidays incl. bans for heavy-duty trucks to access central city areas |

Source: European Commission; Desk research; Roland Berger
While multiple alternative powertrain options exist, FCH offer a 0-emission alternative with operational and payload flexibility.

High-level comparison of powertrain technology portfolio for HDT

<table>
<thead>
<tr>
<th>Reference</th>
<th>Project focus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fossil powertrains</strong></td>
<td><strong>Zero emission</strong>¹</td>
</tr>
<tr>
<td><strong>Diesel</strong></td>
<td><strong>Battery-electric</strong></td>
</tr>
<tr>
<td><strong>LNG/CNG</strong></td>
<td><strong>Fuel Cell-electric</strong></td>
</tr>
</tbody>
</table>

**Description**
- **Combustion engine powered by diesel**
- **Combustion engine powered by LNG/CNG**
- **Combustion engine powered by e-diesel**
- **Electric motor powered by chemic. stored energy in a rechargeable battery**
- **Electric motor powered by a fuel cell, combined with a battery**
- **Electric motor powered by DC from overhead lines using a pantograph**

**Strengths**
- > Established technology with widespread infrastructure
- > Long daily driving ranges
- > Fuel cost advantage compared to diesel
- > Lower particulate emissions than diesel
- > Use of existing infrastructure
- > Use of existing HDT combustion engines
- > Meet emission restrictions
- > High powertrain efficiency
- > Meet emission restrictions
- > Possibility for long daily driving ranges
- > Quick refueling compared to BET
- > Availability of infrastructure
- > Production cost not on competitive level: ~3.5 x diesel price
- > Remaining local emissions (e.g. NOₓ)
- > CO₂ sourcing
- > Cost, size and weight of batteries
- > Range limitations
- > Recharging time and space required
- > Vehicle cost
- > Availability of infrastructure
- > Limited flexibility of routes
- > Early development stage

**Potential constraints**
- > CO₂ and NOₓ emissions and related regulation
- > Infrastructure availability
- > Limited emission reduction potential
- > Relatively low fuel efficiency (~25%)
- > Production cost not on competitive level: ~3.5 x diesel price
- > Remaining local emissions (e.g. NOₓ)
- > CO₂ sourcing
- > Cost, size and weight of batteries
- > Range limitations
- > Recharging time and space required
- > Vehicle cost
- > Availability of infrastructure
- > Limited flexibility of routes
- > Early development stage

¹ With primary energy derived from renewable sources
 Remaining local emissions

Source: Desk research; Roland Berger
The technological readiness level of FCH in heavy duty trucks is comparable to battery electric technologies

Overview technological readiness level

<table>
<thead>
<tr>
<th>Alternative powertrain technologies for HDT</th>
<th>Refuel. / charg. infrastructure</th>
<th>Emission red. potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel cell electric</strong></td>
<td>Idea 1</td>
<td>2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td><strong>Battery electric</strong></td>
<td>Idea 1</td>
<td>2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td><strong>Lower-carbon fuels</strong></td>
<td>Idea 1</td>
<td>2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td><strong>Synthetic fuels / e-fuels</strong></td>
<td>Idea 1</td>
<td>2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td><strong>Catenary and trolley</strong></td>
<td>Idea 1</td>
<td>2 3 4 5 6 7 8 9</td>
</tr>
</tbody>
</table>

1) Emission reduction potential: Tank-to-Wheel  
2) Low carbon fuels (e.g. CNG, LNG), liquid biofuels fuels  
3) Sustainable e-fuels from renewable sources

*) Technology Readiness Level of truck

Source: Roland Berger

Legend:   low level  high level
From a TCO perspective, FCH HDT can become cost-competitive with diesel by 2027 if production volumes are ramped up swiftly.

High-level TCO assessment – Use case I [EUR ct/tonne-km; 1st & 2nd life]

1 Use case I – Tractor 4x2, 140,000 km annual mileage

- FCH trucks for use case I have a cost premium of up to ~19% in 2023 compared to diesel and could become cheaper if implemented at scale.
- FCH truck technologies can be more competitive than the alternatives Diesel E-Fuels, BEV and catenary on a tonne-km basis.
- When considering 1st and 2nd life, a significant cost down potential for FCEV at scale exists.

