MultHyFuel

Deliverable 3.1

State of the Art on hydrogen technologies and infrastructures regarding a multi-fuel station environment

Authors:
Deborah Houssin, Elena Vyazmina | Air Liquide
Sébastien Quesnel, Quentin Nouvelot | ENGIE
Ju Lynne Saw | HSE
Sylvaine Pique | INERIS
Nick Hart | ITM
Stephan Montel | Shell
Matteo Robino | SNAM
Markus Jenne | ZSW

Reviewer:
Alexandru Floristean | Hydrogen Europe

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Executive Summary

Clean Hydrogen and Fuel Cell Electric Vehicles (FCEV) have developed significantly in the past years in order to respond appropriately to the challenges associated with the transition to a net-zero carbon economy.

Associated infrastructure, in particular, Hydrogen Refuelling Stations (HRS), have also developed to respond to the increasing needs for Hydrogen in the mobility sector. The need to mainstream Hydrogen in the mobility sector requires higher levels of accessibility of HRS in the public environment.

In response to these challenges, the MultHyFuel project proposes to study how hydrogen refuelling stations can be relevantly and safely integrated in close proximity, alongside other conventional and alternative fuels for the mobility.

Deliverable 3.1 contains a review of technologies and infrastructures, mostly in relation to hydrogen dispensing, but also for CNG, LNG and conventional liquid fuels as well. Additionally, a review of safety aspects and existing regulation has been conducted in the context of this deliverable. A benchmarking of technologies used in HRS and multi fuels stations have led to the definition of 3 case study models as follows:

- **Configuration #1 – Ready-to-deploy multi-fuel station**
  - Based on existing, « simple » and already used technologies
- **Configuration #2 – On-site H_2 production multi-fuel station**
  - Based on PEM electrolyser on-site hydrogen production and associated requirements
- **Configuration #3 – High capacity & High filling multi-fuel station**
  - Based on future large needs of hydrogen for mobility, including liquid hydrogen storage

These configurations have been detailed in this document, and associated process flow diagrams and preliminary layouts have been provided. These configurations include both refuelling of light and heavy-duty fuel cell-based vehicles but exclude on-board liquid hydrogen storage.

The characteristics and design of these models may be modified and adjusted according to the outputs of the other tasks and works that will be performed in the project, in particular the results of the engagement process with key stakeholders (WP4).

Content

Acronyms

AEL	Alkaline ELectrolyser
ALARP	As Low As Reasonably Practicable
AISI	American Iron and Steel Institute
CGH_2	Compressed Gaseous Hydrogen
CNG	Compressed Natural Gas
DSO	Distribution System Operator
Ez	Electrolyser
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
H_2	Hydrogen
HER	Hazard and Effects Register
HGV	Heavy Goods Vehicle
HRS	Hydrogen Refuelling Station
HSSE	Health, Safety, Security and Environment
L-CNG	Liquid and compressed natural gas
LFL	Lower flammability Limit
LH_2	Liquid Hydrogen
LHRS	Liquid Hydrogen storage-based Refuelling Station
LNG	Liquid Natural Gas
MLI	Multi-Layer Insulation
NG	Natural Gas
PEM	Proton Exchange Membrane
RPIDCS	Regulation, Codes and Standards
RPT	Rapid Phase Transition
PID	Piping and instrumentation diagram
PFD	Process flow diagram
QRA	Quantitative Risk Assessment
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolysis Cell
TEN-e	Trans-European Networks for energy
TEN-t	Trans-European Networks for transport
TSO	Transmission System Operator
UDC	Under-dispenser containment
UVCE	Unconfined Vapour Cloud Explosion

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1 Introduction and Objectives

Mobility, heating and heating networks, industrial processes, the data center market, storage of renewable energies to compensate for intermittent production, steel, chemicals, and many more… The potential of hydrogen is huge. This is particularly the case in terms of sustainable mobility: with a charging time of less than five minutes and a range of more than 770 km (for light duty vehicles), hydrogen fuel cell vehicles offer an efficient solution for intensive use and long trips, which represent the bulk of CO_2 emissions in the transportation sector. By reducing greenhouse gas emissions, urban pollution and reliance on petroleum-based fuel, hydrogen is proving its worth.

Over several years, hydrogen fuel cell-based vehicles and associated infrastructures have developed in order to provide solutions to the challenges associated to our transition to a net-zero carbon economy. This hydrogen alternative for mobility has to be now taken into account at the same level as commonly used fuels and has to become more accessible in the public environment. For this, it is proposed in MultHyFuel project to study how hydrogen refuelling stations can be relevantly and safely integrated close to the other fuels for the mobility.

In this way, the objective of this report is to provide a state-of-the-art review of hydrogen technologies and infrastructures from production to final use, considering hydrogen supply chain as well.

Several options are presented for each step in order to highlight advantages, drawbacks, relevance and potential risks. Equipment, constraints, needs, existing safety features, operational conditions, etc. have been identified as well.

Following the state-of-the-art review, three refuelling station configurations (case study models) have been defined. These configurations will be taken forward by the study team to be further studied in terms of risk, considering a multifuel environment.

2 Brief introduction of the hydrogen supply chain for hydrogen mobility

Before going into more details in each part of the hydrogen infrastructure associated in the mobility supply chain of Hydrogen, Figure 1 gives a simplified overview of the overall hydrogen supply chain, from production to refuelling stations and already shows that, along the supply chain, several options are possible:

- for the production, methane reforming, electrolysis as well as other production pathways are possible;
- for the distribution and the storage, there are many possibilities such as gaseous hydrogen, liquid hydrogen, provided by trailers, in cylinders, via pipelines, etc.

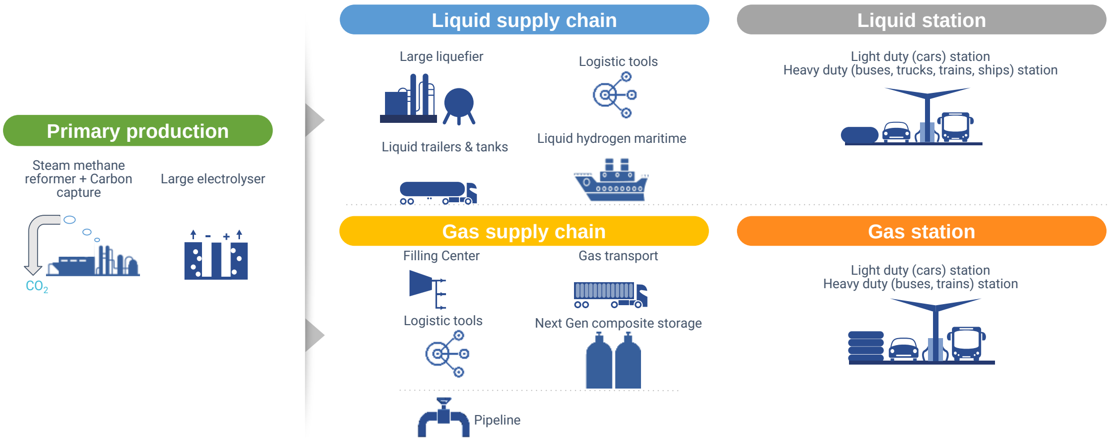

Figure 1 - Hydrogen supply chain, from production to use for H_2 mobility.

Regarding the final use – *the target of the refuelling stations* – some options will be more relevant than others. In order to explore these, the following sections of this report will present each of the potential options in order to guide the choice and the definition of the three configurations (case study models) to be studied in the project.

It is important to mention that on-board liquid hydrogen storage and (as a result), liquid hydrogen dispensing are *a priori* out of the scope of MultHyFuel project. Nevertheless, refuelling stations based on liquid hydrogen storage, but dispensing gaseous hydrogen for the fuel cell vehicles, are considered in this state of the art as they allow a higher quantity of hydrogen to be stored at the station.

Figure 2 and Table 1 present a simplified comparison between these two types of refuelling stations usable for fuelling of fuel cell vehicles with on-board compressed gaseous hydrogen tank(s).

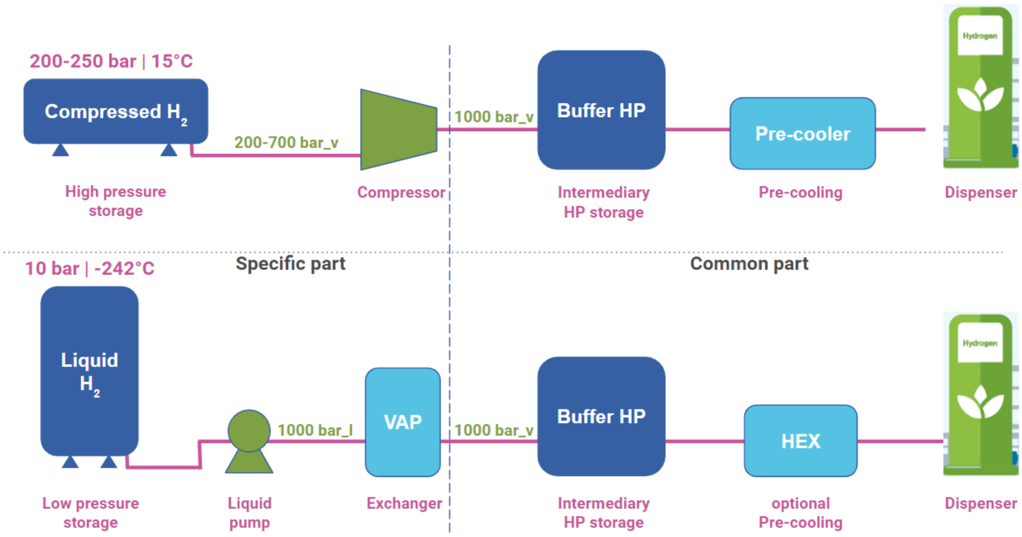

Figure 2 - Simplified comparison between gaseous and liquid hydrogen refuelling stations.

Top: gaseous HRS, Bottom: liquid HRS.

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Table 1 - Comparison between LHRS and HRS.

Topic	LHRS	HRS
Storage	Liquid hydrogen, cryogenic temperature (-240°C), low pressure (up to 10 bar)	Gaseous hydrogen, ambient temperature, high pressure (from 200 to 500 bar)
Refilling of the station	Transfer of liquid hydrogen from trailer to storage	Mainly swap (= full for empty)
Pressurization of hydrogen	Liquid pump and vaporizer required to deliver gaseous H_2	Compressor

3 H_2 refuelling station infrastructure

In this chapter, different elements of the hydrogen supply chain required for hydrogen mobility are described – from production to dispensing. This chapter includes descriptions associated with H_2 distribution as well as several configurations for production.

3.1. Hydrogen sourcing

Currently, hydrogen is mainly produced by large steam methane reforming plants. While electrolysis is a technologically mature application, it captures only a small market share at the moment (although it is expected to increase in the future). Depending on the needs, most relevant production and distribution pathways may differ depending on the following considerations.

When hydrogen is produced remotely (i.e. at a side different than the HRS site), a distribution mode is required. The most relevant methods for distribution are:

- Tube trailers,
- or pipelines.

For other cases, hydrogen can be produced “on-site” by:

- electrolysers,
- or “small” reformers.

These infrastructures are described in this section.

3.1.1. Distribution to the station

3.1.1.1. Gaseous hydrogen distribution

3.1.1.1.1. Gaseous trailer

The most common existing trailers for gaseous hydrogen transportation are made up of 200-bar tube trailers with long horizontal metallic tubes. The average capacity of this kind of trailer is around 300-500 kg-H_2.

Figure 3 - Air Liquide 200-bar H_2 tube trailer.

New trailers using composite cylinders can transport hydrogen at higher pressure (up to 500-600 bar). Thus, the capacity of hydrogen transportation can reach 1 t.

Figure 4 - Air Liquide high capacity trailer (500 bar+).

3.1.1.1.2. Hydrogen pipeline

Pipelines are used in order to transport large amounts of gaseous compounds, in efficient, safe, and economic way. The properties of the carried gas, (e.g. purity, composition) as well as the pressure in the pipelines can vary depending on the requirements of the customers. For hydrogen transportation, the pressure inside pipelines can reach 100 bar.

Today, the supply of hydrogen by pipelines is a convenient end efficient solution, in particular when the HRS is located close to a hydrogen ecosystem that includes a centralized H_2 production plant, and one or more off-takers can be connected to an H_2 distribution grid.

In some specific cases, hydrogen refuelling stations can be located nearby or on top of a hydrogen pipeline. In that case, the hydrogen only needs to be compressed, cooled and dispensed. For example, in Belgium and in parts of the Netherlands, a hydrogen-pipeline network of about 900 km length, operated by Air Liquide, exists. This network runs from Rotterdam (Netherlands) via Antwerp (Belgium) to Dunkerque (France). The pressure level within this pipeline system is approximately 70-100 bar. Hydrogen can be compressed and stored on-site at various pressures, to fill the different requirements and desired pressures. The refuelling station located in Rotterdam (Rhoon HSR), which is supplied directly from this pipeline network is one specific example of this distribution mode.

Figure 5 - Air Liquide Rotterdam refuelling station (Rhoon HRS).

The characteristics of the hydrogen pipeline feeding Rhoon HRS are the following:

- H_2 pressure: 110 bar
- Pipeline external diameter: 6’’
- Material: low carbon API 5L X52 (e.g. Carbon 0.3%, Manganese 1.35%, Phosphorus0.03%, Sulfur 0.03%)

This solution will be even more relevant in the medium term, with the development of a wider and capillary European and national hydrogen transport/distribution infrastructure that will include both the repurposing of the natural gas infrastructure (hydrogen backbones) and new hydrogen pipelines that will connect points of production with a growing number of hydrogen end-users.

