H_2 On-Board Storage Options for Rail Vehicles

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Fuel Cell Hybrid PowerPack for Rail Applications

EUROPEAN HYDROGEN ENERGY CONFERENCE

ASOCIACIÓN ESPAÑOLA DEL HIDRÓGENO

Clean Hydrogen Partnership

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FCH2RAIL

H_2 is Entering the Rail Sector

in operation | demonstrator | in development

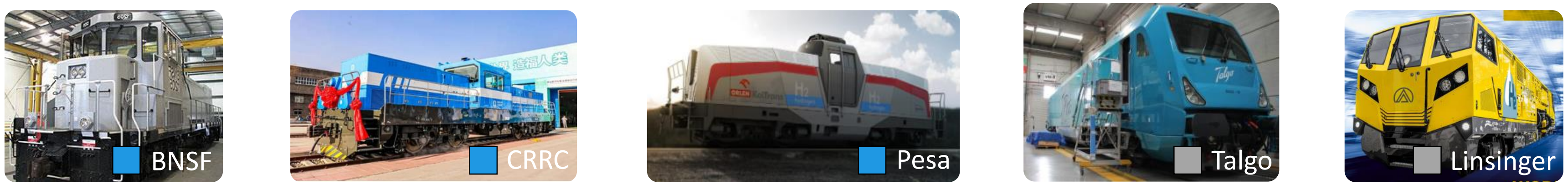
Tram

H_2 consumption | available installation space

Railcar

H_2

Loco



H_2

EHEC 2022
EUROPEAN HYDROGEN ENERGY CONFERENCE

Grant Agreement Number: 101006633

image sources: OEMs & Partners

Clean Hydrogen Partnership

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FCH2RAIL Project in Numbers

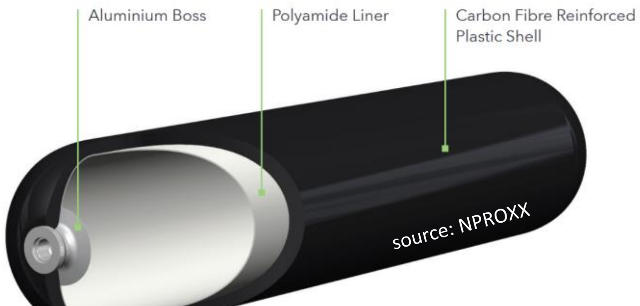
- Start date: 01 January 2021
- Duration: 48 Months
- Total budget: **13.3 Mio €**
- H2020 Innovation Action funded by Fuel Cells and Hydrogen 2 Joint Undertaking, now Clean Hydrogen Partnership
- 7 technical Work packages, 29 Milestones, 43 Deliverables
- **2 Demonstrators**: Fuel Cell Hybrid Power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

renfe DLR CAF Stemmann-Technik A Wabtec Company Infraestruturas de Portugal adif Centro Nacional del Hidrógeno TOYOTA

H_2 Storage Technology Fundamentals

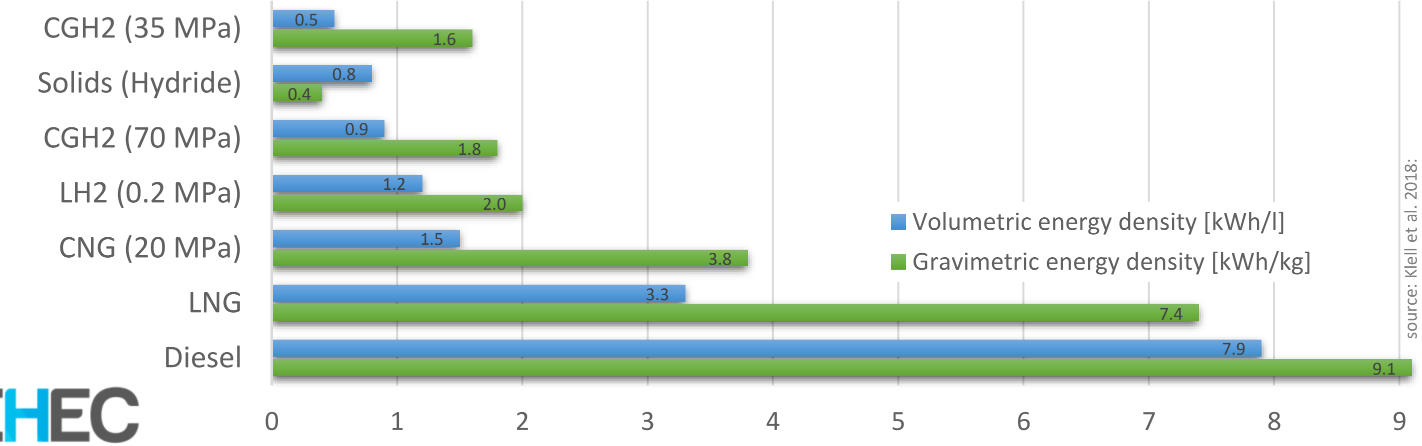
Hydrogen needs to be compressed, liquefied or materially bonded to achieve competitive energy densities compared to diesel:

- physical-based
  - Compressed Gaseous Hydrogen (CGH_2) @ 30-70 MPa
  - Cryo-compressed Hydrogen (CcH_2) @ < -40 °C + high pressures
  - Liquid Hydrogen (LH_2) @ -252,85 °C
- material-based
  - hydrogen stored in chemical or physical compounds (liquids or solids)

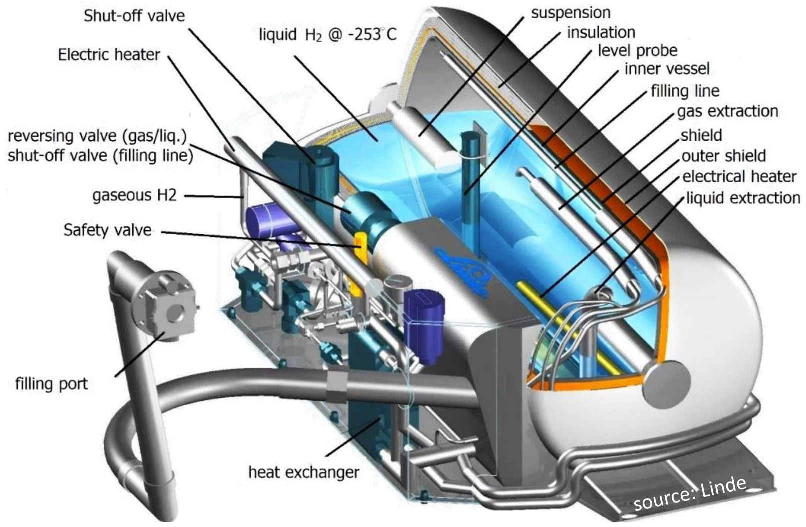


CGH_2 storage tank

Volumetric and gravimetric energy density of vehicle storage systems



source: Klell et al. 2018: https://doi.org/10.1007/978-3-658-20447-1



LH_2 storage tank

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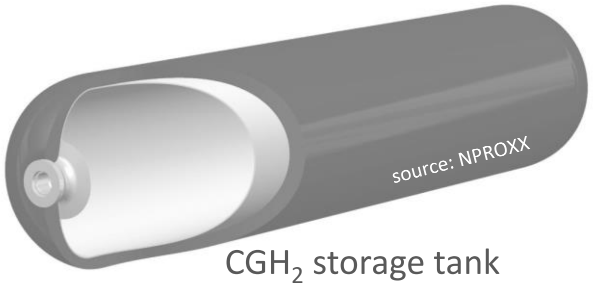
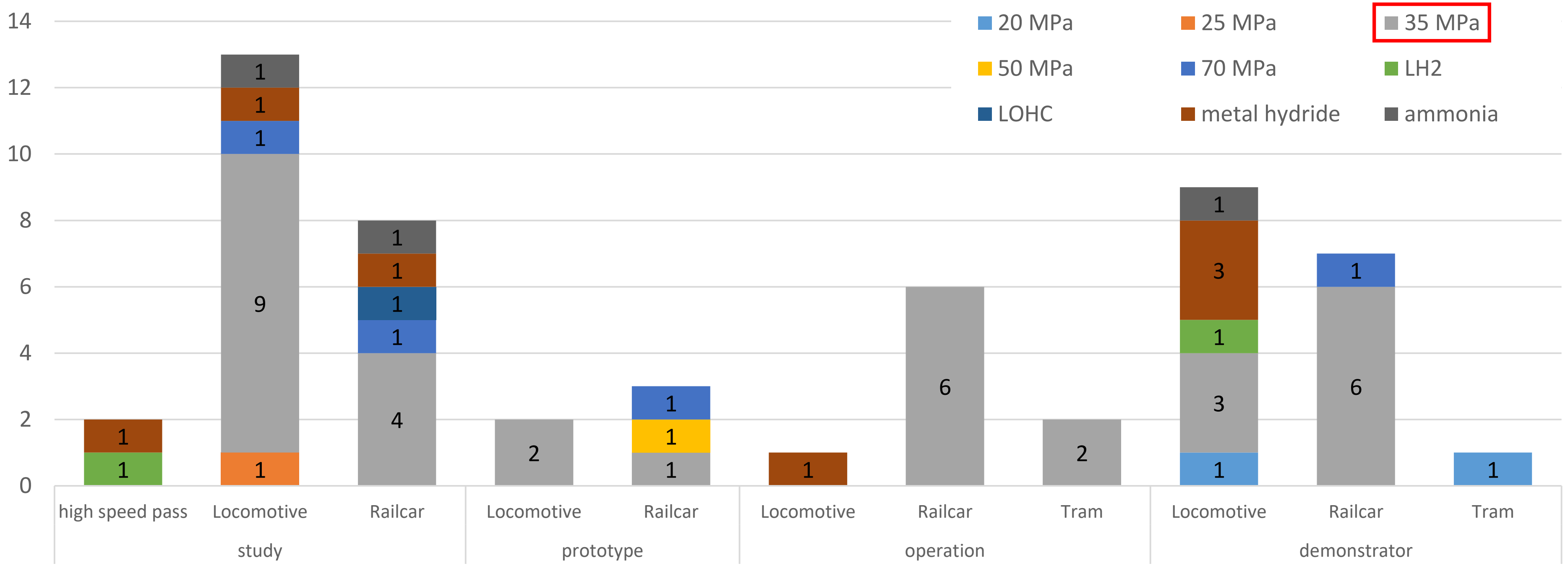