1) Under the assumption that sufficient hydrogen storage can be technically integrated in the current truck chassis architecture. Potential length regulation adjustments required.
2) The technical maturity is at a very early stage and needs to be demonstrated in a truck.

Source: Roland Berger
The market potential of FCEV can increase to an overall sales share of 17% in 2030 – Strong uptake from 2027 until 2030

European market potential of FCEV [# of truck sales] – Total base scenario

> The market potential analysis focuses on selected market segments that represent the most relevant logistics industry segments (sales share of ~53% in the base year)

> In 2023, the sales share of FCEV is at 0.2% due to assumptions made for limited market maturity, yet increasing uptake opportunities

> In 2027, a 1.8% sales share is expected for FCEV

> In 2030, the FCEV sales share increases to ~17%

> The BEV sales share is increasing overall and establishes a market share of 9% until 2030

1) The relative development of ZEV is based on the total number of truck sales in Europe, including the market segments selected for the market potential analysis (53% of total)
2) The market potential analysis refers to specific market segments: international logistics, national logistics, manufacturing industry, wholesale, retail and regional logistics

Source: IHS market forecast; Roland Berger
A fast market ramp-up over the next ten years is crucial for achieving the 2050 climate goals – Fleet replacement required

Assessment of 2050 market potential

> The CO₂ emission reduction targets for 2050 in transport can be reached for the heavy-duty truck segment – if the growth rate of zero emission technology until 2030 materialises

> As zero-emission trucks become cost-competitive, new sales of diesel trucks and other CO₂-intensive technologies could be replaced from 2035 onwards – this is necessary to replace the majority of the fleet of diesel trucks until 2050

> Critical factors:
  - Push to market for zero-emission trucks to ensure scaling effects for cost competitiveness and market uptake
  - Enable infrastructure availability to allow for widespread deployment
  - Change within fleets and diesel phase-out until 2035 as diesel trucks have a total lifetime of 10+ years
  - Specific mandatory targets for all market actors – OEMs in scope of HDT legislation, yet contribution across the whole sector necessary

Source: IHS market forecast; Roland Berger
Case studies demonstrate that requirements for logistics operations can often be satisfied with a flexible FCH zero-emission option

Overview of analyzed case studies

<table>
<thead>
<tr>
<th>Use case</th>
<th>Location</th>
<th>Truck type</th>
<th>Country</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use case I</td>
<td>Košice-Bratislava</td>
<td>4x2, 40 t</td>
<td>SK</td>
<td>Bioway</td>
</tr>
<tr>
<td>Use case I</td>
<td>Alsace region</td>
<td>6x2, 27 t</td>
<td>FR</td>
<td>FM Logistic</td>
</tr>
<tr>
<td>Use case I</td>
<td>Zwickau-Emden</td>
<td>4x2, 18 t</td>
<td>DE</td>
<td>Schnellecke</td>
</tr>
<tr>
<td>Use case II</td>
<td>Hof-Kladno</td>
<td>4x2, 18 t</td>
<td>DE/CZ</td>
<td>DACHSER</td>
</tr>
<tr>
<td>Use case II</td>
<td>Valencia region</td>
<td>4x2, 18 t</td>
<td>ES</td>
<td>DISFRIMUR</td>
</tr>
<tr>
<td>Use case II</td>
<td>Bolzano-Munich</td>
<td>4x2, 18 t</td>
<td>IT/DE</td>
<td>FERCAM</td>
</tr>
<tr>
<td>Use case III</td>
<td>Hatfield</td>
<td>4x2, 18 t</td>
<td>UK</td>
<td>DHL</td>
</tr>
<tr>
<td>Use case III</td>
<td>Leoben-Göss region</td>
<td>4x2, 18 t</td>
<td>AT</td>
<td>Brau Union</td>
</tr>
<tr>
<td>Use case III</td>
<td>Flen-Stockholm</td>
<td>4x2, 18 t</td>
<td>SE</td>
<td>Unilever</td>
</tr>
</tbody>
</table>