The ability to connect to a H_2 distribution network constitutes an element of simplification from the point of view of the logistics of supply of H_2, and very often also of cost-effectiveness, as is the case today for CNG refuelling stations connected to the natural gas network.

As indicated by the EU Commission in the EU Strategy for Energy System Integration, the direction is to support the integration between the energy system and the transport sector to exploit mutual synergies, also considering that in most of the case the TEN-e and TEN-t corridors are located along the same lines.

3.1.1.2. Liquid hydrogen distribution

Cryogenic liquid hydrogen trailers can carry up to 5000 kg of hydrogen and operate up to 12 bar. Boil-off is the consequence of LH_2 warming up along a delivery sequence (during storage but also and especially during transfer). 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 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 storage) high vacuum is limiting heat transfer by conduction and convection.
- A blanket of alternate layers of highly reflecting shields (Aluminum 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.

Figure 6 - Air Liquide LH_2 trailer.

3.1.2. On-site production

The use of hydrogen produced from renewable energy (also known as renewable or "green"" Hydrogen, is increasingly seen as the main pathway for the future production of Hydrogen as we transition towards a net-zero carbon energy system. Electric mobility with fuel cells, as such, only makes sense in the long term if based on sustainably produced hydrogen.

Renewable hydrogen can be supplied through generation (reforming of biogas or via electrolysis) in large, dedicated plants (also known as centralized production) and subsequently distributed to end-uses or it can be generated on site. Production in the immediate vicinity of refuelling stations entails permitting and safety aspects and is therefore very relevant for the MultHyFuel project.

3.1.2.1. Electrolysis

3.1.2.1.1. Principle

One possibility for hydrogen production is the splitting of water into its constituent parts (H_2 and O_2) through the process of electrolysis using, preferably, renewable or low-carbon electricity.

The simplest technical design of an electrolyser consists of the electrolysis stack, its upstream electricity and water supply, the downstream gas separators/purifiers and drying, the storage for hydrogen and the system periphery (cooling, control). If necessary, the oxygen by-product can also be stored or used for other processes (e.g. in wastewater treatment plants).

Electrolytic water splitting was discovered at the beginning of the nineteenth century. By the beginning of the twentieth century, several hundred electrolysers were already in industrial use. A first large electrolyser with a hydrogen production of 10 000 $Nm^3\ h^{-1}$ went into operation in 1939. In 1948, a pressurized electrolyser was successfully built. While alkaline electrolysers had been the technology of choice until then, polymer electrolyte membranes (PEM) were used for the first time in 1966. In the 1970s, development work began on ceramic high-temperature electrolysers and advanced alkaline electrolysers.

Figure 7 - Principle of electrolysis process.

As of today, the maturity levels (TRL) of the above mentioned electrolysis technologies are:

- Electrolysis with polymer electrolyte membrane (PEM) – TRL 8
- Alkaline electrolysis with liquid electrolyte (AEL) – TRL 9
- High-temperature electrolysis (steam electrolysis with molten or ceramic electrolyte) – TRL 6

Alkaline and PEM electrolysis are the main commercially available technologies today. High-temperature electrolysis is less mature but significant progression is being made, with system in operation at MW scale. The main differences between these technologies are:

1. The separator: diaphragm or membrane
2. The electrolyte: liquid, solid, acid or basic

Alkaline and PEM electrolysers can run at atmospheric pressure or under pressure.

	Proton Exchange Membrane	Alkaline Electrolysis	Solid Oxide Electrolysis
Cathode	$2H^+ + 2e^- \rightarrow H_2$	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	$H_2O + 2e^- \rightarrow H_2 + O^{2-}$
Anode	$H_2O \rightarrow ½O_2 + 2H^+ + 2e^-$	$2HO^- \rightarrow ½O_2 + H_2O + 2e^-$	$O^{2-} \rightarrow ½O_2 + 2e^-$
	$H_2O \rightarrow ½O_2 + H_2$	$H_2O \rightarrow ½O_2 + H_2$	$H_2O \rightarrow ½O_2 + H_2$

Figure 8 - Main reactions according to electrolysis technologies.

Other types of electrolysers – not described in more details in this section – exist but either at early stage of development, or with only a few actors.

NB: Besides the electrolyser unit, an on-site station generating hydrogen by electrolysis would also require water purification systems and a hydrogen purification and drier unit to treat the hydrogen produced. Furthermore, many electrolysers generate hydrogen at relatively low pressure, e.g. 10 to 25 bar, so further compression is required to elevate the pressure to storage pressures.

Alkaline electrolysis is the most widespread and cost-effective technique today. Here, aqueous potassium hydroxide serves as the electrolyte. The electrodes are often made of catalysed nickel or nickel-plated steel, separated by a microporous diaphragm. Alkaline electrolysers are usually operated at temperatures around 80 °C and pressures up to approximately 30 bar. Typical current densities are 200 - 400 mA cm^{-2} (10 times lower than with PEM electrolyser). Industrially produced electrolysers are modularly constructed with hydrogen production rates from 1 Nm^3 h^{-1} to approximately 750 Nm3 h^{-1}. The energy required to produce 1 Nm^3 hydrogen ranges from approximately 5 kWh for small electrolysers in pressurised operation to approximately 4.1 kWh for large electrolysers operated without pressure. In relation to the lower calorific value, this results in efficiencies between 60 % and 73 %. Alkaline electrolysers are considered to have a long service life. Revision cycles are due every 7 to 12 years. Availability in industrial applications of 98% is reported. Alkaline electrolysers can be operated with fluctuating power supply as well as at partial load with 20-40 % of their nominal load. In this case, a lower hydrogen quality may be expected due to a stronger transfer of oxygen into hydrogen and vice versa.

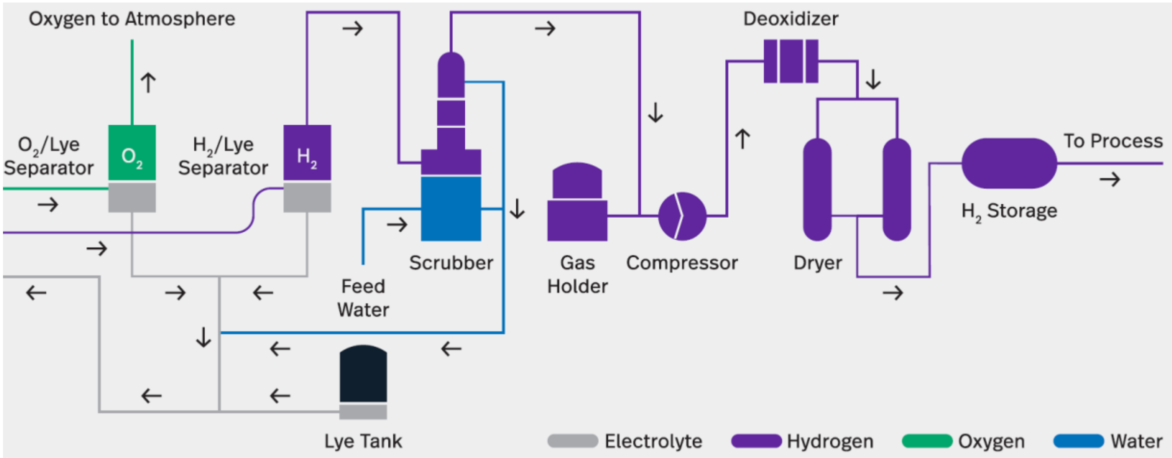


Figure 9 - Alkaline electrolysis principle. Credit: Nel Hydrogen.

PEM electrolysers usually use an acidic ion exchange membrane as the electrolyte. Until a few years ago, only comparatively small plants with hydrogen production rates of 1 $Nm^3 h^{-1}$ to 30 $Nm^3 h^{-1}$ were available. More recently, PEM electrolysis plants with hydrogen production rates of 1000 $Nm^3 h^{-1}$ have been built. PEM electrolysers place high demands on the quality of the feed water, as cations are deposited in the membrane and degrade its properties. The acidic properties of the electrolyte membrane require the use of catalysts containing precious metals (platinum and iridium) and particularly corrosion-resistant electrode materials. At the stack level, the energy input for hydrogen production is approximately 4.1 $kWh Nm^{-3}$, which corresponds to an efficiency of 73% in relation to the lower calorific value of the hydrogen. Pressure operation of PEM electrolysers is possible. As a result of the comparatively gas-tight membrane, significant pressure differences between the hydrogen and oxygen sides are also permitted, so that hydrogen can be produced under pressure while oxygen escapes unpressurised into the atmosphere or is captured to be used for other purposes. The hydrogen quality in the partial load range does not decrease as much with PEM electrolysers as in the case of alkaline electrolysers. PEM electrolysers are also capable of following highly fluctuating loads. Progress has been made in recent years with regard to the expected service life, but there is not as much operating experience as in the case of alkaline electrolysers. Due to the more expensive materials, the capital costs of PEM technology are higher compared to alkaline electrolysers.

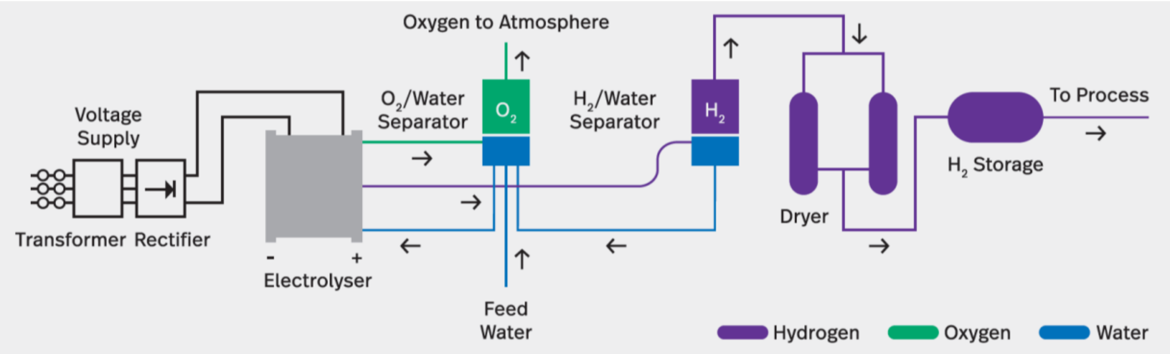


Figure 10 - PEM electrolysis principle. Credit: Nel Hydrogen.

Figure 11 - Sketch of Hydrogenics PEM electrolyser skid.

SOEC electrolysers use a ceramic membrane at high temperature (~800°C) as electrolyte and as separator between hydrogen and oxygen streams. Due to their high operating temperature, SOECs electrolyse steam and not liquid water. Up to now SOECs suffered from a high degradation rate but that is improving.

Norms and standards, such as the ISO 14687 (Grade D) or EN 17124, define product specification and quality assurance for H_2 used in fuel cell applications for road vehicles. These standards secure the right of users of fuel cell vehicles (passenger cars, commercial vehicles, trains) for dispensed hydrogen of a quality that can be assured and which is conducive to the service life of the fuel cell power trains. The limited contaminants could mainly be harmful for the fuel cell operation, fuel cell lifetime or they are defined as canary species for other pollutants. Hydrogen supplied for the transport sector today fulfils quality standard 5.0 (in future possibly 3.7) as a technical gas. The common technical gas definition, for example 5.0, means, that 99.999 Vol-% of the gas fraction consists of hydrogen and the rest 0.001 Vol-% could be any other gaseous component. Since this technical standard does not usually declare the essential fuel cell pollutant components (carbon monoxide, sulphurous compounds, oxygen, humidity, etc.), there is a large discrepancy with the legal situation and thus pressure to act. For hydrogen from electrolysis, example risk assessments recommend the monitoring of a limited amount of species like humidity, oxygen, nitrogen (from flushing events) and carbon dioxide.

3.1.2.1.2. Examples of applications involving electrolysis H_2 production

- **H_2-Whylen: power-to-hydrogen plant with connected R&D platform**

The largest power-to-gas plant in southern Germany has been successfully producing green hydrogen since December 2019 by the operator Energiedienst. The plant, based on alkaline electrolysis technology, has an electrical input power of 1 MW. In addition to this industrial plant, the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) is testing a 300 kW alkaline electrolysis plant optimised according to the current state of the art. The researchers are intensively measuring and evaluating the operating modes of the two plants.

In a five-year project started on 1 January 2021, the electrolysis plant in Grenzach-Wyhlen (near the Swiss border) will be expanded into a "real laboratory of the energy transition" funded by the German Federal Ministry of Economics. This will involve an expansion of the electrical input range from 1 to 6 MW.

Figure 12 - The power-to-gas plant at the hydropower plant in Grenzach-Wyhlen. Credit: Energiedienst

Figure 13 - View inside the research alkaline electrolyser of the ZSW. Credit: ZSW

Essential technical specifications of the existing industrial plant are the following:

- Electrical connected load ≥ 1 MW
- Electrolysis technology used: Alkaline electrolysis (AEL)
- Specific energy consumption of the electrolyser at nominal load ≤ 4.5 $kWh.Nm^{-3}$ H_2.
- H_2 output with a hydrogen purification unit suitable for FCEV according to EN 17124
- Dynamic operating capability of the plant (nominal power range min. 20 % - 100 % with load gradient ≥ 20 $\%.s^{-1}$; start-up from stand-by < 300 s).

Key features of the existing research facility plant:

- Flexible, container-integrated test environment for AEL pressure electrolysis blocks
- Newly developed high-efficiency rectifier with current and voltage control
- Separate liquid and gas cooling with condensate return to the electrolysis circuit
- Independent safety concept with safety-oriented system control.

For the economic operation of power-to-gas plants, the costs must drop to the order of hundred of euros per kilowatt. This can only be achieved by scaling up to larger power classes and industrial, automated large-scale production.