H_2 Storage Technologies for Railways

Due to available technology, successful application for bus & heavy duty and lower costs, **35 MPa CGH_2** systems are most used.



CGH_2 storage tank



Data basis: review of 47 hydrogen rail projects + 21 conceptual designs, feasibility and case studies (Böhm et al., submitted to the Int. Journal of Hydrogen Energy, 04/2022).

 LOHC - liquid organic hydrogen carriers

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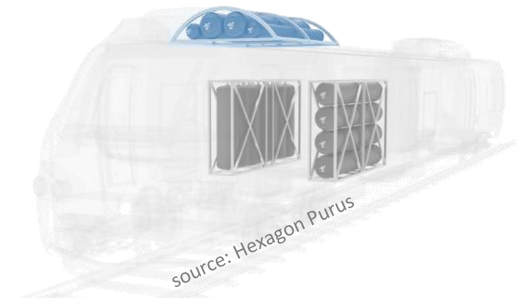
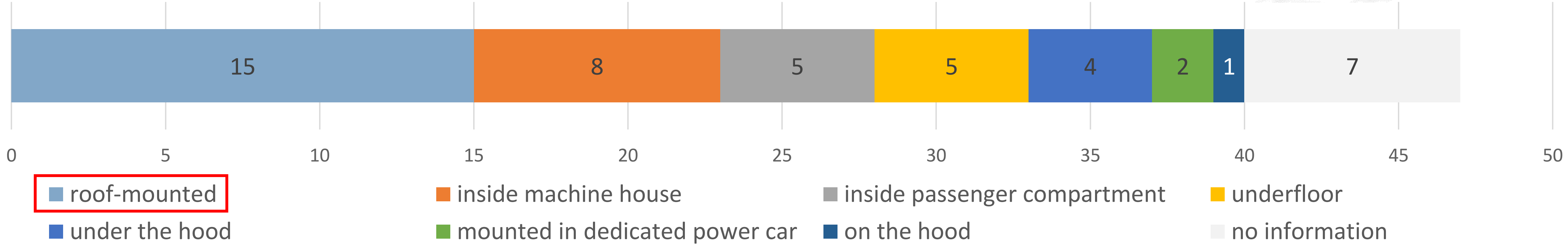
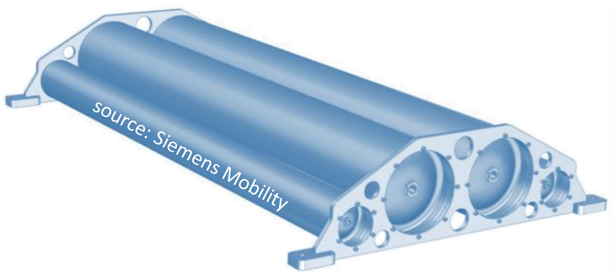
Installation Position inside Trains



