Hydrogen on-board storage options for rail vehicles

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This paper discusses hydrogen on-board storage options for rail vehicles, with a focus on the comparison for current implementation projects in hydrogen powered passenger trains. Within the framework of the EU project FCH2RAIL, data on pressurized hydrogen storage systems and other physical storage forms analyzed in terms of technical data.

Today, hydrogen storage manufacturers offer a variety of 35 MPa compressed gaseous hydrogen (CGH_2) type III and IV hydrogen storage cylinders for hydrogen trains. In 2016, the Coradia iLINT prototype, a fuel cell hybrid electric multiple unit, was equipped with Xperion's Type IV cylinders [1]. The current iLINT series trains attain mileages of up to 1,000 km with 24 roof-mounted 35 MPa Type IV cylinders from NPROXX [2]. Hexagon Purus will deliver Type IV 35 MPa cylinders for Talgo´s Vittal-One and for Stadler's Flirt H2 multiple units [2], [3]. The company announced that the cylinders are approved according to rail regulation codes and standards [4]. Luxfer's G-Stor H2 Type III cylinders also have been used for railway applications. Luxfer indicates that every rail project is specifically approved case by case by the railway authority in charge as there is no standard regulation available [5], [6]. The Korea Railroad Research Institute announced that it will apply 70 MPa CGH_2 in its regional train prototype [7] and liquid hydrogen (LH_2) in its locomotive [8]. JR East, Hitachi and Toyota announced to use 70 MPa storage cylinders for the HYBARI Project [9].

Materials and Methods

Data on hydrogen storage systems of manufacturers active globally were evaluated using technical data provided by manufacturers, with a focus on available data for 35, 50 and 70 MPa CGH_2. If data was not available on their websites, hydrogen storage manufacturers were directly contacted. Also, current standardization activities in the field of rail were researched. Moreover, alternative hydrogen storage technology candidates applied in other fuel cell powered transport modes (e.g. lorries) were evaluated, which, due to the high hydrogen quantities stored on-board, are in principle also suitable for rail applications. Material based hydrogen storage technologies were not considered in the analysis since they are not available commercially today.

Results and Discussion

Based on requests and data specifications from worldwide CGH_2 storage manufacturers Hexagon Purus, NPROXX, Quantum, Faurecia, Luxfer, Worthington, Faber, Mahytec, Steelhead Composites, CLD and supplemented by literature findings in regard to LH_2 and CcH_2, system weight, system volume and hydrogen capacity of the different hydrogen storage systems are shown in Figure 1 and Figure 2. A large part of the cylinders exists for H_2 storage capacities below 10 kg. Larger quantities are mostly used for gas transportation vehicles. The higher weight of the 50 MPa cylinders results from higher safety requirements of gas transportation.