The research institute wants to pave the way for this within the 5-years R&D project H_2-Wyhlen. To this end, it is investigating and developing materials and production methods that allow this transition to scalable production processes suitable for series production – such as advanced electroplated electrodes, plastic cell frames produced in injection moulding processes or 3D printing processes integrated into the manufacturing process. The results flow into production-optimised electrolytic block prototypes in the electrical power class up to 500 kW, which are tested in the ZSW research platform on site in Wyhlen in a real environment.

- **HyBalance: a demonstration of electrolyser producing hydrogen for HRS**

In Hobro (Denmark), thanks to the HyBalance FCH-JU funded project, a demonstrator (see Figure 15) was built in order to produce hydrogen by PEM electrolysis – 1.25 MW – providing:

- a gaseous refuelling station,
- and filling of gaseous hydrogen trailers for hydrogen distribution in other locations.

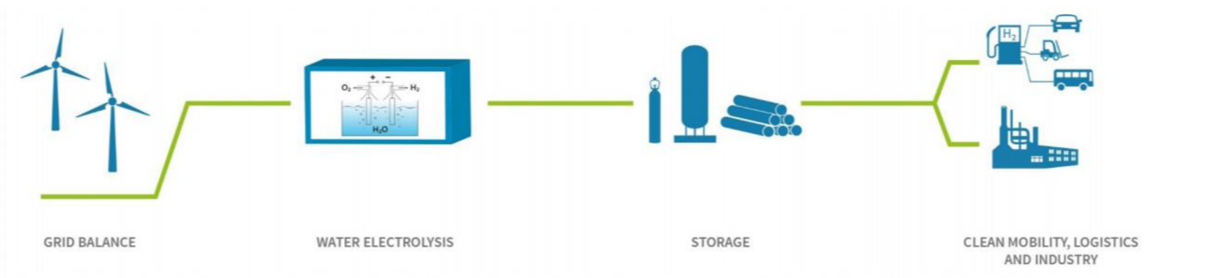


Figure 14 - HyBalance project concept.

The Hydrogenics 1.25 MW PEM electrolyser is able to produce 230 $Nm^3\ h^{-1}$ of hydrogen, i.e. an equivalent of 500 kg per day. This production would be theoretically enough for 1 000 hydrogen cars.

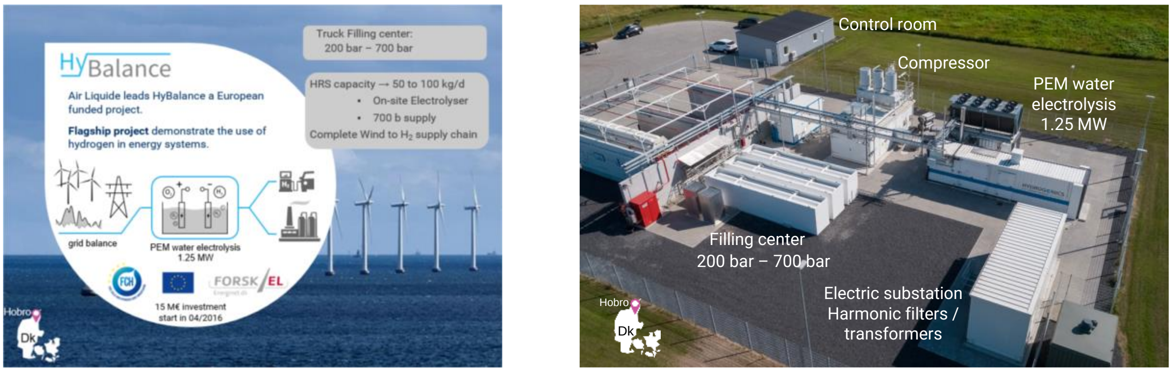


Figure 15 - PEM electrolyser providing hydrogen for HRS and filling center. HyBalance FCH-JU project

3.1.2.2. On-site reformer

The Steam Methane Reforming process (SMR) uses steam and a catalyst to make hydrogen from a light hydrocarbon such as methane or propane. The process basically strips the hydrogen from the hydrocarbon and from the water necessary to convert all of the resulting carbon and oxygen to CO_2. According to IEA Green House Gas (IEAGHG, 2017), the basic process of converting natural gas into hydrogen in a SMR consists of:

- Feedstock purification of hydrocarbons (e.g. desulfurization)
- Steam reforming
- Shift reaction/syngas heat recovery
- Hydrogen purification (e.g. with PSA section)

The main chemical reactions involved in this process are the followings:

- Endothermic steam methane reforming reaction: $CH_4 + H_2O \Rightarrow CO + 3\ H_2$
- Exothermic water gas shift reaction: $CO + H_2O \Leftrightarrow CO_2 + H_2$

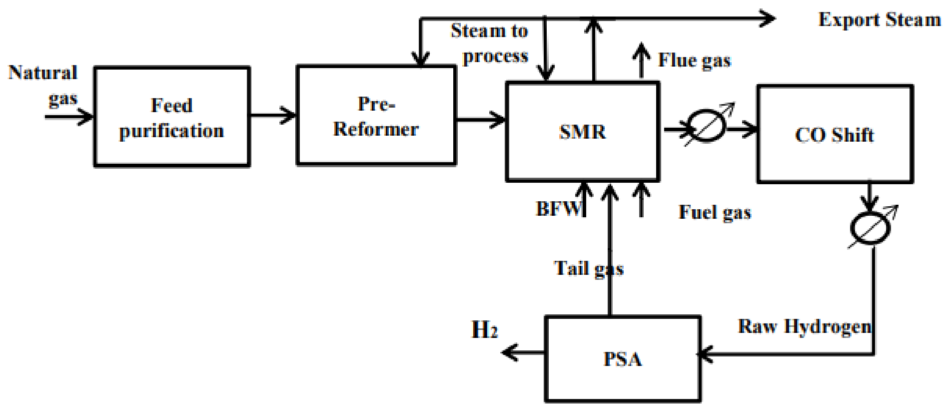


Figure 16 - Process flow diagram of SMR.

An example of this configuration used for the purposes of HRS dispensing has been installed in Osaka, Japan (2010), with a production capacity of 30 $Nm^3\ h^{-1}$ of H_2 in order to fill the vehicles at 350 bar (JHFC, 2011)[1].

As illustrated in the Figure 17, the SMR facilities are implemented in an iso-container with the main equipment inventoried in Table 2.

[1] *http://www.jari.or.jp/portals/0/jhfc/e/station/kansai/osaka.html; Japan Hydrogen & Fuel cell Demonstration project 2011*

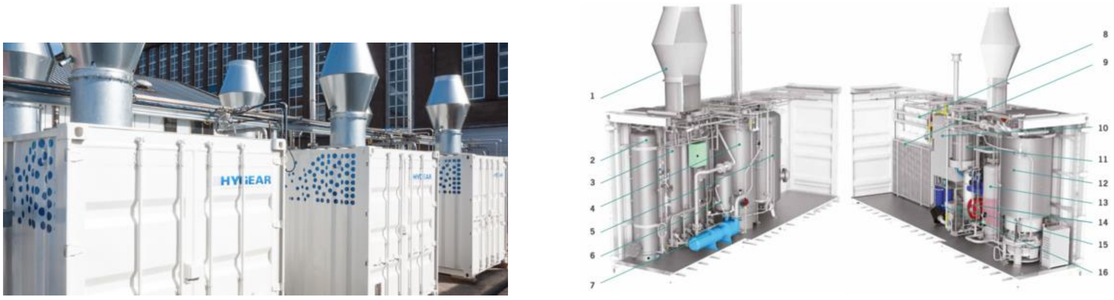


Figure 17 - HyGEAR on-site steam methane reformer.

Table 2 - Hy.GEN on-site hydrogen generation system.

Hy.GEN main components			
1. Ventilation fan	5. Hydrogen storage	6. Reformate cooler	13. Low temperature shift
2. Desulphurisation vessel	6. Water separator for vacuum pump	10. Electronics cabinet	14. Coolant expansion vessel
3. PSA-vessels	7. Vacuum pump	11. Steam generator	15. Burner air blower
4. Off-gas storage	8. Coolant heater	12. Reformer unit	16. Water purification system

Figure 18 - Bayotec on-site steam methane reformer.

3.2. Hydrogen storage

There are several options of storing hydrogen: either in cryogenic liquid state (LH_2) at deep temperatures (-253°C) or as pressurized gas (CGH_2 = compressed gaseous hydrogen) at high pressure and ambient temperature.

3.2.1. Gaseous hydrogen storage

Gaseous hydrogen storage can be provided:

- by "swapping" empty versus full "vessel",
    - directly from a tube-trailer 200, 350 or 500 bar (same trucks as described in section 3.1.1.1.1 p 4),
    - with cylinder bundles,
- by bunkering of a stationary storage at 200 bar.

(A) (B) (C)

Figure 19 - Gaseous hydrogen storages for refuelling stations.
(A) tube-trailer, (B) hydrogen bundle, (C) stationary gaseous storage.

Storage is currently achieved with the use of different types of hydrogen storage cylinders presented in Figure 20. Specificities mainly depend on the internal maximal pressure of storage. Classical cylinders, so-called type-I, are made of metal and can store gaseous hydrogen at a maximum pressure of 300 bar. In order to slightly increase storage pressure, reinforcement of these cylinders is possible with wrapping fibers, giving type-II cylinders. Type-I and type-II cylinders have a strong fire resistance compared to composite cylinders.

In order to significantly increase the storage pressure – up to 700-1000 bar – composite cylinders were developed. They are composed of an internal liner in aluminum or steel for type-III, in "plastic" for type-IV, and wrapped with fibers for mechanical resistance.

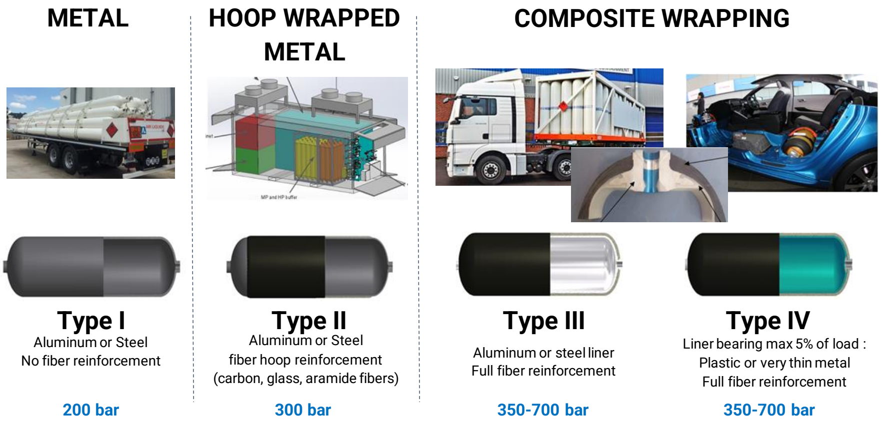


Figure 20 - Pressure vessel types. Ready-to-use cylinders.

Hydrogen can be stored in the four types of pressure vessels. The choice of the storage is based on the final application which requires a compromise between technical performances and cost competitiveness. H_2 generally used by industry is stored in type-I tanks, the pressure of which is from 150 to 300 bar (usually 200 bar, as mentioned in Figure 20). These are the most widely spread high pressure vessels today and are the cheapest. Type-II tanks are usually preferred for stationary applications when high pressures are required. Type-III and type-IV vessels are preferred for use in mobile applications (e.g. FCEVs), for which weight savings and increased volumetric density is essential.

Thus, for the stationary storage of large amounts of H_2, the following cylinders can be used:

- type-I for 200 bar (or less) storage with various volumes: 50 L, 123 L, 2.234 m^3,
- type-II for 900-1000 bar storage: 50 L, 123 L,
- type-IV potentially for very high pressure but very expensive (under-study, up to more or less 350 L).

3.2.2. Liquid hydrogen storage

Liquid hydrogen storage is a mature storage technology and has been used in professional and commercial contexts for some time. Currently, there is no liquid hydrogen storage applied to HRS in public domain. However, considering the development of hydrogen as an energy vector – for the mobility and other applications – this status could change in a near future.

Liquid Hydrogen storage can be achieved in vertical or horizontal position. Cryogenic stationary storages have a volume from 10 m^3 to 300 m^3 with an internal pressure around 12 bar.

Figure 21 - Horizontal and vertical liquid hydrogen storages.

In order to manage storage at -253°C, for large storage (> 100 m^3 water volume) double-walled vacuum insulated pressure tanks are used (see Figure 23). Such vessels consist of 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 (see Figure 22). For smaller storages (< 100 m^3), single-walled pressure tank with multi-layer insulation coating is used.

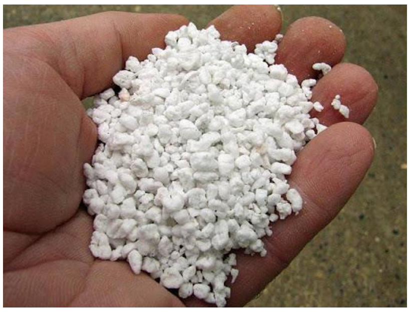


Figure 22 - Perlite for thermal insulation of stationary LH_2 tanks.

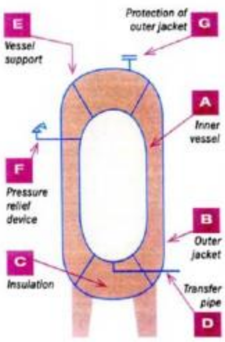


Figure 23 - Sketch of a double jacket LH_2 tank.

In most of the cases, LH_2 storages are aerial. Nevertheless, a few cases of underground LH_2 storage exist, buried or vault as illustrated and defined in Figure 24.

