Pre-normative REsearch for Safe use of Liquid HYdrogen (PRESLHY)

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

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Disclaimer

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Liquid Hydrogen, Cryogenic tanks, Trailers, Trucks, Fueling stations, vaporizers, pumps, buffers, dispenser, refueling stations

Abbreviations

LH_2	Liquid Hydrogen
MLI	Multi layers insulation

Introduction

Hydrogen is a versatile energy carrier with favourable characteristics since it does not release any CO_2 at the point of use as a clean fuel or energy source, and can play an important role in the transition to a clean, low-carbon, energy system.
Hydrogen technologies and products have significantly progressed over past years and are now being introduced to the market.
To follow the increasing demand of hydrogen for FCV, the use of liquid hydrogen (LH_2) improving the global logistic of hydrogen is a credible option.
This report describes the liquid hydrogen installations of this whole logistic chain from the liquefaction to the use in a fueling station.

1 Liquid hydrogen delivery infrastructure

The foressen liquid delivery infrastructure is as follow (figure 1) :

- A centralized hydrogen production via large electrolysis (more than 100 MW, Proton Exchange Membrane, Alkaline or High Temperature Electrolysis) using renewable electricity or Steam Methane Reformer (SMR) with CCS (Carbon Capture and Storage). Others alternative pathways of production are also under development : electro-photocatalysis, water splitting, fermentation ….
- A large Liquefaction plant
- Large cryogenic storages at liquefier site
- Logistic via liquid trucks
- Small LH_2 storages of fueling station site

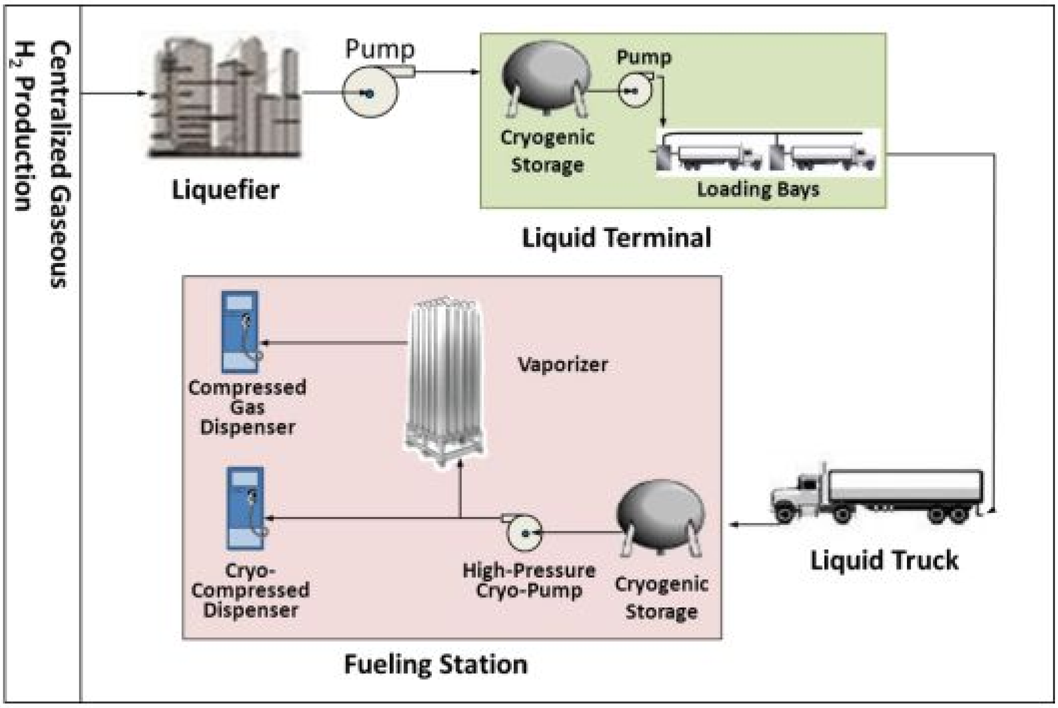


Figure 1: Liquid Hydrogen delivery infrastructure (the pumps between liquefier and storage and between storage and trailers are optional)

2 Liquefaction plants

One of the challenges in building a hydrogen economy is the establishment of an efficient production and supply infrastructure. Large scale distribution favors the relatively dense liquid phase LH_2, but liquefaction still suffers from low energy efficiencies. Historically, LH_2 was mainly used as a rocket fuel, where the low efficiency in the production did not matter. A major program of hydrogen liquefaction was started in the USA within the Apollo space project leading to the design and construction of large-scale liquefaction plants.

