End-uses: Transport

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Clean Hydrogen Partnership
Sessions on end-uses: transport

16th Nov. 9:30-11:00
End-Uses: Transport
Luca Feola

16th Nov. 11:30-13:00
Building Blocks for Transport Applications
Pietro Caloprisco
Decarbonizing transport: portfolio overview

Transport modes
- Cars
- Buses
- Urban Lorries & Trucks
- Maritime
- Train
- Aviation

Building blocks
- FC stack components, BoP
- Hydrogen tanks
- Hydrogen infrastructure
Decarbonizing transport: portfolio overview
Allocation of funds into different transport modes

Transport: Clean H₂ JU support

€ 489 M

JU funding per transport mode

- Aeronautic applications
- Bus / Coaches
- Heavy Duty Vehicles
- Waterborne applications

RIA: Research & Innovations Actions
IA: Innovation Actions (Demo)
Decarbonizing transport: portfolio overview
Allocation of funds toward entity types and type of actions

JU Funding per type of beneficiary

- PRC: Private Companies
- REC: Research Centres
- HES: Higher Education Schools
- PUB: Public Bodies
- SME: Small Medium Enterprises
- OTH: Others

JU Funding per type of Beneficiary (per call)
Decarbonizing transport: from building blocks into prototypes
Prototype tests ongoing for all transport modes

Transport modes

**Cars:** Demo projects concluded: sharing lessons learned

**Buses:** FC technology reliable, HRS to be improved

**Urban Lorries & Trucks:** Tests ongoing or planned

**Maritime:** vessels construction delayed

**Train:** test on public rail

**Aviation:** first flight of liquid H₂ powered aircraft

Prototype tests ongoing for all transport modes
Light duty vehicle demonstration
Demo projects concluded: lessons learned shared

Achievements (H2ME/ZEFER)
- ~20% of all FC vehicles and ~20% of all HRSs in EU funded through these projects (1,740 cars and 46 HRSs)
- 245 tons of H\(_2\) dispensed in 2022
- 1,4 million h of operation/ 1,400 tons CO\(_2\) avoided

FCEVs cumulative distance driven
- x100 in 7 years
- ~55 Million km driven

Fleet business models
- Spreading to other ZE cities
- Infrastructure + vehicles deployment at same time
- Increasing size of fleet, widening the applications (Hype taxi in Paris)

Lessons learnt from cars projects
- (+) Fuel Cell technology reliable for mass deployment
- (+) FCEV refuel time remains advantageous versus EVs
- (-) HRS infrastructure to be further improved:
  - (-) low availability of HRS due to technical issues
  - (-) low redundancy of HRS on the territory
  - (-) decreased performance if HRS is underutilised
Fleets of 5-50 buses in fifteen locations across EU
FC technology reliable for the end-use, HRS still to be improved

**Real operational data**
- 252 FCB deployed (~65% of all FC buses in EU)
- Range similar to diesel bus (>350km)
- Excellent fuel efficiency 6-7kgH₂/100km
- More than 13 million km driven
- Expected infancy issues cleared

**Increasing buses availability, HRSs availability to be further improved**
- Positive trend of FCB availability (target 90%)
- 85% of issues causing FCB unavailability are due to non-FC related components
- HRSs still face issues of unavailability due to technical issues (software, hardware, H₂ supply)

**Fleet mileage data**
- Monthly distance travelled (km)
- Number of buses in all fleets

**Buses availability data**
- Average availability (%)
- JIVE 1+ JIVE 2
- Target
- Only JIVE
- Only JIVE 2
- Trendline
FCB exploring new markets and increasing awareness

Increasing market and awareness

- Zero Emission Bus conference
- New bus OEMs entering the market
- Demand for coaches and 18m buses
- Best practices guide available: [www.fuelcellbuses.eu](http://www.fuelcellbuses.eu)

JIVE2 Central and Eastern Europe Roadshow

- Display FCB and Mobile HRS in Central and Eastern Europe.
- Showcase the technology to the Public, Governments, PTO, PTA.
- Evaluate FCB performances in different environments.

