H₂ On-Board Storage Options for Rail Vehicles

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H₂ is Entering the Rail Sector

- **in operation**
- **demonstrator**
- **in development**

**Tram**
- CRRC
- FEVE
- Heiterblick
- Hyundai Rotem

**Railcar**
- Alstom, LNVG / RMV
- Porterbrook, Uni. of Birmingham
- CAF
- JR East, Hitachi, Toyota
- Talgo

**Loco**
- BNSF
- CRRC
- Pesa
- Talgo
- Linsinger

*Image sources: OEMs & Partners*
FCH2RAIL Project in Numbers

• Start date: 01 January 2021
• Duration: 48 Months
• Total budget: **13.3 Mio €**
• H2020 Innovation Action funded by Fuel Cells and Hydrogen 2 Joint Undertaking, now Clean Hydrogen Partnership
• 7 technical Work packages, 29 Milestones, 43 Deliverables
• 2 **Demonstrators**: Fuel Cell Hybrid Power Pack and Bi-Mode Train
• 8 Beneficiaries from Belgium, Germany, Spain and Portugal
H₂ Storage Technology Fundamentals

Hydrogen needs to be compressed, liquefied or materially bonded to achieve competitive energy densities compared to diesel:

- **physical-based**
  - Compressed Gaseous Hydrogen (CGH₂) @ 30-70 MPa
  - Cryo-compressed Hydrogen (CcH₂) @ < -40 °C + high pressures
  - Liquid Hydrogen (LH₂) @ -252,85 °C

- **material-based**
  - hydrogen stored in chemical or physical compounds (liquids or solids)

![Volumetric and gravimetric energy density of vehicle storage systems](image-url)
Due to available technology, successful application for bus & heavy duty and lower costs, **35 MPa CGH$_2$** systems are most used.

Installation Position inside Trains

Depending on vehicle type and clearance gauge, most of the H$_2$ storage systems in demonstrator, prototype and series railway vehicles are mounted on the roof.

- **e.g. Siemens Mireo Plus H**
- **e.g. Stadler (Zillertalbahn)**
- **e.g. Stadler Flirt H2**
H₂ System Storage Capacity

- Largest H₂ storage capacities are installed in railcars
- Lower amounts of H₂ were installed in demonstrators and prototypes
- For multi-car railcars, the current storage capacity at 35 MPa is described as sufficient for daily operation by vehicle manufacturers

FCH2RAIL H₂ Storage System

4 modules x 8 cylinders = 160 kg @ 35 MPa
Available H₂ Storage Systems

- CGH₂ systems are available on the market for different H₂ capacities, certified for road
- 35 MPa systems are lighter than 70 MPa but need more storage volume for the same H₂ amount

Data basis: worldwide requests to manufacturers: CLD, Faber cylinders, Faurecia, Hexagon Purus, Luxfer Gas Cylinders, MAHYTEC, NPROXX, Quantum Fuel Systems, Steelhead Composites, Worthington.
**H₂ Storage System Development for Trucks**

Several OEMs and manufacturers currently work on the further development of LH₂ and CcH₂ storage technology, making the technology also conceivable for railway applications in the future.

MB GenH2 Truck prototype on testing grounds in Wörth, DE (05/2022)

CryoTRUCK consortium
(MAN Truck & Bus, Clean Logistics, Cryomotive, IABG, TUM)

~ 2*50 kg sLH₂

~ 2*40 kg CcH₂

sLH₂ storage tanks

source: Daimler Truck

source: SAG AG

source: Cryomotive

source: Cryotherm GmbH & Co. KG

source: SAG AT

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**H₂ Storage System Comparison**

- 35 MPa → 70 MPa: energy density increases by 1.68, lower on storage system level
- CHP targets are slightly behind expectations for CGH₂ and are difficult to achieve in the future
- LH₂ and CcH₂ systems could double the volumetric energy storage capacity compared to CGH₂ but no series tank systems available, technology under development
- For vehicle integration, additional packaging factors need to be considered, which includes the valves, pipes and mounting depending from diameter and construction space

<table>
<thead>
<tr>
<th></th>
<th>CGH₂</th>
<th>CGH₂</th>
<th>CGH₂</th>
<th>LH₂ *)</th>
<th>sLH₂ *)</th>
<th>CcH₂ *)</th>
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<tbody>
<tr>
<td><strong>pressure [MPa]</strong></td>
<td>35</td>
<td>50</td>
<td>70</td>
<td>0.4</td>
<td>1.6</td>
<td>30</td>
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<tr>
<td><strong>density [g/L]</strong></td>
<td>23.3</td>
<td>30.8</td>
<td>39.2</td>
<td>&gt;63</td>
<td>&gt;63</td>
<td>72</td>
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<tr>
<td><strong>vol. capacity [g/L]</strong></td>
<td>15-18</td>
<td>15-21</td>
<td>18-26</td>
<td>28-40</td>
<td>58-60</td>
<td>33-46</td>
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<tr>
<td><strong>grav. capacity [%]</strong></td>
<td>2.5-8.6</td>
<td>3.2-5.6</td>
<td>1.7-6.8</td>
<td>4.5-5.3</td>
<td>~10</td>
<td>7.5-10</td>
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<tr>
<td><strong>TRL [-]</strong></td>
<td>7.9</td>
<td>7.9</td>
<td>7.9</td>
<td>7</td>
<td>6</td>
<td>7</td>
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**Clean Hydrogen Partnership Targets**

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<tr>
<td><strong>pressure [MPa]</strong></td>
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<td>6</td>
</tr>
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(on-board gaseous hydrogen storage tank in general)
Conclusions

- **CGH$_2$ storage systems** are the most advanced technology (TRL 7-9) for rail vehicles; systems are **market-available** and certified for road at various pressure levels.

- **35 MPa dominating for railcars**; higher energy densities are beneficial, especially for mainline locomotives.

- Currently **no available sector-specific regulations**; existing regulations from road are used; hazards are addressed by individual actions up to an acceptable risk level – but standardization is on the way.

- Efforts to promote the **development of LH$_2$- and CcH$_2$-storage-systems** for trucks (TRL 4-7) making the technology also conceivable for future railway applications.

- Alternative storage solutions e.g. ammonia (TRL 5) and LOHC (TRL 2-3) have been considered for railways and are currently discussed also for other sectors.
Thank you for your attention