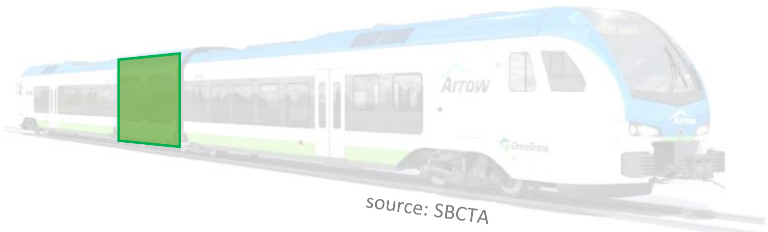
Depending on vehicle type and clearance gauge, most of the H_2 storage systems in demonstrator, prototype and series railway vehicles are mounted on the roof.





e.g. Siemens Mireo Plus H

e.g. Stadler (Zillertalbahn)



e.g. Stadler Flirt H2

Data basis: review of 47 hydrogen rail projects (Böhm et al., submitted to the Int. Journal of Hydrogen Energy, 04/2022).

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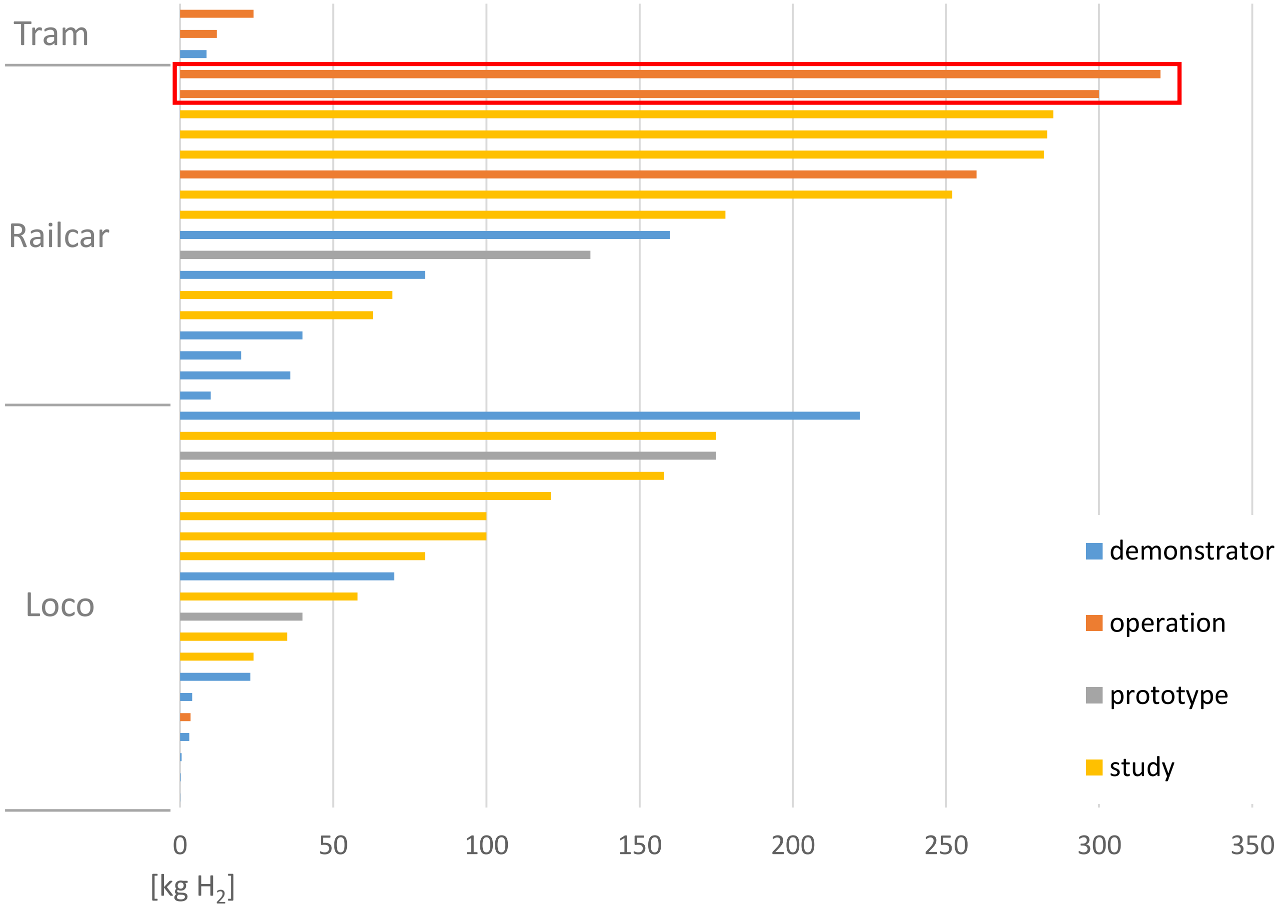
H_2 System Storage Capacity