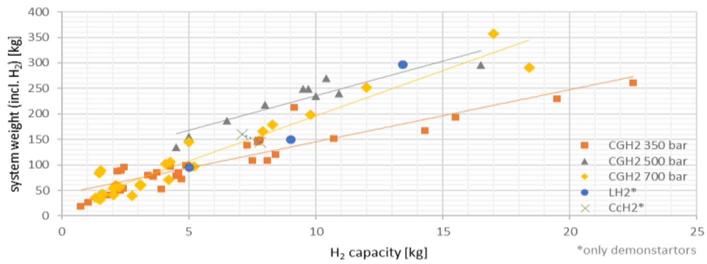

Figure 1. System weight and H_2 capacity of H_2 storage systems

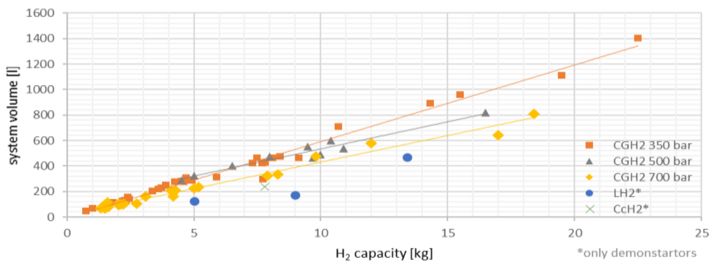

Figure 2. System volume and H_2 capacity of H_2 storage systems

Table 1 compares CGH_2, LH_2 and CcH_2 storage systems in terms of pressure, density on substance level, volumetric and gravimetric capacity and TRL. When doubling the storage pressure from 35 to 70 MPa, it results only in 1.68 times increased energy density on substance level due to the isothermal properties of hydrogen. On vehicle storage system level that increase is lower (~1.25) because of the higher tank material requirements and thus there is a higher specific weight compared to 35 MPa CGH_2 storage systems. With LH_2 and CcH_2 storage systems, volumetric energy storage capacity could be doubled compared to CGH_2 systems. Boil-off and blow-off losses may not be relevant for trucks and railway vehicles due to constant operating times, as opposed to passenger cars. Currently, no series LH_2 and CcH_2storage tank systems are available on the market, but industry pushes forward development. Especially for heavy-duty truck applications, there are currently efforts to integrate LH_2- und CcH_2 storage systems. Development and validation of the first LH_2 heavy-duty truck prototype vehicles is expected to be completed in 2023.

Section	CGH_2	CGH_2	CGH_2	LH_2[*)]	LH_2[*)]	CcH_2[*)]
Pressure (MPa)	35	50	70	0.4	1.6	30
Density, substance (g/L)	23.3 [1)]	30.8 [1)]	39.2 [1)]	63 [2)]	>63 [2)]	72 [3)]
Vol. capacity (g/L)	15-18	16-20	19-23	28-40	58-60	33-46 [3)]
Grav. Capacity (%)	4.4-6.9	3.4-4.2	3.8-5.0	4.5-5.3	~10	7.5-10 [3)]
TRL (-)	7-9	7-9	7-9	7	4	7 [4)]

[*)] technology is being developed for road transport, currently no series tank systems available; [1)] isothermal data for T = 25°C for hydrogen at substance level [10]; [2)] Source BMW presentation 2012; [3)] Cryomotive presentation 2021, Simmons_2020_Cold and Cryo Compressed Hydrogen Storage R&D [11]; [4)] for cars, TRL 7-8 for heavy-duty trucks in 2023-2024 expected.

Table 1. comparison of different hydrogen storage systems

Currently, there are no rail-specific standards and regulations for use of hydrogen storage systems in rail vehicles. Most hazards can be controlled by applying existing regulations from other hydrogen usage sectors in combination with existing non-hydrogen-related railway-specific standards. The remaining hazards must be covered by individual actions down to an acceptable remaining risk, whereby the corresponding procedure is not yet uniformly regulated at present [12]. For hydrogen-powered road vehicles, for example, hydrogen pressure storage systems must have a type approval in accordance with regulation (EC) no. 79/2009 of the European Parliament and the Council of the European Union. There is currently no separate regulation for rail vehicles. In the International Electrotechnical Commission (IEC) TC 9, specifically in 'PNW 9-2697 ED1: Railway applications – Rolling stock – Fuel cell systems for propulsion - Part 2: Hydrogen storage system', international standardization work is ongoing in the field of hydrogen storage systems for rail. The publication of the results is planned for February 2024 [13].

Conclusions

Based on this research, ten manufacturers worldwide produce sufficiently sized CGH_2-storage systems at different pressure levels that could potentially be used in rail vehicles. It can be concluded, that currently there are no series vehicle storage tank systems available for LH_2 but development of LH_2-storage systems for aviation purposes is being driven forward. For heavy-duty trucks, there are currently efforts to increase the system pressure of LH_2-storage tanks. Nevertheless, in current hydrogen powered passenger train projects, ranges of about 1,000 km are achieved with 35 MPa, which should be sufficient in most cases. If less space is available, e.g. in case of vehicles for smaller structure gauges, shorter vehicles, or higher power requirements, e.g. in locomotives, higher pressure levels or LH_2 are an option to increase the energy density at vehicle storage system level. Announced projects will demonstrate the feasibility here.

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