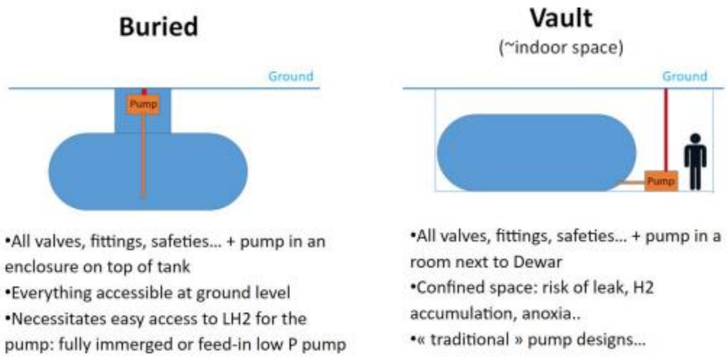


Figure 24 - The two main possible designs for underground LH_2 storages.

"Buried" design has safety advantages but requires an immersed LH_2 pump (low or high pressure), that is a technology not very well mastered. "Vault" design keeps the earth/fill away from direct contact with the system using a wall. It does not have any technical barriers, but has limitations in terms of safety (leaks, anoxia), and possibly higher civil work cost.

Table 3 - List of known underground liquid hydrogen storages.

Year	Location	Design	Station operator
2004	Washington DC	Vertical, in a sleeve	Shell
2005	London	Vault	BP
2007	Munich	Vault	Total
2010	Berlin	Vault	NA

3.3. Compression and/or Pumping

As H_2 is usually delivered at low or medium pressures (around 10 bar for liquid H_2 and 200 bar for compressed gaseous H_2), there is the need for compression to elevated pressure levels up to 850-1000 bar for storage – in intermediary tanks – before being dispensed to the vehicle's tank (required pressure: 700 bar).

3.3.1. Hydrogen compression for HRS with gaseous storage

Different technologies of compressors exist, these include mechanical compressors (mechanical piston, liquid piston, diaphragm, linear, ionic liquid, etc,) and non-mechanical compressors (cryogenic, metal hydride…), as illustrated in Figure 25.

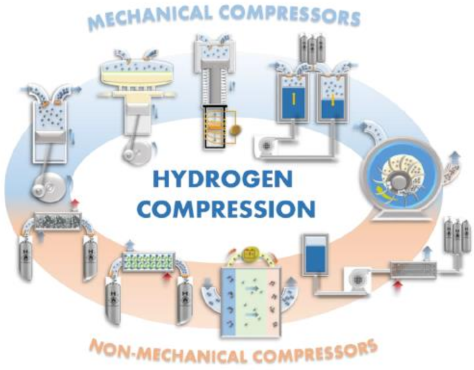


Figure 25 - Summary of the hydrogen compression technologies currently used for stationary and automotive applications[2].

The reciprocating piston compressor is the most commonly used typology of compressor, and it ensures good performance especially for high-pressure applications. As a result, the compression technology this report will focus on is based on a piston compressor.

The piston compressor is a positive-displacement compressor that uses pistons driven by a crankshaft to compress hydrogen to high pressure. The force required for gas compression is generated by the oil pressure from the hydraulic system and the corresponding ratio of piston diameters. The capacity is regulated by the piston speed (number of strokes) through varying the flow rate of the hydraulic pump. The frequency of strokes and, thus, the suction capacity of the compressor can be continuously regulated between 0% and 100%.

Figure 26 - H_2 compressor.

Depending on the chosen way of compression, it is possible to reach the final maximum pressure required for the filling:

- in two steps with a medium (around 400 bar) and a high pressure (around 1000 bar) compressor,

[2] *Sdanghi G. et al., Review of the current technologies and performances of hydrogen compression for stationary and automotive applications. Renewable and Sustainable Energy Reviews, Elsevier, 2019, 102, pp.150-170.*

- or with a single compressor which is able to deliver the maximum pressure.

3.3.2. Liquid hydrogen pumping and vapourizing for HRS with liquid storage

3.3.2.1. Liquid pump

Cryogenic pumps allow to transfer liquid from the storage tank to the heat exchanger. The pressure of liquid hydrogen is slightly increased between storage and the heat exchanger.

Figure 27 - Cryogenic pump.

The pump is submerged in a vacuum jacketed sump as illustrated in Figure 28.

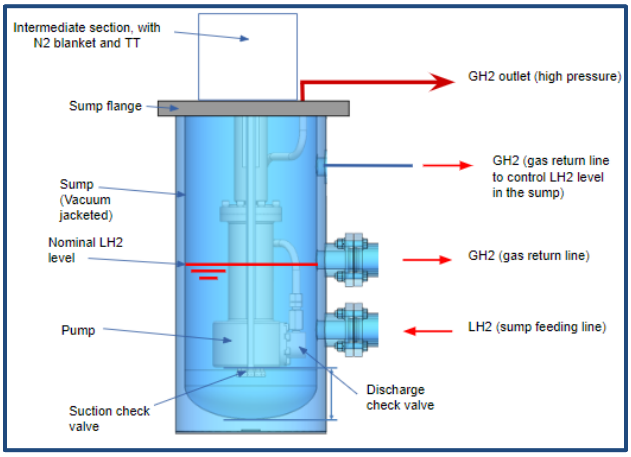


Figure 28 - Pump in vacuum jacketed sump.

3.3.2.2. Liquid vaporizer

The aim of the vaporizer is to increase pressure of the gaseous hydrogen which will be stored in intermediary buffers at a pressure up to 900 bar. Temperature of hydrogen is increased as well from -220 to -30°C.

Several technologies are available for this heat exchanger. The main are:

- atmospheric vaporizer,
- and tube-in-tube vaporizer.

(A) (B)

Figure 29 - Heat exchangers.
(A) Atmospheric vaporizer, (B) tube-in-tube heat exchanger in LHRS skid.

3.4. Dispensing

The dispensing is the part of the refuelling station which allows the consumer (members of the public) to fill their fuel cell vehicles. The dispenser is at the interface between the station process skid(s) and the vehicle.

3.4.1. Dispenser description

In the standard configuration, the skid is an external hydrogen dispenser offering a comparable experience to existing conventional fuel (petrol/diesel/CNG) stations. The dispenser enables a fast, easy and safe connection between the station and the vehicle to process the fuelling. Several designs of dispensers are available according to the manufacturer and refuelling station evolutions (see Figure 30).

Figure 30 - Hydrogen dispensers.

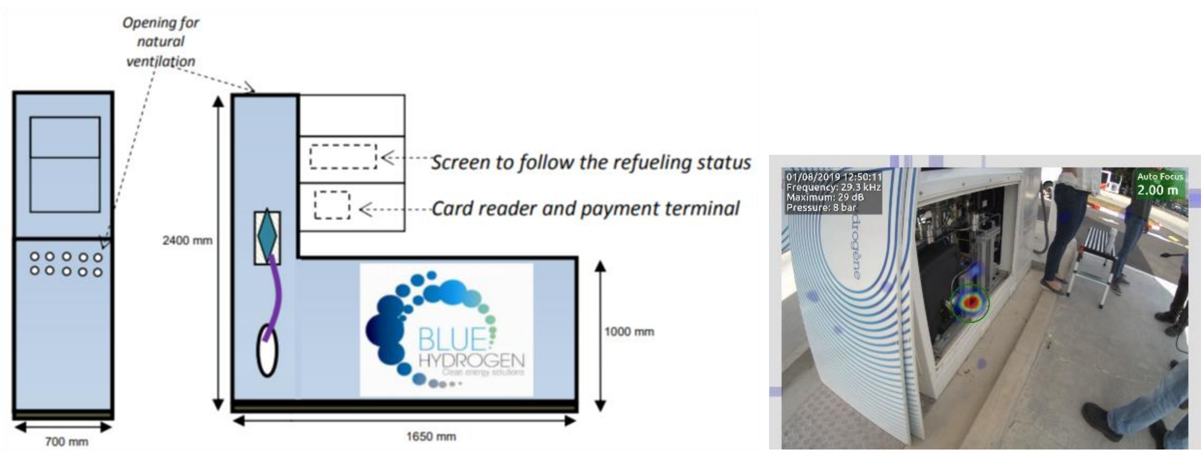
As noted in the introduction of this section, the dispenser is at the interface between the station process skid(s) and the vehicle. Hydrogen coming from the process skid(s) is gaseous, at a pressure up to 900-1000 bar according to the characteristics of the refuelling station, and circulates inside a pipeline with a diameter around 9/16'' which can be:

- underground and totally buried (in this case connection by fittings in the buried part are totally forbidden and welding is to be avoided),
- underground-like in gridded or accessible (thanks to removable plates) trench,
- or aerial (a very few cases for the main part of the pipeline).

According to the characteristics of the refuelling station, in future developments this 9/16''-diameter may be higher.

The dispenser is composed of a number of sub-assemblies:

- Distribution: Mast and valves panel with automatic filling valve, nozzle, hose and breakaway
- Control: HMI - Filling automatic control – Electrical panel – Access control



(A) **(B)**

Figure 31 - (A) Dispenser main elements and indicative dimensions, (B) valve skid.

A generic and simplified Piping and Instrumentation Diagram (PID) for gaseous hydrogen dispensing is given in Figure 32.

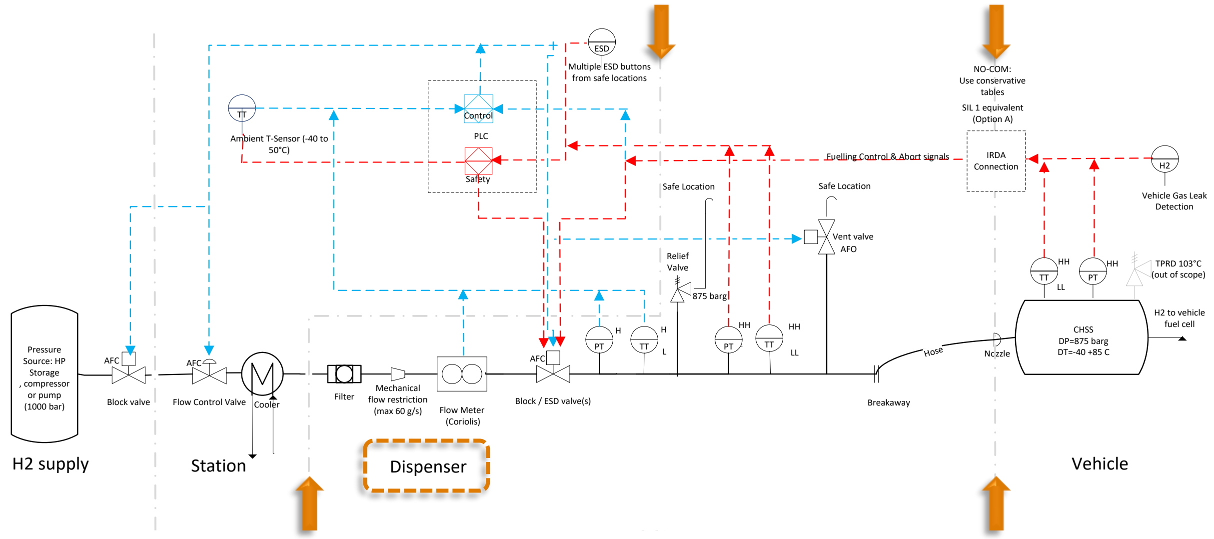


Figure 32 - Typical dispenser set-up.
Source: PRHYDE FCH-JU funded project.

(A) **(B)** **(C)**

Figure 33 - (A) View of dual dispenser for LDV refuelling,
(B) nozzle for LDV refuelling, (C) nozzle for HDV refuelling.

The station in Figure 33 (A) is capable of dispensing hydrogen through two fuelling positions simultaneously into light duty vehicles (2-10 kg-H_2) with the dual dispenser.

The nozzle of connection is different depending on the type of vehicle, as shown in Figure 33, with the picture (B) for cars and (C) for buses or trucks.

Pressures of delivery according to the kind of dispenser are:

- 350 bar for electric cars with hydrogen range extender,
- 700 bar for fuel cell cars,
- 350 bar for buses and trucks.

Several kinds of dispensers exist:

- Single:
  - 350 bar for cars or buses
  - 700 bar for cars
- Dual:
  - 350 bar and 700 bar for cars
  - 350 bar buses / 700 bar cars

Maximum flow rates are:

- 60 g s^{-1} for cars refuelling,
- and 120 g s^{-1} for buses and trucks 350-bar refuelling.

Research is being conducted in order to increase these flow rates up to 300 g s^{-1} as peak flow rate with 180 g s^{-1} of average flow rate for heavy duty applications. The purpose is to enable the filling of higher capacity on-board storages within acceptable filling time while ensuring safe filling conditions and integrity (no damages) of on-board storage cylinders.

Temperature of delivery ranges from -40°C to +40°C (fuelling protocol: SAE J2601 H70 T40).

3.4.2. Equipment between dispenser and vehicle

The technical characteristics and features of the dispenser include:

- Fuelling is automatic and requires minimum customer manipulations (Nozzle + start push button),
- The vehicle connector or nozzle is easy to use and approved as per SAE J2600 standard,
- A breakaway coupling ensures a mechanical interruption of the fuelling in case the vehicle drive away from the dispenser without removing the nozzle,
- Infrared nozzle (compliant with SAE J2799) for 700 bar line allowing fuelling characteristics monitoring.