- Largest H_2 storage capacities are installed in railcars
- Lower amounts of H_2 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



Data basis: review of hydrogen rail projects + conceptual designs, feasibility and case studies (Böhm et al., submitted to the Int. Journal of Hydrogen Energy, 04/2022).

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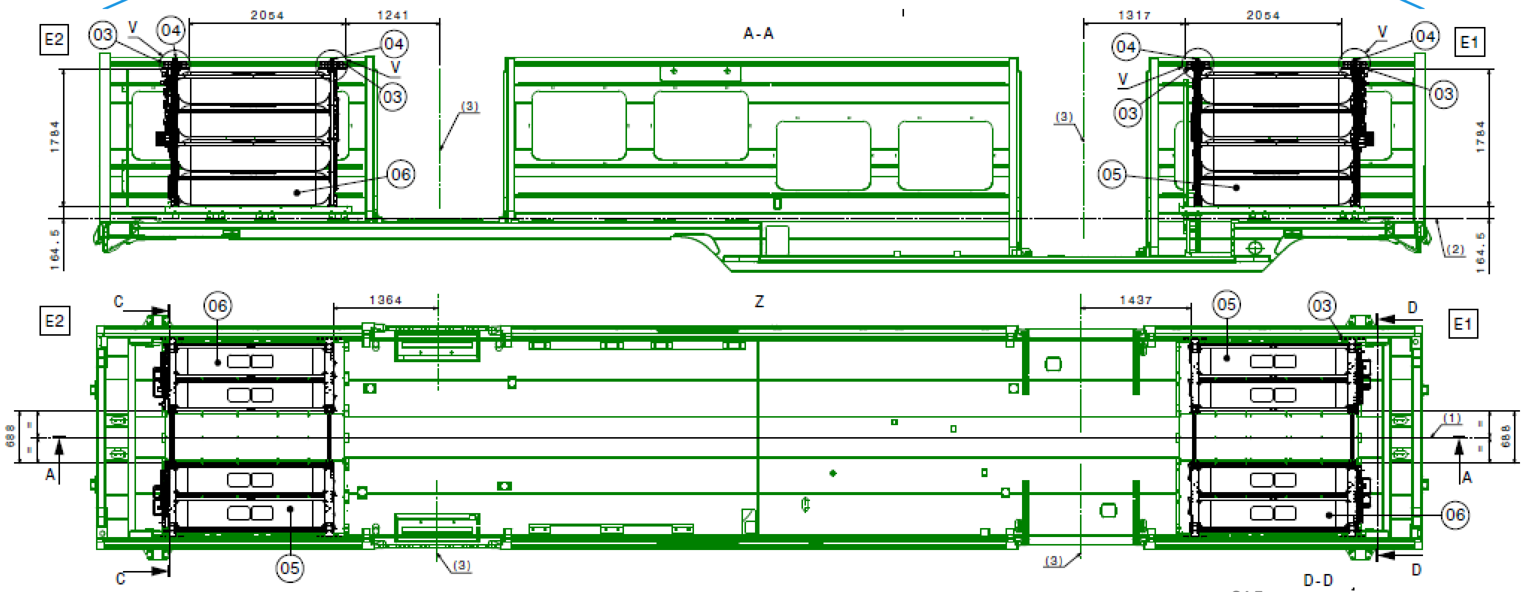
FCH2RAIL H_2 Storage System