The liquefaction of H_2 is a highly energy intensive process. The minimum work required for the liquefaction of hydrogen (at ortho-para equilibrium) is 3.92 kWh of electricity /kg of H_2 or 0.12 kWh /kWh of H_2. Typical values for the whole process, however, are in the range of 8 - 14 kWh/kg for relatively large liquefaction units. Reducing the energy consumption of liquefiers is an active subject of development for the LH_2 industry (see IDEALHy FCH JU project for instance).

Most plants (11) are located in North America. In Europe, plants (3) in France, Netherlands, and Germany are operated with a total capacity of 19 t/d. Largest plant size is currently 68 t/d (New Orleans, USA). The latest (2017) start-up liquefier (10 t/d) is owned by Airgas (now Air Liquide) in Calvert City.

It has to be notice that LH_2 liquefiers are outside of the scope of the PRESLHY project.

3. Stationary LH_2 large storages

Cryogenic vessels are commonly used for more than 40 years for the storage and transportation of liquid hydrogen.

In order to manage storage at -253°C, for large storage (> 100 m^3 water volume) double-walled vacuum insulated pressure tanks are used (figure 2). Such vessels consist in an inner pressure vessel, an external protective jacket and compressed perlite under vacuum in the space between the inner vessel and the outer jacket. Perlite is an inorganic amorphous volcanic glass that represents a good tradeoff between cost and insulation properties.

For smaller storages (< 100 m^3), single-walled pressure tank with multi layer insulation coating are used (so-called MLI). This technology is described in details at paragraph 2.2 on liquid hydrogen trailers.

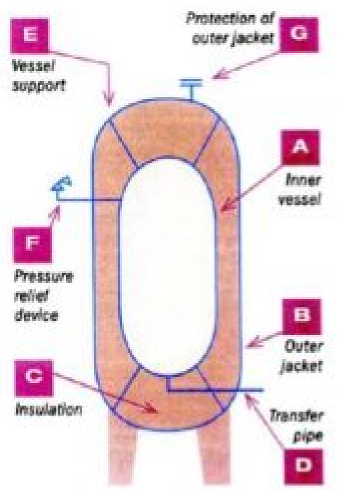


Figure 2: Principal schematic of a double jacket LH_2 tank

The world largest LH_2 tank is located at the NASA Kennedy Space Center in Florida (figure 3). The tank is a 3800 m^3 (3218 m^3 of LH_2) double wall vacuum perlite (1.3 m of thickness) insulated spherical (in/ex diameter = 18.75 / 21.34 m) storage vessel. The tank operated at a pressure of 6.2 bar and has a boil off rate of 0.025%/d.