Key lessons learned from the Roadshow

- Preference of turnkey solution FCB/HRS/H₂/maintenance for deploying FCB fleet by cities and operators.
- Need of synergies with funding programs (CEF, Cohesion fund, Modernisation funds, etc etc).
- Quick adoption (bus orders, commitment) following the roadshow (Estonia, Latvia, Hungary).
Urban heavy-duty applications
Operations started

2022

Deployment 55%

- Antwerp x2
- Breda x 2
- Helmond x 2

6 trucks deployed. 5 more to be deployed in Gothenburg, Groningen, Noordenveld

2024

Urban bin lorries configuration

- Vehicle gross weight 27 t
- Drivetrain 210 kW
- FC Stack 45 kW
- Max speed 90 km/h
- Payload 9 t
- H₂: 15 kg @ 350 bar

Preliminary Data

- Mileage (km) 22,837
- Operating hours 1,670
- H₂ consumed (kg) 3,208

Performance data not mature yet: Teething phase of newly deployed vehicles.

Clean Hydrogen Partnership
European Hydrogen Week
Co-funded by the European Union
Long haul applications
HRS deployment started in synergy with CEF program

Partners and Locations
Targets: 16 HD trucks deployed in 4 EU Countries
6 HRS stations deployed

Latest HRS deployment
- HRS Fos-sur-Mer operational
- 1ton H₂/day
- 700 bar
- Pipeline supply
- Other 5 HRS in Belgium, France and Switzerland currently in operation being upgraded

Truck configurations
<table>
<thead>
<tr>
<th></th>
<th>42t</th>
<th>27t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross weight (tons)</td>
<td>42</td>
<td>27</td>
</tr>
<tr>
<td>Drive train power (kW)</td>
<td>480</td>
<td>210</td>
</tr>
<tr>
<td>Stack Power (kW)</td>
<td>132</td>
<td>50</td>
</tr>
<tr>
<td>Onboard H₂ (kg)</td>
<td>73</td>
<td>30</td>
</tr>
<tr>
<td>H₂ pressure (bar)</td>
<td>700</td>
<td>350</td>
</tr>
<tr>
<td>FC efficiency</td>
<td>55%</td>
<td>47%</td>
</tr>
</tbody>
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Truck deployment
- Truck delivery delayed
- Final tests ongoing, first delivery expected in Q1 2024

H₂Accelerate: Synchronized approach between programs
- 150 trucks
- Range over 600km
- 8 Member States
- 5 TEN-T corridors
- 30 M EUR from Clean Hydrogen JU

3 projects funded:
- 29 HRS
- 1-ton H₂/day @ 350 or 700 bar
- 8 Member States
- 56 M EUR from CEF

Timeline
R&D and deployment
- First 100 trucks
- HRS in clusters

Industrial scale-up
- First vehicle series
- HRS expansion

2022 2026 2028
Ships: towards larger vessels testing different fuels and FC

Building the pilots and experiments to speed up standards for waterborne applications

**Pre-Normative Research**
- Hydrogen for passenger vessels
  - Experimental data
  - Guidelines for safe design for the new IGF chapter on hydrogen

**Challenges**
- Delayed implementation
- $\text{H}_2$ supply issues
- Supply chain issues for large SOFC
- Lenghty authorisation process

**Synergies**

**Maritime**

- R&D vessel $\text{CH}_2$ PEM
- Platform vessel $\text{NH}_3$ SOFC
- Ro-Ro vessel $\text{LH}_2$ PEM

**Fluvial**

- 2 cargo vessels $\text{CH}_2$ PEM
- Barge vessel $\text{CH}_2$ PEM
- 6 inland vessels $\text{CH}_2$ PEM
Ports as hydrogen «coastal hubs»
Pilots for clean port operations in container and ferry terminals

**Heat and on-shore power for ferry terminals**
- Port of Palma = 100kW
- Port of Orkney = 75 kW
- Port of Tenerife = 100kW
- Port of Helsinki = 600kW

**Studies and pilots on:**
- Infrastructure for H₂/NH₃ bunkering
- NH₃ and synthetic fuels for maritime
- Retrofit of port vessels fleet
- Passenger ferries

**Ports as hydrogen «coastal hubs»**
- Creating / Serving H₂ demand locally for energy intensive industry (steel, chemicals, refineries, etc)
- Integration of renewable electricity
- International trading routes for H₂
- Multimodal transport node

**Heavy machinery for container handling**
- Port of Valencia

**Study on hydrogen in ports and industrial coastal areas**
- European Hydrogen Ports Network
  - **Report 1**: Hydrogen demand & supply, business models
  - **Report 2**: R&I, safety and governance gaps
Supporting the uptake of clean rail
Taking the steps towards zero-emission rail

Objective

- Develop a bi-mode fuel cell hybrid train to operate on catenary and on FC/battery propulsion
- Test, validate and carry out the homologation of the prototype