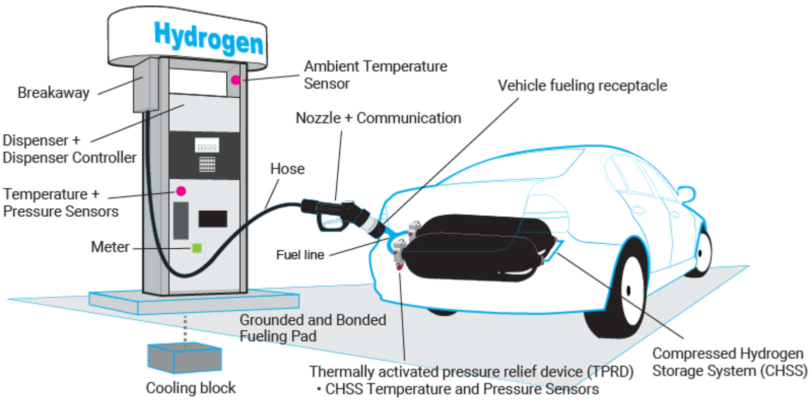


Figure 34 - Inventory of equipment interfacing hydrogen distribution and FCEV.

NB: Contrary to the illustration in Figure 34, the configuration with underground cooling system and/or heat exchanger is relatively rare and will not be dealt within MultHyFuel project. Most stations are equipped with heat exchanger placed near the dispenser or directly inside it.

In terms of safety, very close to the dispenser or inside, the following equipment can be found:

- H_2 detectors inside the dispenser,
- natural ventilation of the dispenser or, in some cases, mechanical ventilation,
- flame detector, outside, close to the dispenser,
- emergency shut-down buttons,
- bollards for physical protection of dispenser against shock coming from vehicles
- video camera.

More details on safety features are given in chapter 3.5 p 28. Additionally, note that for liquid hydrogen storage-based refuelling station (LHRS), the dispenser can be exactly the same as the dispenser of HRS, or small-cooling unit can be integrated inside the dispenser when the cooling is not realized upstream the dispenser.

3.4.3. More details about equipment inside the dispenser

Table 4 makes a generic inventory of the main equipment inside or close to the dispenser, with – when relevant – associated size and maximum allowed working pressure.

MultHyFuel

Table 4 - Generic inventory of main equipment, size and maximum allowed working pressure inside or closed to the dispenser.

Designation	Inlet diameter	Outlet diameter	Working pressure	Specificities
Gas Detector	-	-	-	Catalytic
Check Valve	1/4" DRC	1/4" DRC	250 bar	-
Heat Exchanger	3/8" C&T	3/8" C&T	975 bar	Insulated
Dispensing flexible hose	3/8'' C&T	3/8'' C&T	875 bar	Length 4 m
Flow Valve	1/4" C&T	1/4" C&T	975 bar	-
Flow Valve	9/16" C&T	9/16" C&T	975 bar	-
Double Block and Bleed	9/16" C&T	9/16" C&T	975 bar	Vent connection 1/4" C&T
Pressure Control Valve	9/16" C&T	9/16" C&T	975 bar	Vent connection 1/4" NPT
Pressure indicator and transmitter	1/4" C&T	1/4" C&T	975 bar	Ex
Pressure Safety Valve	-	-	975 bar	6 mm - Vent connection 1" NPT
Restricted Orifice	1/4" C&T	1/4" DRC	975 bar	0.7 mm
Solenoid Valve	6-8 mm	4-6 mm	10 bar	-
Temperature Transmitter	1/4" C&T	-	-	Ex
Shock Detector	-	-	-	-
Break-Away	3/8'' C&T	3/8'' C&T	875 bar	-
Nozzle	3/8'' C&T	3/8'' C&T	875 bar	-

DRC: Double ring compression fitting, C&T: Cone and thread fitting, NPT: National pipe thread fitting, Ex: ATEX certified.

3.4.4. Multi-fuel station

The definition of a multi-fuel station, for the MultHyFuel project, is a station that provides several types of fuels for vehicle refuelling, answering - by this way - to the existing and future needs.

At this stage of the project, the multi-fuel station uses the same codes, visuals and functions as a conventional station - which is also already a multi-fuel station - but integrating hydrogen.

Thus, leaving aside the process area, the main parts of the station are:

- The dispensing forecourt, where the dispensers are located, distributed in one or several dispensing islands, covered or not by one or several canopies to protect the customer,
- The dispensing islands, usually an elevated curb (the “island”) where the dispensers are located; one island is a fuelling post for one vehicle, or two vehicles located on both sides of the island,
- The dispenser, composed of one or several nozzles delivering potentially different types of fuels.

In Figure 35, two stations in Germany with H_2 and liquid fuel dispensers. Pictures show H_2-dispenser very near to dispensers with liquid fuels on the same island, but not included in the same dispenser.

Figure 35 - Dispensing forecourt with H_2-dispensers close to other fuel-dispensers on the same dispensing island (Germany).

3.5. Existing safety features for H_2 refuelling stations

Table 4 shows an inventory of the safety features typically set up in a hydrogen refuelling station.

Table 5 - Safety features for HRS.

What	Where	For what
Qualified and validated hose and fittings	Process and dispenser	Avoid accidental leakages
Periodic replacement of the hose	Dispenser	Avoid accidental leakages
H_2 detection	Inside the process container Inside the dispenser Compression area	Activate warning, and shut-off valves if required in case of accidental leakage
Flame (UV/IR) detector	In the process container Outside, close to the dispenser	Activate warning, and shut-off valves if required in case of accidental ignited release
Automatic shut-off valve	Several between H_2 storage and dispenser	Limit H_2 inventory in case of accidental release
Process pressure monitoring	General	Detect abnormal pressure drop due to leak or piping rupture
Naturally ventilated confined spaces	Process container Dispenser	Avoid to reach flammable limits of H_2-air mixture in case of accidental release
Forced ventilation	Process container for some models	Avoid to reach flammable limits of H_2-air mixture in case of accidental release if natural ventilation not possible or not efficient enough
ATEX certified equipment	In confined spaces where leaks can occur (i.e. skids and dispenser)	Avoid ignition sources
Hose grounded	Dispenser	Prevent sparks caused by static electricity during refuelling and so avoid ignition
Automatic leak test before filling	General	Avoid accidental leakages
Flow restrictors	General	Limit flow rate in case of release or piping rupture
Automatic closing time	General	Close H_2 feeding valves in case of hose rupture or leak
Hose break-away device	Dispenser	Avoid major leak by closing feeding flexible in case of tearing by forgetting to disconnect the vehicle
Shock protection (bollard)	Dispenser	Protect the dispenser from major mechanical aggression by vehicle accidental stamping and avoid catastrophic leak
Emergency punch stop	Few meters from the dispenser	Close H_2 feeding valves in case of emergency
Conductive (grounded) concrete slab	Dispenser	Prevent sparks caused by static electricity during refuelling
Pressure safety valve	Stationary storage	Avoid major leak by releasing overpressure to safe location
Fence	Storage	Avoid external aggression

What	Where	For what
Walls; for some configurations (depending on geographic requirements and/or HRS location)	Close to storage and/or process skid(s)	Physical protective barrier against thermal effects and/or overpressure effects in case of fire or deflagration
Video camera(s)	Dispenser and/or process area	General monitoring of unmanned station (to monitor process accidental event, dysfunction, intrusion, misbehaviour, vandalism…)

4 Overview of the other refuelling stations

4.1. "Conventional" liquid hydrocarbon (HC) stations

4.1.1. Fuel distribution

Hydrocarbon fuels are typically delivered to site via fuel delivery vehicles that are eventually unloaded into underground storage tanks via a hose connected to an above or underground fill point, Figure 36 below. The fuel flow from the fill point to the underground tank is driven by gravity only. Targeted fuel delivery vehicles unloading rates are 800-1200 $L.min^{-1}$. Above-grade fill points are preferred since these limit the required vehicle maneuvering, feature better ergonomics for the fuel delivery vehicle operator and eliminate flash fire risk of below-grade fill points. However, both options can be found in the field.

Figure 36 - Above grade fill point (left) and below grade fill point (right).

The refuelling station design are typically based on the largest delivery vehicle anticipated in the market, which is typically a 14.6 m (40 t) fuel truck, see sketch in Figure 37 below.

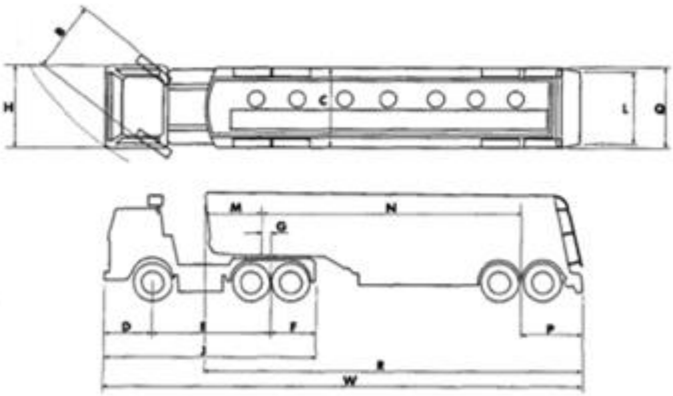


Figure 37 - Standard fuel delivery vehicle.

The fuel delivery vehicle route through the respective retail site should always minimize space required on site but also avoid excessive maneuvering. Reversing of the delivery vehicle from discharge position is not permitted at Shell sites. It is generally recommended to avoid all reversing maneuverers if possible. Discharge positions may not obstruct site entrance nor exit. In case of lack of alternatives, the retail site is to be closed during fuel delivery by the fuel delivery vehicle. The fill points should be located as close as possible to the underground storage. The discharge location should be easily accessible for the delivery vehicle and should preferably be located outside customer traffic areas. The delivery vehicle should be able to reach and leave the discharge location without reversing.

4.1.2. Fuel storage

Above ground fuel storage designs were abandoned in view of associated fire and explosion risks and are now rather uncommon. Today's fuel storages are typically installed underground, either in single wall (suitable for low-risk sites only) or double wall vessel design, the latter allowing interstitial leak detection and automatic shutdown in case of a storage vessel leak.

Figure 38 below shows a typical double wall storage. Minimum wall thicknesses (for 2.5-3 m diameter steel tanks):

- Double wall design: 7 mm inner wall, 4 mm outer wall
- Single wall design: 8 mm wall

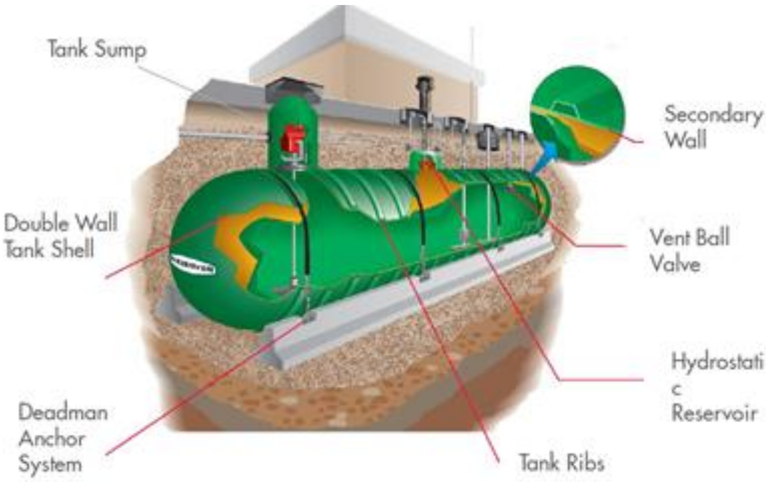


Figure 38 - Underground Double-Wall Storage Tank (fiberglass reinforced plastic).

The underground storage tanks are equipped with so-called tank top chambers which are intended to provide leak tight containment of tank top fittings, prevent corrosion of metallic components and provide access for maintenance & inspection; see Figure 39.

Figure 39 - Tank top chamber.

4.1.3. From storage to dispenser

Figure 40 hereafter shows a typical underground fuelling system layout with 2 underground storage tanks (in yellow), 4 tank top chambers on top of the storage tanks (grey colour), underground fuel piping (in green) towards the 4 under-dispenser containment sumps and electrical conduits (in orange colour). The tank top chambers, as well as the dispensers, are connected via underground piping (in purple colour) to either a vent or a vapour recovery system (depending on local regulatory requirements at local retail site). The connection of the underground tank to the vent allows for breathing of the tank; i.e. compensation of changes in gas/liquid ratio corresponding to changes in fuel level in the tank. All of the above-mentioned equipment is underground and usually not visible apart from the actual fuel dispenser which is installed on top of the under-dispenser containment sump. The underground tanks are regularly topped up from fuel delivery vehicles via the fill pipe (top right corner of Figure 40). The system typically also contains an oil/water separator which is not shown in the schematic below, though.