Source: Roland Berger
Europe is already at the forefront of FCH truck demonstration however cost reduction and addressing remaining barriers is key

Geography of key fuel cell hydrogen HDT trial and demonstration projects

Europe: Overall, 12 relevant projects have been identified – many projects are conducted cross-nationally

<table>
<thead>
<tr>
<th>Country</th>
<th>Projects</th>
<th>Cross-National Projects</th>
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</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>5 projects (5)</td>
<td>1 project</td>
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<tr>
<td>France</td>
<td>5 projects (3)</td>
<td>1 project</td>
</tr>
<tr>
<td>Germany</td>
<td>5 projects (3)</td>
<td>6 projects (5)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6 projects (5)</td>
<td>1 project</td>
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<tr>
<td>Norway</td>
<td>1 project</td>
<td>1 project</td>
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<tr>
<td>Sweden</td>
<td>1 project</td>
<td>4 projects (1)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1 project</td>
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</tr>
</tbody>
</table>

North America: 9 projects

USA: 8 projects

Canada: 1 project

South Korea: 1 project

Asia: 2 projects

1) Finalised, ongoing and planned HDT trial and demonstration projects since 2015 until today  2) The number in ( ) signals the number of cross-national projects

Source: Desk research; Roland Berger
While still some remaining barriers exist at this stage of market development no roadblocks have been identified.

Overview of barriers and priority for short-term R&I

<table>
<thead>
<tr>
<th>Priority and need for action</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
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<tbody>
<tr>
<td>1. Truck product development and system integration</td>
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<td>2. Truck performance</td>
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<td>3. OEM development cycles</td>
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<tr>
<td>4. FC stack lifetime &amp; FC degradation</td>
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<td>5. Thermo-dynamics</td>
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<td>6. Service and maintenance requirements</td>
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<tr>
<td>7. Standardisation of H₂ storage technology</td>
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<tr>
<td>8. Weight/volume limitation due to H₂ storage</td>
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<tr>
<td>9. H₂ supply to HRS</td>
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<tr>
<td>10. H₂ refuelling networks</td>
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<tr>
<td>11. Communication of truck and HRS</td>
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<tr>
<td>12. Standardised refuelling protocols</td>
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<tr>
<td>13. CAPEX and OPEX of HRS</td>
<td></td>
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<tr>
<td>14. CAPEX of truck powertrain</td>
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<td></td>
</tr>
<tr>
<td>15. H₂ cost development</td>
<td></td>
<td></td>
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<tr>
<td>16. 2nd life market</td>
<td></td>
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<tr>
<td>17. Financing and funding support</td>
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<tr>
<td>18. Supplier diversity</td>
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<tr>
<td>19. Long-term plannability</td>
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<tr>
<td>20. Type approval</td>
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<tr>
<td>21. Safety and emergency measures</td>
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<tr>
<td>22. Stakeholder dialogue</td>
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</tbody>
</table>

1) Prioritisation, esp. with regards to safety & emergency measures, does not reflect the overall importance of the topic, but the perspective on main need for action in the HDT sector.

Source: Study analysis, Roland Berger
The study suggests four tailored R&I projects, with an estimated total budget of EUR 470 million to overcome remaining barriers.