Regulation, codes and standards

- Identify gaps normative framework
- Modifications of relevant standards and technical specifications for interoperability

Tests on railway ongoing

- Tests completed on public railways from Zaragoza to Canfranc.
- Next tests will be on public line Zaragoza - Soria as of Nov. 2023
- Use of mobile HRS

Next steps (2024)

- Track testing of demo in Portugal
- Build own HRS for demo purposes
- Assess competitiveness of H₂ vs diesel train
Toward a clean aeronautic transport
From small planes to long range H₂ powered aircrafts

From Auxiliary Power Unit to small aircraft propulsion
- 2023 - Flying demo with LH₂ tank achieved
  - 4 tests flights completed
  - One flight over 3 hours
  - Flying range doubled from 750km to 1500km
- 2017 - FC for emergency operation
- 2012 - APU for secondary electrical system

Moving to hydrogen powered regional aviation
- Synergy with Clean Aviation JU (CAJU)
- Technology maturation (up to TRL 5/6)
  - Dedicated Fuel cells for Aviation from stack to full system (MW)
  - Disruptive next-gen high temperature fuel cells for future aviation
- Ground and flight tests
  - 2022
  - 2026
  - 2030
- Challenges
  - As outcome of the Workshop (April ’23) with CAJU:
    - LH₂ storage, infrastructure, LH₂ supply
    - Safety measures, regulations and procedures for LH₂
    - FC stack and components size up to 1.5MW
Decarbonizing transport: from building blocks into prototypes
Addressing the main challenges of demanding transport modes

FC stack components, BoP: research on performance increase

Hydrogen tanks: optimising space with comfortable tanks

Hydrogen infrastructure: increasing size, availability to be improved
Driving forward fuel cell technology for HD
Advancing fuel cell components toward performance and durability targets

**MEA/Stack development**
- Focus on charge, mass and heat transports phenomena
- Light-weight and compact fuel cell stack (100kW) designs suitable for automotive applications.

**Focus on durability**
Development of durable and high-power density MEAs for trucks. Target = 30000h at system level.

### Graphs
- **MEA - Areal Power Density**
  - Target = 1.8 W/cm²
  - (All projects – TRUST data)
- **Stack Durability**
  - SRIA Target = 20000 h
  - (All projects – TRUST data)
Driving forward fuel cell technology for HD
Advancing fuel cell components toward performance and durability targets

Heavy Duty Specific projects

Definition of the specifications
- Define dimensions
- Physical interface
- Application Program Interface

Testing campaign
- Partners are building and testing the FC modules
- 50% of the modules built!

Dissemination
- Exploitation workshop done (Sept 2022)
- European Hydrogen Week Side Event (22 Nov 2023)
- Public deliverables

Optimisation of stacks for High Power Range Application
- Deliver a public open-design platform with high efficiency and durability under HD conditions.
- Started June 2023
Hydrogen on-board storage and transport
Developing solutions from gas to liquid hydrogen for all transport modes

Automotive and Road Transport
- High payload road transport: 1.5 tons @ 700 bar H₂ trailers with Type V cylinders
- New materials (type V): cost effective thermoplastic composite
- Conformable tanks: Fitting solutions for tight spaces

Tank cost target: 400€/kg of H₂

Aviation
- Composite conformal LH₂ tank for aviation use
- 57kg with >25% gravimetric efficiency
- Dormancy >24h, Boil-off < 2% day
- Vacuum insulated
- Started 2023 - Ending 2026

Maritime
- Next generation of large LH₂ tanks for shipping on vessels
- Long-term storage and long-distance transport
- Material research
- 180m³ ⇔ 10t LH₂ demonstrator
- Started 2023 - Ending 2027
Witnessing the operation of the new generation HRS

Shifting towards tonnes of H₂ per month for large and solicited stations

Robust HRS service
- Larger HRS sustaining fleets of buses or cars
- Operators handling a network of HRS
- Improved customers experience (payment system, back-to-back, multidispensers, etc.)

HRS availability to be further improved

HRS downtime analysis H2ME & ZEFER (*)

Conclusions

Bus & Cars: FC technology suitable for the end use. Disseminating best practices and lessons learnt at projects conclusion. Infrastructure to be further improved.


Ships, aircrafts, trains and heavy machinery: tests ongoing for the commercial products in the heavy duty segment.

R&D Building blocks: keep improving performances. New materials and tank types on various end uses.