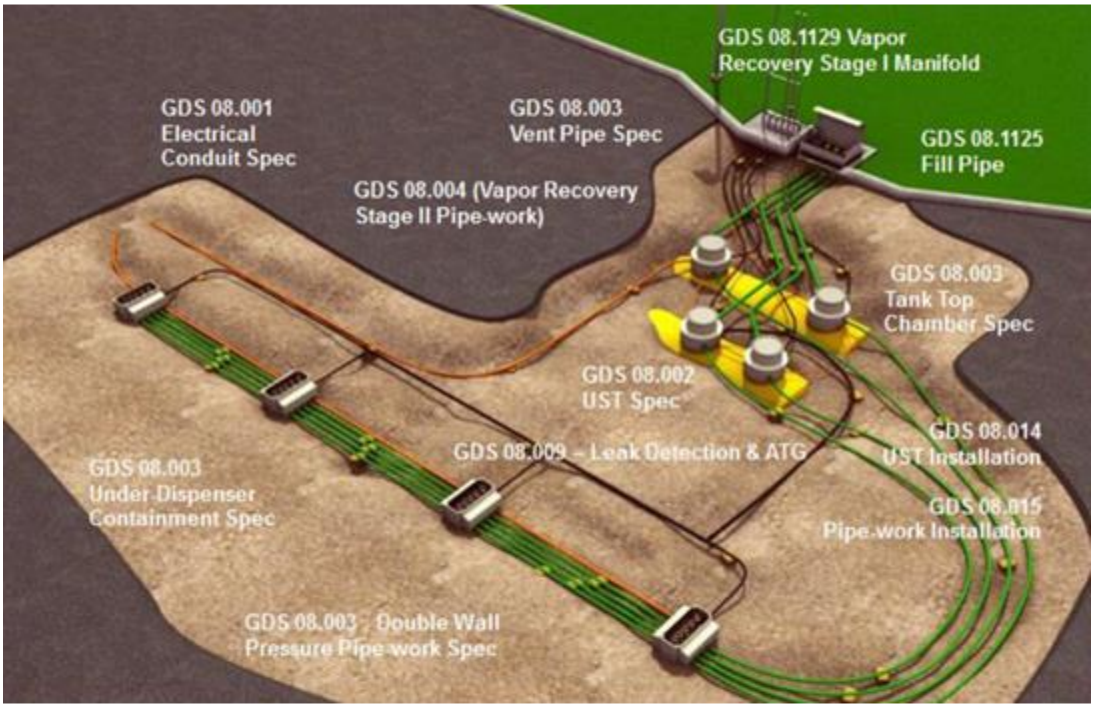


Figure 40 - Schematic of a general underground fuelling system layout including relevant Global Design Standards (GDS) per equipment item.

While the mentioned fuelling system is obviously designed as per industry standards, past experience shows that leaks and resulting contamination of the ground in vicinity of the system can occur in very rare cases. Figure 41 below shows a summary of the most common cases.

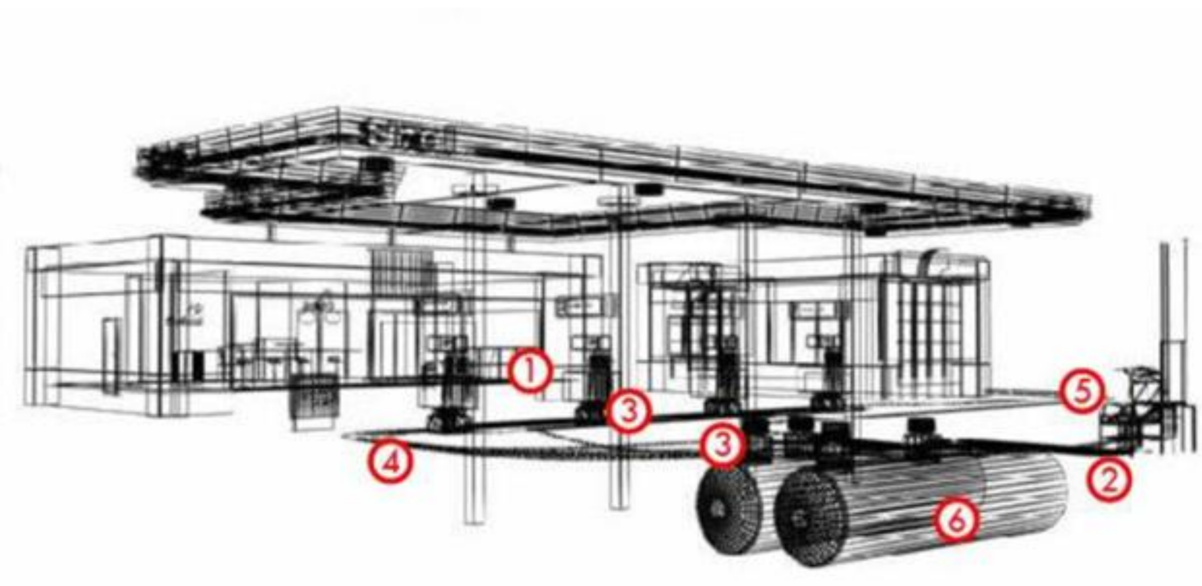


Figure 41 - Common causes of fuel leakages / spills.
Captions of circled numbers are given in Table 6.

Table 6 - Potential fuel release scenarios and threat corresponding to the sketch of Figure 41.

No	Location & release point [(1)]	Threat [(1)]
1	Dispenser	Customer refuelling error, dispenser knockdown
2	Underground vent pipework	Loose connection points, corrosion
3	Tank top & under dispenser	Loose fittings, not vapour/liquid tight containment, seismic impact
4	Underground fuel pipework	Corrosion, loose fittings, failure of mechanical joints
5	Direct and offset fill points	Error resulting in spill or tank overfill, bad fittings resulting in a spill
6	Underground storage tanks	Corrosion, damage during maintenance/installation, manufacturing flaws

[(1)] *Table denotes examples of potential fuel release scenarios and threats, rather than a complete list of potential fuel release scenarios.*

4.1.4. Dispensing

The dispensers should deliver a fuel flow of 80 L.min^{-1} for a two-sided dispenser, and 130 L.min^{-1} HGV for a single sided dispenser with all nozzles in operation. There are two principles of delivering fuel from the storage tank to the dispenser, see Figure 42 hereafter:

- Suction, i.e. one fuel pump per grade in each dispenser, typically applied for systems with 3 or less dispensers
- Pressure, i.e. fuel pumps inside storage tanks, typically applied for systems with 4 or more dispensers

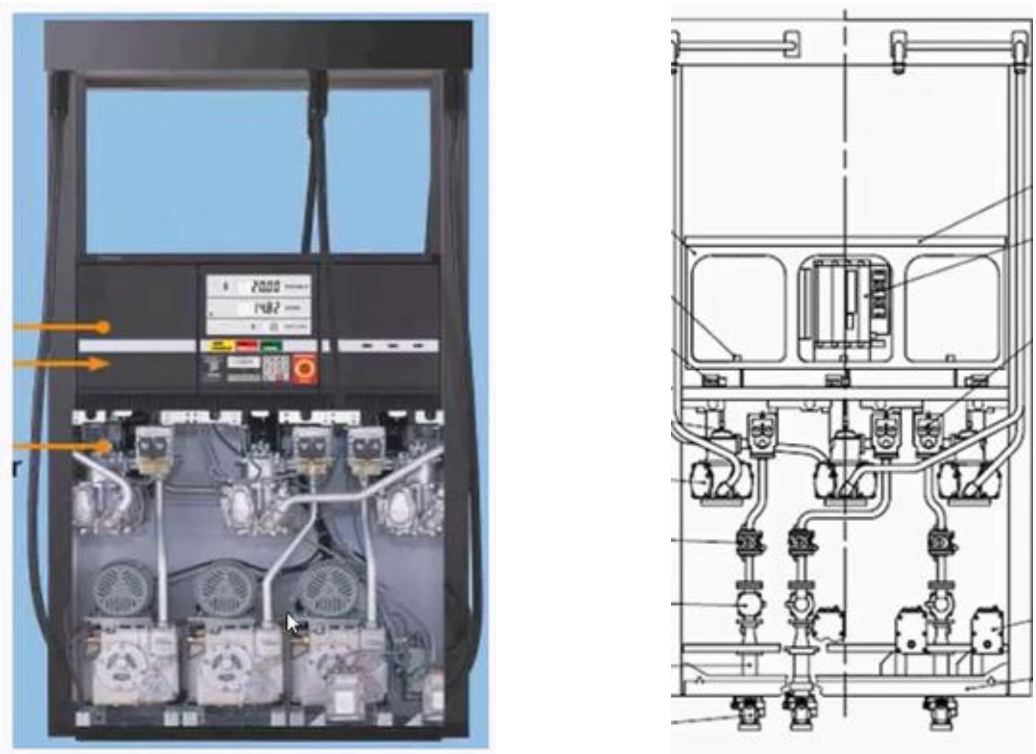


Figure 42 - Dispensers – suction type (left) and pressure dispenser (right).

The dispenser is installed on a so-called under-dispenser containment (UDC) sump (see Figure 43), providing containment of product leaks that may occur from dispenser hydraulics or pressurized mechanical connection under the dispenser and equipped with a number of additional safeguards against product loss as a result of mechanical impact, such as:

- crash protection, e.g. by bollards around the dispenser, see Figure 44,
- a shear valve in the UDC for closing off fuel supply from the storage tank upon vehicle impact, see Figure 45, and
- a breakaway coupling at the dispenser hose for stopping the flow from the dispenser in case of hose rupture due to vehicle drive away, see Figure 46.

Figure 43 - Under-dispenser containment sump.

Figure 44 - Crash protection.

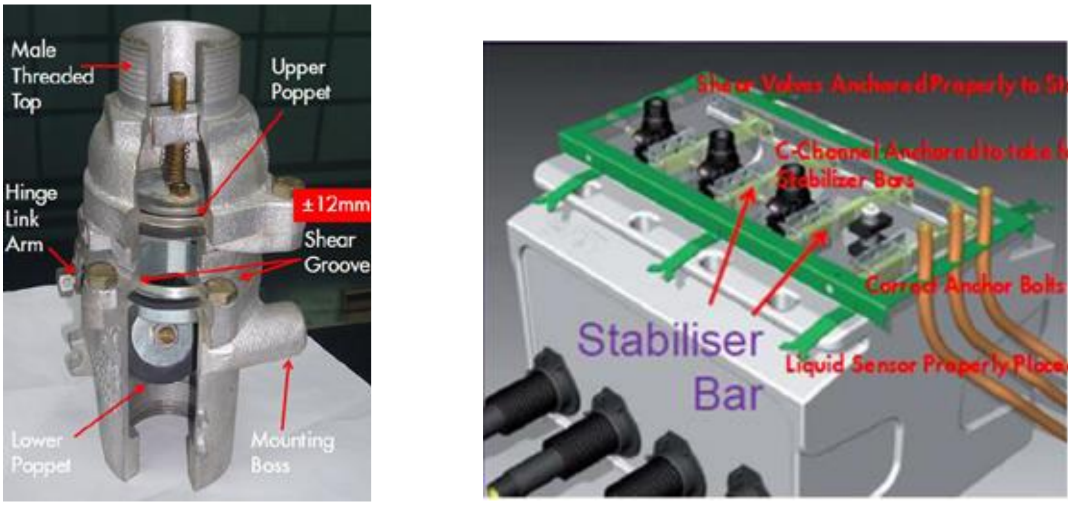


Figure 45 - Shear valve.

Figure 46 - Breakaway coupling.

4.2. LNG/CNG stations

Refuelling stations for vehicles powered by natural gas usually include three possible configurations, which are available and deployed:

- **CNG:** Compressed Natural Gas is provided from NG grid or non-stationary storage in gaseous state to fill the vehicle at a pressure between 200 to 250 bar. It is the most developed technology for buses, short distance trucks and cars.
- **LNG:** Liquefied Natural Gas is provided by road tanker trucks which unload LNG to a on-site storage at low temperature (-160°C)**.** It is less developed and mainly used to supply long distance trucks as the liquefied natural gas allows to store on board more natural gas thanks to the higher density of the LNG compared to the CNG.
- **L-CNG:** It is a combination of the previous technology by storing LNG which is vapourized and compressed to CNG in order to supply CNG vehicles.

An example of a LNG & L-CNG station is illustrated by Figure 47 and Figure 48.

Figure 47 - LNG & L-CNG station.

Figure 48 - CNG station (left) and LNG station (right).

When locating a refuelling station, two main factors have an important impact:

- the distance from the natural gas transport network,
- and the proximity to high-traffic corridors or urban centers.

The first characteristic affects the way natural gas is supplied (NG pipeline, tube-trailer trucks or LNG), the second affects the size of the station.

4.2.1. Fuel distribution

When we consider CNG stations (gaseous fuel only), the Natural Gas (NG) is supplied to the refuelling station in two main ways:

- NG pipeline,
- tube trailer trucks.

The pressures of the NG in the pipelines range from 1 bar (connection to DSO gas infrastructure) to about 75 bar (connection to TSO gas infrastructure), while in the tube-trailer trucks, the NG is stored at about 220 bar.

In the case of LNG or L-CNG refuelling stations, NG is – instead – transported in liquid state by cryogenic tankers at a maximum pressure of 18 bar and at a temperature of approximately -160°C to be stored onsite.

Figure 49 - Cryogenic high pressure pump (top left), cryogenic LNG pump (top right), CNG compressor (bottom left), L-CNG Tank connection (bottom right).

4.2.2. Fuel storage

The typical CNG station configuration, considering both the NG supplying systems (pipeline and tube-trailer trucks), usually includes an integrated compressed NG storage in the compressor cabinet, constituted of steel cylinders of about 80 L each in racks (15 or 30 cylinders depending on the delivery configuration) both at medium (up to 180 barg) and high pressure (up to 250 barg).

LNG stations configuration, on the other hand, includes an on-site cryogenic tank whose average size is usually about 60-80 m^3 (even if it is possible to find on the market capacities ranging from 30 to 100 m^3), preferably placed in a vertical position in order to minimize the boil-off phenomenon.
L-CNG stations includes within their perimeter both the solution for storing the liquid and compressed NG.

Figure 50 - LNG Vertical tank (left), CNG storage (right).

4.2.3. From storage to dispenser

In CNG refuelling stations, the NG flows from the compression/storage system to the dispenser through a primary pipe in AISI 316 stainless steel (multitube "Parker" type), for the delivery of both the medium and high-pressure lines.

A secondary pipe conveys the purges of the dispensing nozzles of the refuelling station into the system. This pipe is usually laid underground in a special duct, in order to be protected from vehicle transit.

The pipes (both primary and secondary) have an external coating consisting of a layer of FR-PVC plastic material (Flame retardant compound), in order to avoid perforation due to corrosive phenomena that may be caused by passive currents and/or chemical agents.

In LNG refuelling stations, the distribution of NG in liquid form takes place through the use of a cryogenic pipeline usually placed in an inspectable tunnel.