source: CAF

4 modules x 8 cylinders = 160 kg @ 35 MPa

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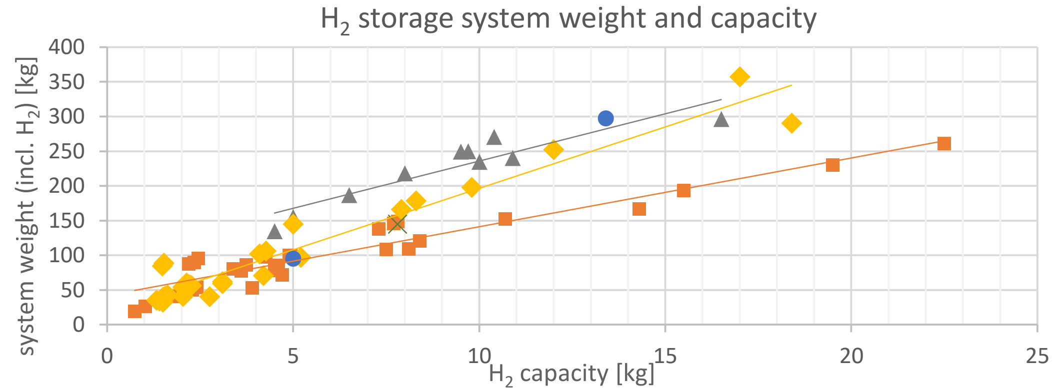
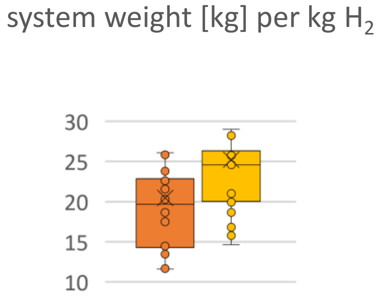
Available H_2 Storage Systems

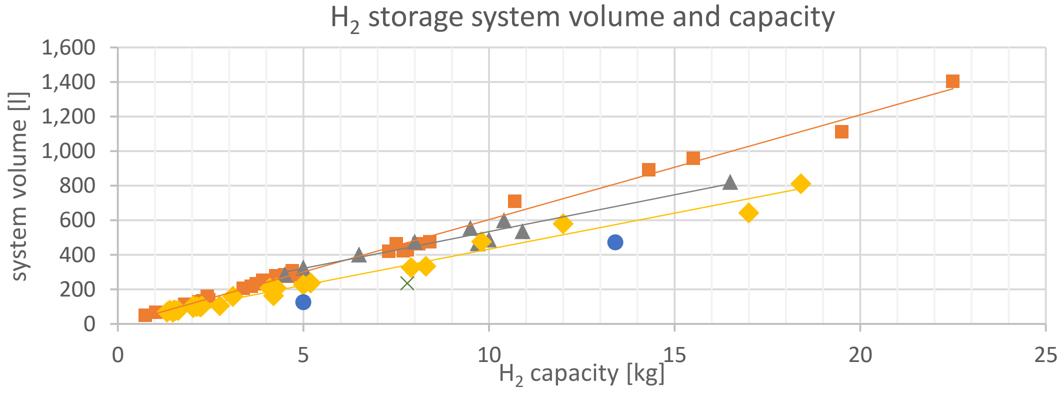
- CGH_2 systems are available on the market for different H_2 capacities, certified for road
- 35 MPa systems are lighter than 70 MPa but need more storage volume for the same H_2 amount

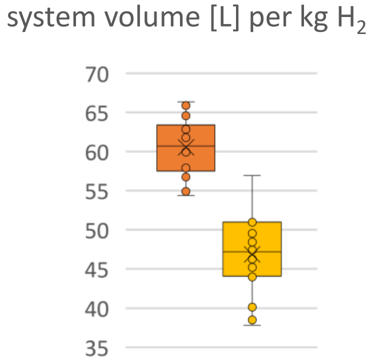




- CGH2 35 MPa
- CGH2 50 MPa
- CGH2 70 MPa
- CcH2*
- LH2*

*only demonstartors





Data basis: worldwide requests to manufacturers: CLD, Faber cylinders, Faurecia, Hexagon Purus, Luxfer Gas Cylinders, MAHYTEC, NPROXX, Quantum Fuel Systems, Steelhead Composites, Worthington.