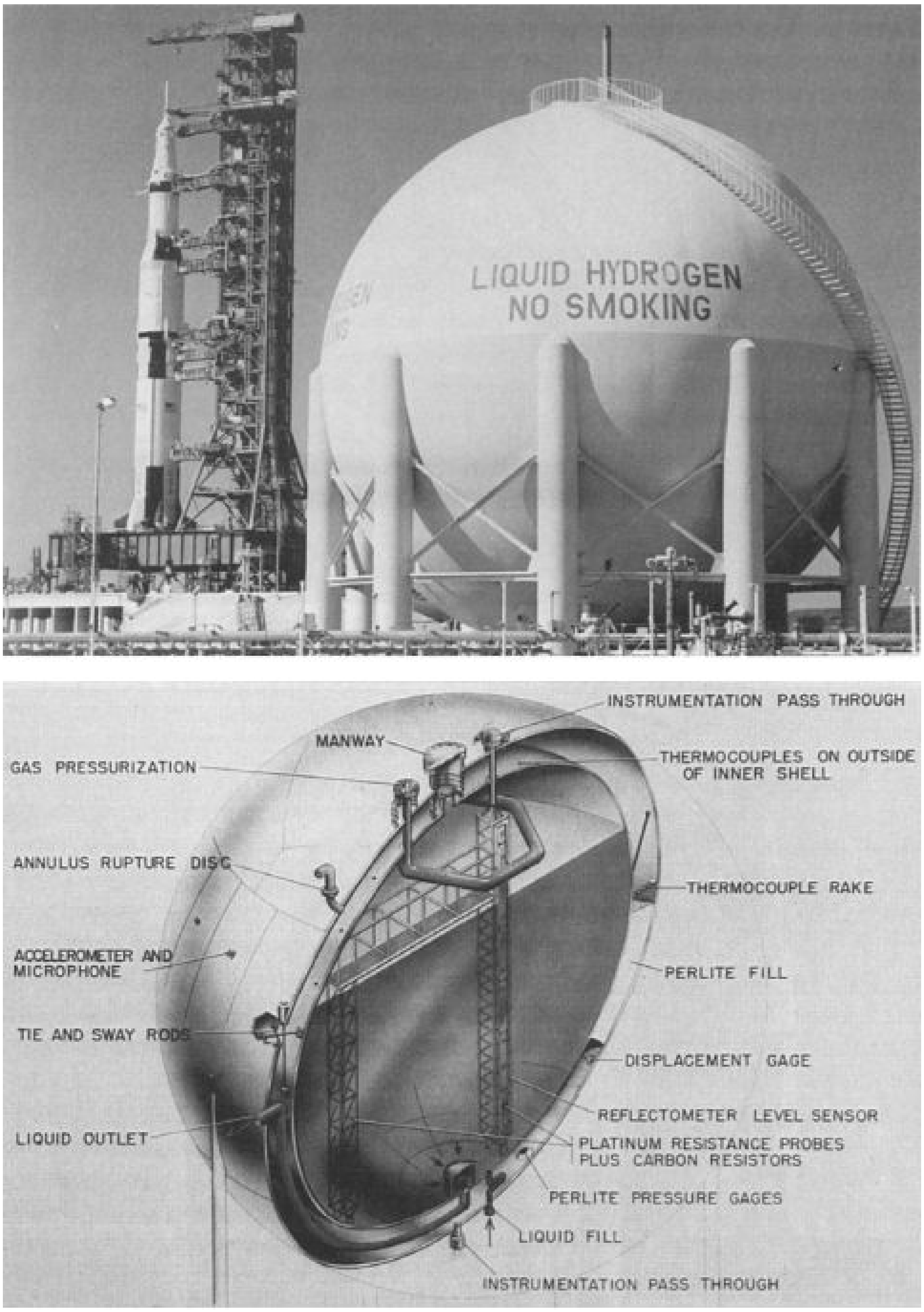


Figure 3: Schematic of the 3218 m^3 LH_2 tank at Kennedy Space Center

The largest tanks are of spherical shape but large scale LH_2 tanks at the production site are typically horizontal and have a capacity of more than 100 t (1 400 m^3). For instance, at the Kourou Ariane launch site in French Guiana, Air Liquide operates 5 semi mobile tanks of 320 m^3 each (3.9 bar) and 1 réservoir of 110 m^3 (11 bar) (figure 4). The total capacity is 22 t. On the Kourou site there is also a 2.5 t/d liquefaction plant.

Figure 4: LH_2 storages at Kourou - French Guiana

In Waziers in France (Liquefaction unit = 10 t/d), AL operates 4 horizontal tanks of 250 m^3 each (internal/external diameter = 4.02 / 5.1 m - perlite thickness = 500 mm) (figure 5).

Figure 5: LH_2 storages at Waziers - France

2.2 Liquid Hydrogen Trailers

Cryogenic liquid hydrogen trailers can carry up to 5 000 kg of hydrogen and operate up to 12 bar. Hydrogen boil-off can occur during transport despite the super-insulated design of these tankers, potentially on the order of 0.5% per day. Hydrogen boil-off of up to roughly 5% also occurs when unloading the liquid hydrogen on delivery.

The LH_2 trailers are insulated using a vacuum super insulation. This insulation is also used for transfer piping systems (Vacuum MLI Insulated Piping).

The Vacuum Super Insulation is a system of thermal insulation which includes:

- A double shell insulation space (inter-space) where static or dynamic for large storages high vacuum is limiting heat transfer by conduction and convection.
- A blanket of alternate layers of highly reflecting shields (Aluminium for instance) and insulating spacers (Lydall for instance) to prevent heat transfer by radiation as well as conduction between shields.
- An adsorbent (molecular sieve) placed in the vacuum space in order to achieve an adequate level of vacuum at low temperature by adsorption of residual gases and moisture.

According to Reddi et al. (2015), a LH_2 trailer is mass equivalent to 5 high capacity composite trailers and 15 classical metallic trailers.