4.2.4. Dispensing

The CNG stations are usually equipped with 2 or 4 dispensing nozzles for the simultaneous delivery of compressed NG.

It is also possible to have "combo-dispensers" for dispensing both traditional liquid fuels and methane and/or LPG; in this case there are two different nozzles (one for CNG, the other for LNG) connected to the same dispenser. It consists of a mass meter and an electronic head for displaying the quantity of product sold.

There are different attachment nozzles for vehicles, both standard light and heavy vehicles (NGV1 and NGV2), and proprietary, for older vehicles of different member state.

The LNG dispenser, specifically designed to operate with cryogenic LNG, has a single or double dispensing nozzle. It is designed to measure, through the Coriolis effect, the mass of liquid dispensed, regardless of the density and net of any transfer of the gas present in the vehicle tank. The amount of gas removed from the vehicle is measured with a second mass meter. The information from both meters is acquired by an electronic head, which will allow to view the amounts and weights relating to the refuelling performed. The delivery nozzle topology is standard (NGV1 for passenger cars and NGV2 for bus/truck, both based on ISO 14469), unique for all vehicles currently on the market.

Figure 51 - LNG dispenser (top left), LNG dispenser: internal view (top right), CNG dispenser (bottom left), Multi-fuel dispenser (bottom right).

5 Overview of existing regulation in France, in Europe, in the World for stand-alone fuel stations

The majority of regulations applicable to hydrogen refuelling stations in Europe are general in nature and are comprised of legislation relating to health and safety or to the CE marking of equipment placed on the market or other elements associated with the handling of flammable fuels and pressurised atmospheres.

Legislation specifically intended for hydrogen refuelling stations tends to be applicable on a national basis, either as Regulations, or in the case of the USA, Codes that are adopted by different regional governments.

One notable exception to this is the legislation covering the interoperability of refuelling points with vehicles – addressed in the Alternative Fuels Infrastructure Directive[3] (referred to as the AFID, or DAFI) which was written with the intention of bringing a degree of standardisation to HRS around Europe. At this point in time, the AFID covers the dispensing of gaseous hydrogen only.

A few countries around Europe also have additional legislation specific to hydrogen refuelling stations – examples of separation distances for gaseous hydrogen refuelling stations included in legislation is outlined in the chapter below, also the separation distances for liquid hydrogen stations sourced from a range of regulations, codes and standards from around the world.

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) funded project Hylaw (www.hylaw.eu) made a summary of the applicable rules and regulations at EU level that apply to or are relevant to the design, permitting and operating of Hydrogen Refuelling Stations. These can be found at the website linked above.

Work Package 1 of the MultHyFuel project will carry out a more in-depth analysis of the applicable legislation, risk assessment approaches and separation distances[4], with a focus on 14 European jurisdictions, which will be presented at a later stage in the project (See D1.3).

[3] *Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure*

[4] *See D1.1. for the research framework used for this workstream*

5.1. GH_2/LH_2 stations

5.1.1. GH_2 stations

Safety distances requested by the French regulation are summarized in the scheme hereafter (see Figure 52).

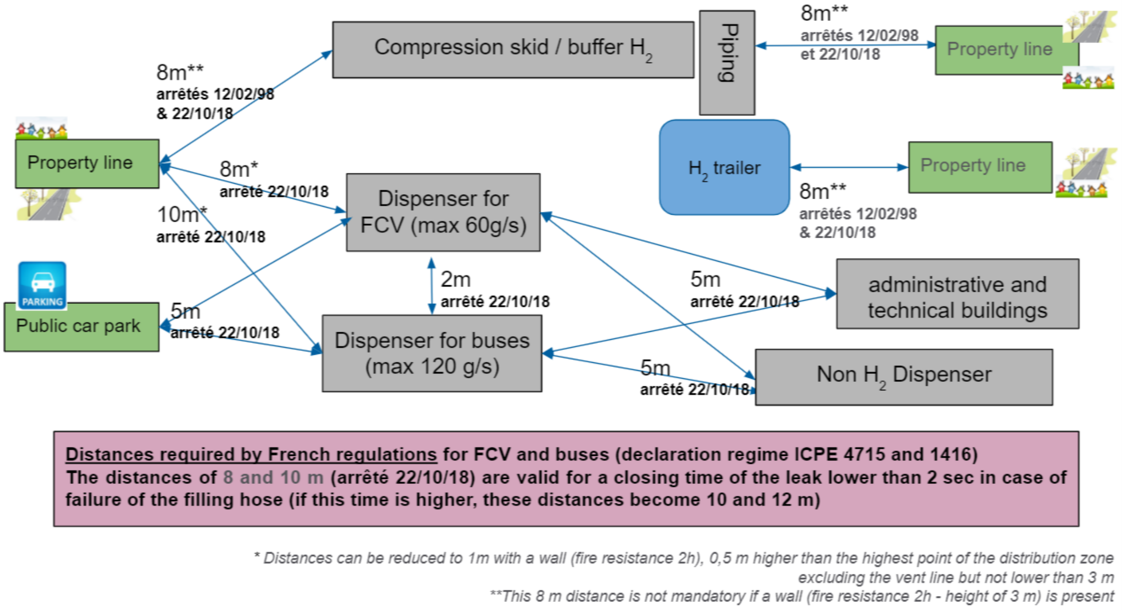
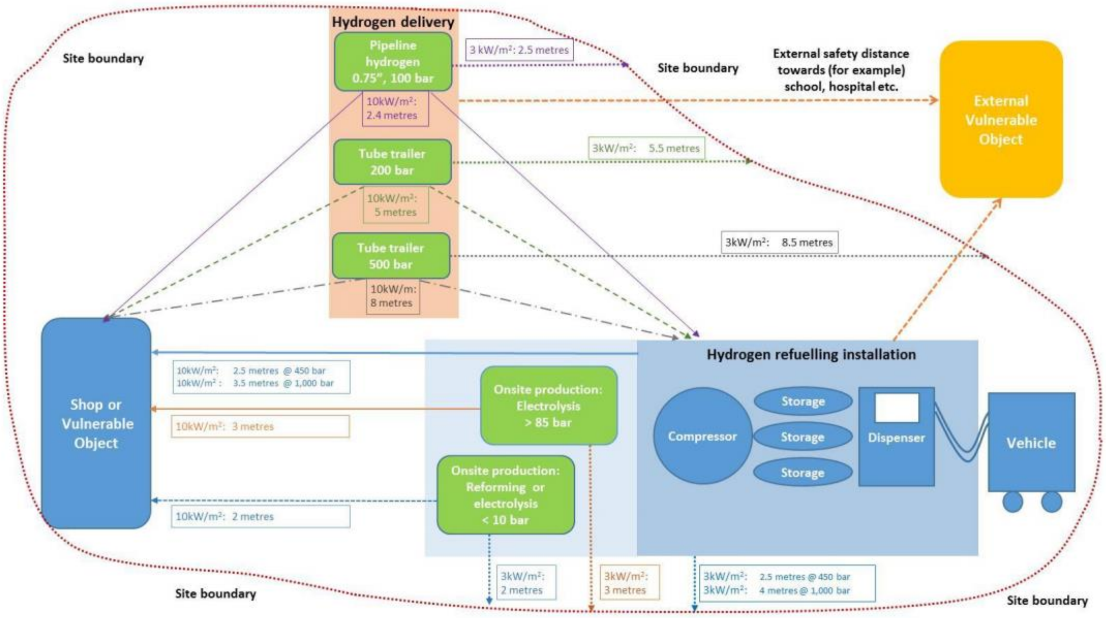


Figure 52 - Safety distances in France for gaseous hydrogen refuelling stations.

Safety distances are calculated based on a 60 g s^{-1} (for cars) and 120 g s^{-1} (for buses) release during 2 s followed by ignition (i.e. UVCE overpressure effects).

Safety distances requested by the Netherlands regulation [PGS 35] are summarized in Figure 53.



Remarks:
- Not to scale.
- Distances rounded to nearest 0.5 metres.

Figure 53 - Safety distances in Netherlands for gaseous hydrogen refuelling stations Hazardous Substances Publication Series, 2015.

Safety distances requested by Italian regulation[5] are summarized in Figure 54. Safety distances different from those can possibly be identified by applying the methodologies of the engineering approach to fire prevention provided for by the decree of 9 May 2007[6].

[5] *Decreto del Ministero dell'Interno 23 October 2018*

[6] *Decreto del Ministro dell'Interno 9 May 2007*

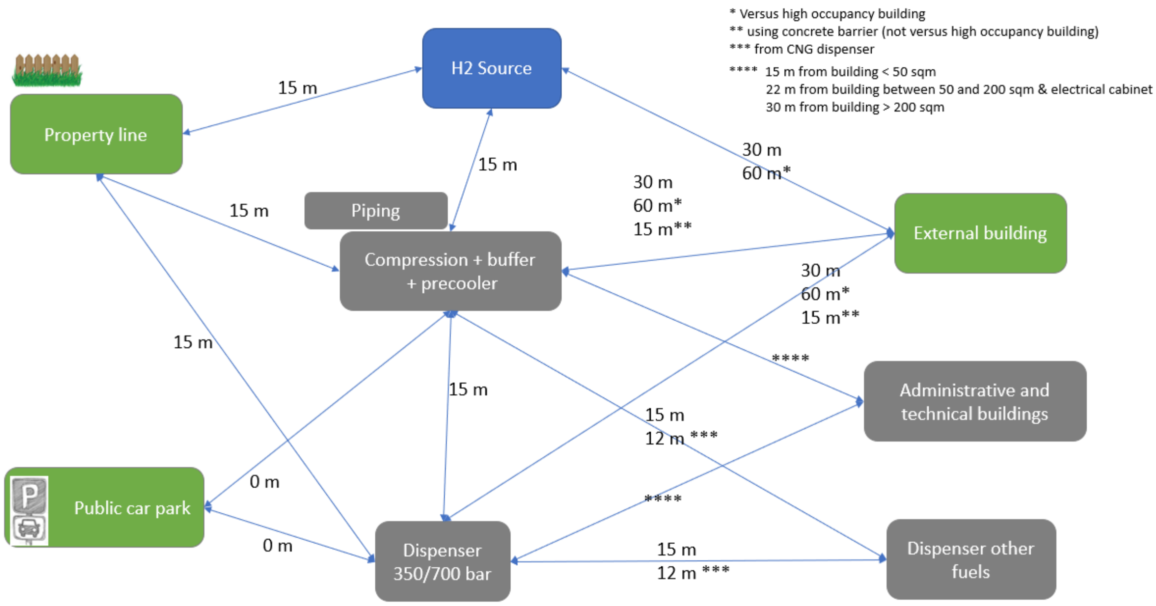


Figure 54 - Safety distances in Italy for gaseous hydrogen refuelling stations. (DECRETO 23 ottobre 2018: Regola tecnica di prevenzione incendi per la progettazione, costruzione ed esercizio degli impianti di distribuzione di idrogeno per autotrazione)

Analysis was carried out by ISO/TC 197/WG 24 during the preparation of ISO/TS 19880-1 (published 2018). When ISO 19880-1 was developed as a standard, published in 2020, the specific section on separation distances was removed, however it is still accessible through the ISO maintenance portal – see extract from ISO 19880-1 in Appendix p 73 and below:

> *"**A.2.2 Example safety distances from each country / region***
> *ISO maintenance portal URN (https://standards.iso.org/iso/19880/-1/ed-1/en) includes a table of examples of safety distances collected by ISO/TC 197, through country representative members during the preparation of ISO/TS 19880-1, which conveys a status of country specific safety distances at that the time of publication of the ISO/TS 19880-1 (2016). It demonstrates the wide range of results that can be found for similar equipment in similar environments around the world."*

Note: *The table in the ISO maintenance portal was not an all-inclusive list of values internationally and is not meant to be a recommendation for these applications.*

5.1.2. LH_2 stations

Table 7 gives an overview of safety distances required when considering liquid hydrogen applications. It should be noted a lack of uniformity between the minimum safety distances.

Table 7 - Overview of regulation for liquid hydrogen refuelling stations.

Country	Status	Distance to property lines
USA	Permit given by Fire Marshals NFPA55 “recommended”	Lot lines ⇒ 15 m Buildings ⇒ 23 m
France	Storage > 1 t (Europe 5 t) ⇒ authorization given by Prefecture	LH_2 ⇒ 20 m Dispenser (60-120 $g.s^{-1}$) ⇒ 10 m
Germany	No specific regulation for LH_2 if < 5 t (Low Seveso)	LH_2 ⇒ 5 m Dispenser ⇒ 2 m
Japan	Specific LH_2 regulation	LH_2 ⇒ 10 m Dispenser ⇒ 8 m
China	Strictly restricted to military use up to 2018	Under-development
Korea	Not yet regulation	Dispenser ⇒ 5 m

5.2. "Conventional" liquid HC stations

Every country has its own safety regulations and requirements regarding the positioning of main elements in a retail outlet. This chapter describes general guidelines and rules for positioning the main elements as per Shell’s Global Design standard 01.002 Basic Design Requirements and Principles and should always be applied together with local legislation.

During the design process of the stations, potential hazards associated with the storage and use of retail fuels must be considered. This means considering the different hazard zones and distance implications. Due to the higher vapour pressure and flammability petroleum spirit is the most relevant compared to other conventional liquid fuels, e.g. diesel fuel.