<table>
<thead>
<tr>
<th>A</th>
<th>Technology development and optimisation for standardised on-board hydrogen storage systems for FCH HDT and refuelling protocol development</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; Integrated technology development for optimised hydrogen storage for FCH HDT</td>
<td></td>
</tr>
<tr>
<td>&gt; Optimisation and standardisation of filling pressure, tank size, tank location, filling protocol, etc.</td>
<td></td>
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<tr>
<td>&gt; Analysis of total value chain TCO</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Development of FC truck and powertrain prototypes for integration and standardisation of FCH technology</td>
</tr>
<tr>
<td>&gt; Development of prototypes in the area of truck and powertrain design to improve integration and standardisation of FCH technology in existing truck architecture</td>
<td></td>
</tr>
<tr>
<td>&gt; Design of new truck models optimised for FCH applications</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Cross-border multi-national demonstration of FCH HDT fleets</td>
</tr>
<tr>
<td>&gt; Large scale demonstration of 500 or more FCH HDT could accelerate the roll-out of fleet sized FCH truck deployment</td>
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<tr>
<td>&gt; Potential split in several sub-projects</td>
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<tr>
<td>D</td>
<td>Technology development for high throughput, low footprint and high energy efficiency HRS for HDT</td>
</tr>
<tr>
<td>&gt; Development of refuelling protocols, storage optimisation, refuelling time and frequency for the roll-out of a comprehensive HRS network across Europe and/or several regional hubs, e.g. hydrogen valleys</td>
<td></td>
</tr>
<tr>
<td>&gt; Analysis of value chain and TCO calculations</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
<th>Technology development and optimisation for standardised on-board hydrogen storage systems for FCH HDT and refuelling protocol development</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 bar 700 bar LH₂</td>
<td></td>
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<tr>
<td>Other options: 500 bar ( \text{ccH}_2 )(^1)</td>
<td></td>
</tr>
<tr>
<td>EUR 10 m</td>
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<tr>
<td>B</td>
<td>Development of FC truck and powertrain prototypes for integration and standardisation of FCH technology</td>
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<tr>
<td>5-20 units</td>
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<td>5-20 units</td>
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<td>5-20 units</td>
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<tr>
<td>EUR 100 m</td>
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<td>C</td>
<td>Cross-border multi-national demonstration of FCH HDT fleets</td>
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<tr>
<td>500</td>
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<tr>
<td>EUR 350 m</td>
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<tr>
<td>D</td>
<td>Technology development for high throughput, low footprint and high energy efficiency HRS for HDT</td>
</tr>
<tr>
<td>GH₂ supply to gaseous refuelling</td>
<td></td>
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<tr>
<td>On-site production to gaseous refuelling</td>
<td></td>
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<tr>
<td>LH₂ supply to gaseous refuelling</td>
<td></td>
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<tr>
<td>LH₂ supply to LH₂ refuelling</td>
<td></td>
</tr>
<tr>
<td>EUR 5-10 m</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Cryo-compressed hydrogen

Source: Expert interviews; Roland Berger
Structured market incentives offered at different political levels should provide the necessary framework for production at scale

Policy recommendations

**EU**
1. Road toll exemption for zero-emission vehicles for longer time periods, e.g. for 10 years, as well as considering road toll increases for higher emitting vehicles, such as in the Eurovignette Directive
2. Government-driven base infrastructure coverage of countries, e.g. as already in discussion as part of the Alternative Fuels Infrastructure directive
3. Adjusted regulations on FCH heavy-duty truck dimension to provide a legal framework for integrating alternative powertrains in trucks

**National governments**
4. Exemption of levies and fees for production of green hydrogen within an extended time period of up to 10 years and/or until binding targets of green hydrogen shares are fulfilled
5. Subsidies for hydrogen refuelling station OPEX when stations are underutilised, improving cost competitiveness of H₂ through higher plannability for station investors
6. Tax breaks for logistics operators that transition to FCH HDT, for example via stricter supply chain laws that incorporate provisions on CO₂ emission as an additional tax on logistics services and offerings
7. Introduction of CO₂-related taxation in the logistics and delivery industry, creating an additional incentive for logistics providers to speed-up a transition to zero-emission vehicles

**Municipalities**
8. Preferred treatment for zero-emission vehicles, e.g. through the establishment of lanes specifically dedicated to ZEV and guaranteed free parking zones for ZEV at refuelling stations and motorway rest stops
9. Special permits for zero-emission vehicles to enter restricted areas, e.g. city centre and urban areas during early morning or evening/night times

Note: Policy measures not in order of priority

Source: Roland Berger
With a concerted effort, fuel cells and hydrogen can play a leading role in decarbonizing transport in Europe

Source: Roland Berger
For further information, please feel free to reach out to...

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Source: FCH JU, Roland Berger