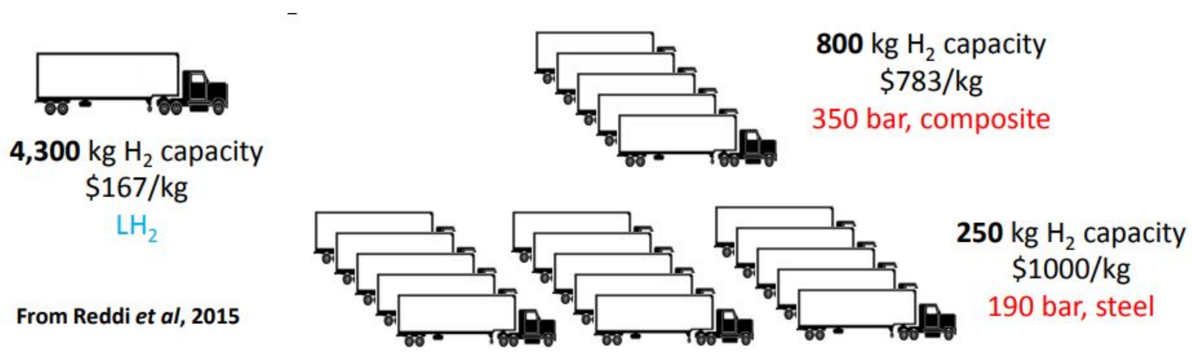


Figure 6: LH_2 trailers in Canada (up : Whistler / down : Becancour liquefier site)

To transfert LH_2 from a storage to another (for instance from a large storage to a truck or from a trailer to a storage at use site), there are two methods :

- pressure build up (natural pressure build up or voluntary vaporization of LH_2 via a small external heat exchanger). Hence, the pressure in the "mother storage" becomes more than the pressure in the "daughter storage" and LH_2 transfer is easy. The main drawbacks of this method are a long operating time and an increase of the pressure of the "mother" storage leading sometime to the need of a pressure venting
- pumping in the "mother storage" using an appropriate transfer centrifugal cryogenic pump. The main drawbacks of this method are the cost of the pump and the need of frequent maintenance of the pump mostly due to cavitation (low available NPSH - Net Positive Suction Head: difference between liquid pressure and saturation vapour pressure of the considered compound - due to low density of LH_2).

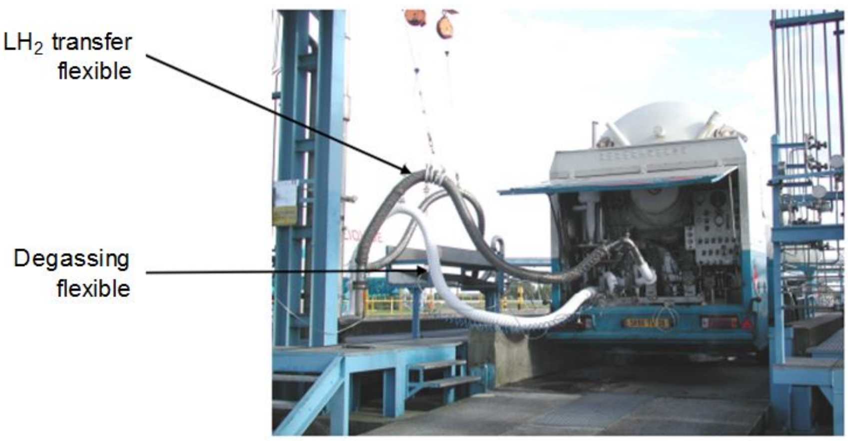


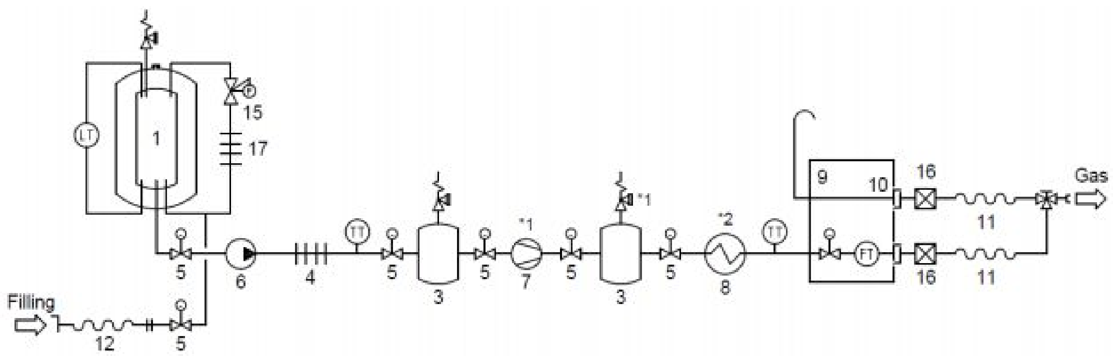
Figure 7: Photo of a LH_2 trailers during transfer.