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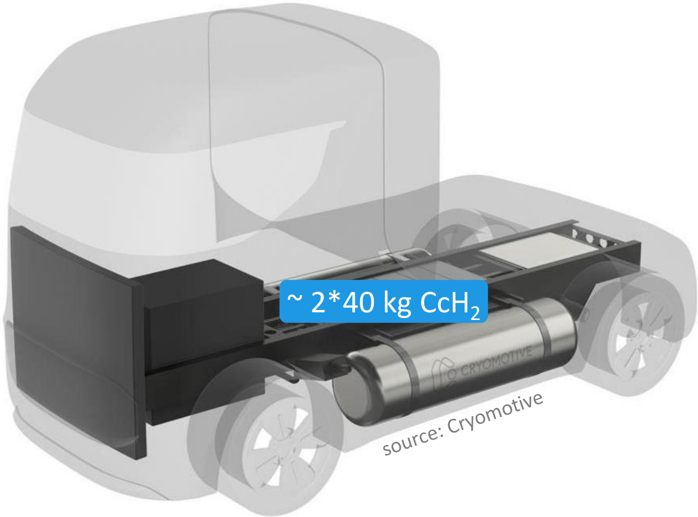
H_2 Storage System Development for Trucks

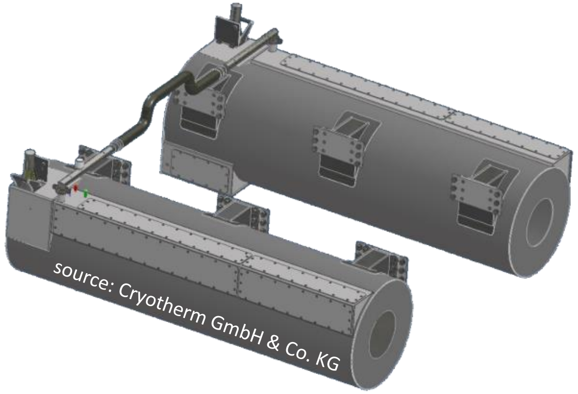
Several OEMs and manufacturers currently work on the further development of LH_2 and CcH_2 storage technology, making the technology also conceivable for railway applications in the future.

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



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

sLH_2 storage tanks



sLH_2 - Subcooled Liquid Hydrogen

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storable H_2 quantity

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H_2 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 CGH_2 and are difficult to achieve in the future
- LH_2 and CcH_2 systems could double the volumetric energy storage capacity compared to CGH_2 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

		CGH_2	CGH_2	CGH_2	LH_2*)	sLH_2*)	CcH_2*)
	pressure [MPa]	35	50	70	0.4	1.6	30
substance level	**density** [g/L]	23.3[1)]	30.8[1)]	39.2[1)]	63[2)]	>63[2)]	72[3)]
storage system level	**vol. capacity** [g/L]	15-18	15-21	18-26	28-40	58-60	33-46[3)]
storage system level	**grav. capacity** [%]	2.5-8.6	3.2-5.6	1.7-6.8	4.5-5.3	~10	7.5-10[3)]
	TRL [-]	7-9	7-9	7-9	7	6	7[4)]

*) no series tank systems available, technology in development for road transport; 1) isothermal data for T = 25°C [NIST Chemistry WebBook, SRD 69 - Isothermal Properties for Hydrogen, 2018]; 2) BMW presentation 2012; 3) Cryomotive presentation 2021; 4) for cars, TRL 7-8 for heavy-duty trucks in 2023/24;

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Clean Hydrogen Partnership Targets

	2020	2024	2030
pressure			
density			
vol. capacity	30	33	35
grav. capacity	5.3	5.7	6
TRL			

https://www.clean-hydrogen.europa.eu/knowledge-management/key-performance-indicators-kpis_en
(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

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Fuel Cell Hybrid PowerPack for Rail Applications

Thank you for your attention

www.fch2rail.eu

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