4. LH_2 based fueling station

Basically a LH_2 based fueling station consists in :

- a vertical or horizontal LH_2 tank. Tanks at the utilisation site are usually smaller with capacities from 100 to 2 500 kg for vertical tanks and up to 5 000 kg for horizontal tanks. Usually, the maximal operating pressure is 12 bar.
- an insulated process line from the bottom of the storage to the LH_2 pump (reciprocating or submerged) pumping LH_2 from the storage tank to the atmospheric vaporizer. This device allows to pump LH_2 up to 1000 bar.
- an atmospheric vaporizer in order to heat up hydrogen at 1000 bar.
- 1000 bar gaseous buffers (few m^3). These buffers are generally bundles of type I or II metallic cylinders or long metallic tubes.
- all the other parts (dispenser, filling hose, …) of the refueling station are similar to classical gaseous refueling station.

The LH_2 tank is delivered by a LH_2 truck. This LH_2 truck is composed of a 40 m^3 horizontal tank operating between 1 and 12 bar. The connection between the storage and the truck is done by a flexible transfer line. The transfer is performed without a pump. Then a small vaporizer is present on the trailer to produce a pressure build up in the truck tank and then to allow to transfer the liquid H_2 in the stationary vertical storage.



1. liquid hydrogen storage unit	8. chiller	15. pressure regulator
2. gaseous hydrogen storage unit	9. dispenser	16. breakaway coupling
3. intermediate gas storage	10. safety valve	17. pressure build-up evaporator
4. evaporator	11. delivery hose	
5. emergency shutdown system	12. off-loading hose	LT level sensor
6. pump	13. fill	FT flow sensor
7. compressor	14. purifier	TT temperature sensor

Figure 8: Process flow of a LH2 based fueling station

The station could be packaged as shown on the figure 9 below:

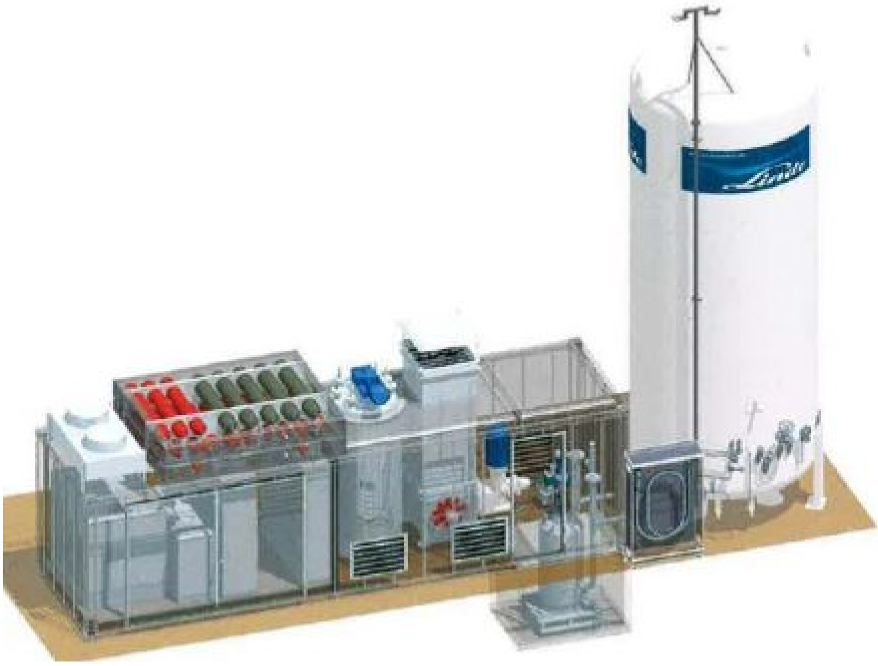


Figure 9: View of a LH_2 based fueling station (900 bar - 100 kg/d)

Figure 11: Photo of a LH_2 installation (Little Town - USA)

Figure 12: H_2 forklift fueling station (Coca Cola - Charlotte - USA).

4. Conclusions

This report describes the liquid hydrogen installation for the whole logistic chain, from the liquefaction to the use in a fueling station.
One of the main challenge of the LH_2 infrastructure is risk and safety. This means that it is needed to improve our knowledge of LH_2 accidental behavior to provide adapted regulation codes and standards context for the use of LH_2 in populated areas (cities). For instance, it is needed to objectively assess the effect distances of accidental scenario without conservatism in order to suggest some separation distances between LH_2 objects and public domain (land planning).