Petroleum spirit is a highly flammable liquid and gives off flammable vapour even at very low temperatures. Released vapour, when mixed with air in certain proportions, forms a flammable atmosphere which burns or explodes if a source of ignition is present. A flammable atmosphere exists when the proportion of vapour in the air is between approximately 1% (the lower flammable, or explosive limit) and 8% (the upper flammable, or explosive limit). Petroleum spirits’ vapour is heavier than air and does not disperse easily in still air conditions. It tends to sink to the lowest possible level of its surroundings and may accumulate in tanks, cavities, drains, pits or other depressions. Petrol floats on the surface of water; it may, therefore, be carried long distances and create a hazard far away from its point of release. An overview of typical hazardous areas is given in Table 8 and Figure 55.

Table 8 - Zones (Shell 01.002 Basic Design Requirements and Principles).

Definition	Examples of where on site
Zone 0 Where an explosive gas-air mixture is continually present or present for long periods of time.	Inside petrol tanks and any chamber with tank filling connections
Zone 1 Where an explosive gas-air mixture is likely to occur in normal operation.	Inside metering pump and dispenser housings. In the vicinity of vent openings. Pits and depressions below ground level within a Zone 2 area.
Zone 2 Where an explosive gas-air mixture is not likely to occur in normal operation and if it did occur, would only exists for a short time.	Any other area that may be affected by occasional spillage or where the release of vapour could occur from the plant or equipment.

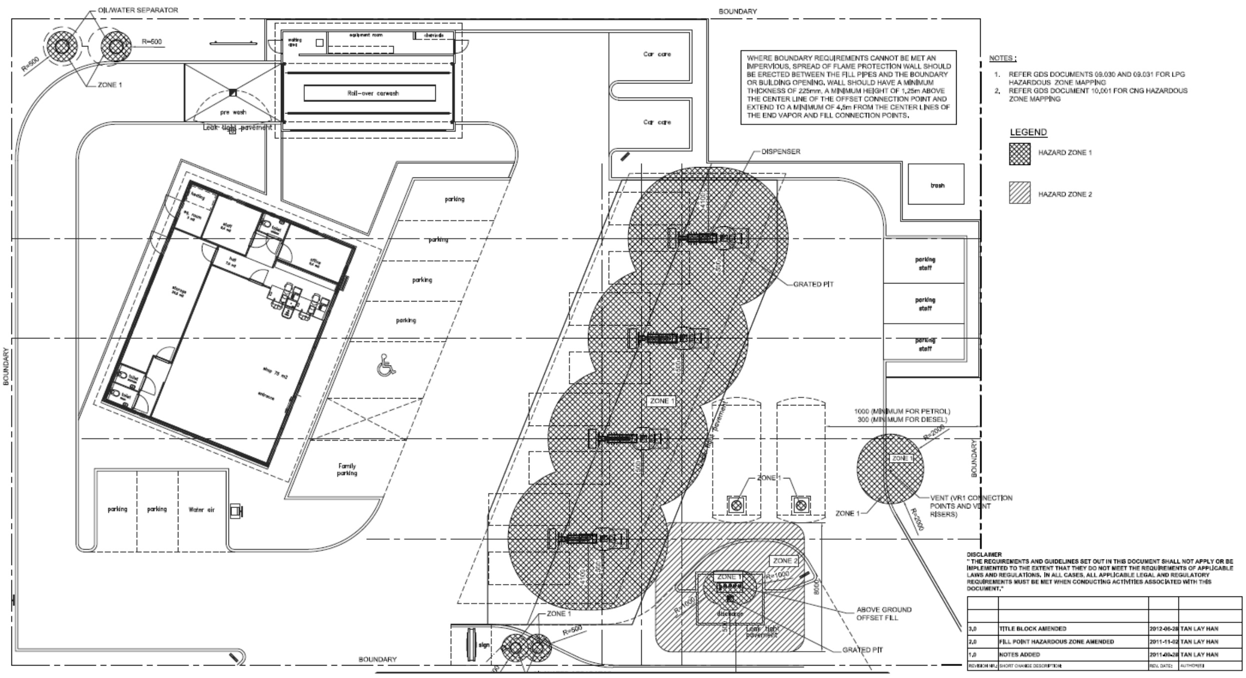


Figure 55 - Typical site hazardous zone layout (Shell Standard 01.080).

5.2.1. Tanks

The centre line of any delivery connection, manhole chamber or other opening into an underground tank must be located more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than 1.25 m above ground level) in any occupied building. Underground offset fill points must be located so that the centre line of each manhole chamber is more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than 1.25 m above ground level) in any retail outlet building or kiosk.

All underground tank delivery chambers have a Zone 0 classification. Only essential electrical equipment should be installed within the chamber (i.e. tank gauge probes, overfill protection controls, etc.). Such equipment, associated supply cable and connections must be approved for use in Zone 0 areas and be protected against accidental damage. Note: The manhole chamber is classified as Zone 0 only when it contains tanker delivery hose connection points.

All underground tank access chambers without openings for tanker delivery connections have a Zone 1 classification. Only essential electrical equipment should be installed within the chamber (i.e. tank gauge probes, overfill protection controls, etc.). Such equipment, associated supply cable and connections must be approved for use in Zone 1 areas and be protected against accidental damage. All above ground offset fills should be sited so that each fill pipe centre line is located more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than 1.25 m above ground level) in any retail outlet building or kiosk.

Alternatively, an impervious, spread of flame protection wall should be erected between the fill pipes and the boundary or building pening. This wall should be built to a minimum thickness of 225 mm, a minimum height of 1.25 m above the centre line of the offset connection point and extend to a minimum of 4.5 m from the centre lines of the end connection points. All above ground vapour return connections (stage 1b) should be located so that each return pipe connector centre line is located more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than 1.25 m above ground level) in any building.

Alternatively, an imperforate, spread of flame protection wall should be erected between the vapour return connector and the boundary or building opening. This wall should be built to a minimum thickness of 225 mm, a minimum height of 1.25 m above the centre line of the vapour return connection point and extend to a minimum of 4.5 m from the centre line(s) of the connection point(s).

The tanker discharge position should be located so that the delivery vehicle stands in the open air, well away from buildings, kiosks, dispensing activities and escape routes. The layout should ensure that the foot valves and tanker connection points are normally situated more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than

1.25 m above ground level) in any retail outlet building. A hazard area exists within 1 m in all directions, from any opening on the tank top of a delivery vehicle. No electrically driven equipment or lighting should be installed in the vicinity of the delivery vehicle.

Note: The manhole chamber is classified as Zone 0 only when it contains tanker delivery hose connection points.

5.2.2. Tank vent pipes

Tank vent pipes should be located in the open such that the centre line through the vertical vent pipe opening is more than 3 m away from any site boundary, or from any opening within an occupied building and electrically driven equipment. Tank vent pipes should be located such that they are adjacent to the tank fill points to simplify the installation of stage 1 bar vapour recovery pipe work.

As a last resourse, in tight locations where no other alternative is possible, tank vent pipes can be located against walls of buildings, provided the discharge point is taken a minimum of 2 m above the finished roof level. There should be no window, vent, air or other intake openings within 3 m in any direction from the centre line of any vent pipe, from the top discharge point down to ground level.

No electrical equipment should be installed within 3 m in all directions from the tank vent stack opening or within a radius of 3 m around the discharge point down to ground level. If this is unavoidable all electrical equipment should be intrinsically safe to the relevant standards.

5.2.3. Metering pumps/dispensers

All single hose petroleum metering pumps/ dispensers should be located so that the centre line through the hydraulic unit is more than 4.25 m away from any site boundary or from any door or low level window opening (i.e. openings which are less than 1.25 m above ground level) in any building. Extra safety distances should be allowed where multiproduct dispensers are employed, to accommodate the longer hydraulic units and the wider hose spread. No additional electrical equipment (e.g. loudspeakers, spreader boxes or other illuminated signs) must be installed in a zone, contained within a 3 m radius circle from the top of the hydraulic housing and horizontally coning downwards to 4.25 m radius circle at forecourt level, centred on the centre line of the metering pump/ dispenser. If the metering pumps/dispensers are fitted with high hoses or radial arms incorporating a sight glass, the hazardous area is extended to 0.75 m above the sight glass and within a 0.15 m radius circle down to forecourt level. No additional electrical equipment should be installed within this area.

5.2.4. Other equipment

All diesel dispensers and tank facilities may, at some time in the future, be converted for gasoline or other class 1 fuel. They should therefore, at the time of installation, be treated as gasoline equipment and the hazardous area rules applied. All pits, trenches, ducts, etc. within the hazardous area, must be regarded as Zone 1. Only electrical equipment, supply cable and connections approved for use in Zone 0/1 areas and protected against accidental damage should be used.

Great care should be taken to site other electrical driven equipment (e.g. kerosene dispensers, LPG equipment, CNG equipment, oil changer machines, vacuum cleaners[7], car wash machinery, lighting, etc.) well outside all hazardous areas. All electrical equipment, cables and connections used within hazardous zones must be approved and stamped by an internationally recognized body (i.e. BASEEFA, PTB, CEN, DIN, etc.) as suitable for the appropriate zone.

5.2.5. Control of vapour migration

Underground services can provide vapour paths from sources of retail fuels to potentially dangerous locations outside hazardous zones. In particular, ducts or conducts for power or signal cabling to dispensers or tanks are possible vapour migration paths from Zone 0 or Zone 1 areas.

These ducts should be sealed at both ends to prevent vapour migration. Particular attention should be given to the design of chambers and duct entries to the sales building or any other occupied building linked to the fuel storage or dispensing activities.

[7] *Beware that vacuum cleaners positioned outside hazardous areas could draw in vapours from the extended vacuum hose. Position the vacuum cleaner well away from hazardous areas*

5.3. CNG/LNG stations

Safety distances requested by Italian regulation[8] for CNG stations are summarized in Figure 56.

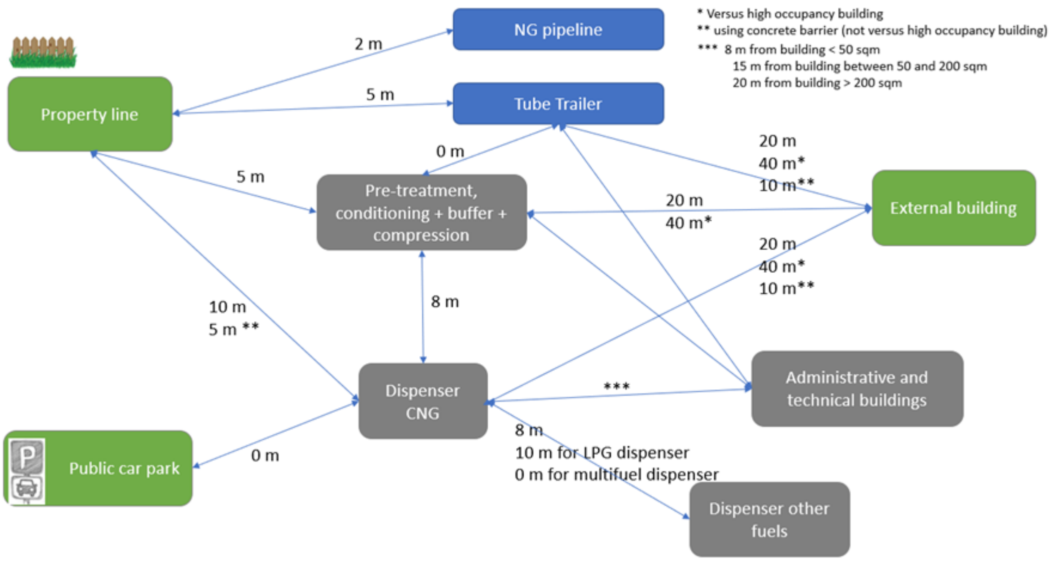


Figure 56 - Safety distances in Italy for CNG refuelling stations.

Safety distances requested by Italian regulation[9] for LNG & L-CNG stations are summarized in Figure 57.

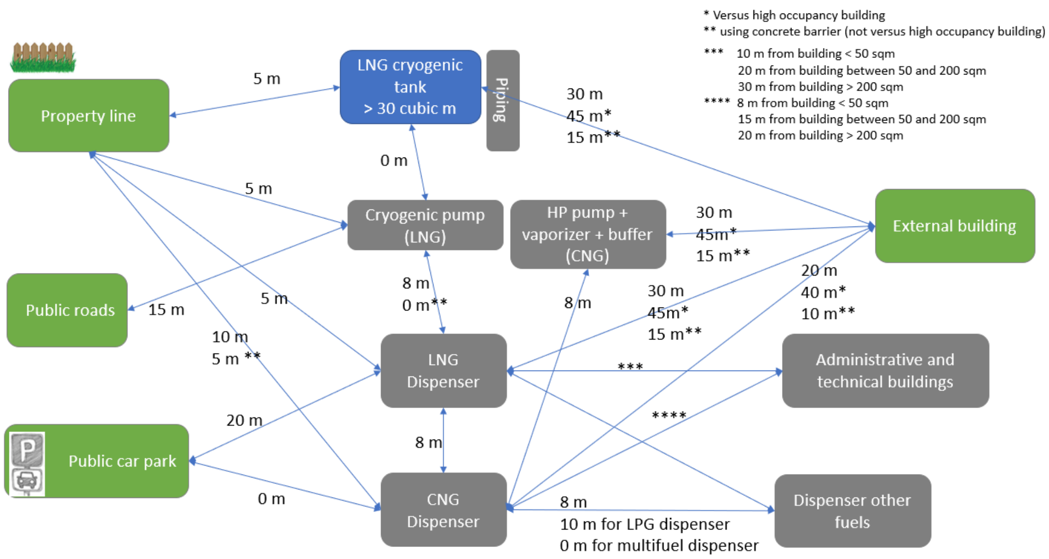


Figure 57 - Safety distances in Italy for LNG & CNG refuelling stations.

[8] *Decreto del Ministero dell'Interno 24 May 2002, and subsequent amendments and additions*

[9] *Fire Brigade Technical Guide num. 5870 18 May 2015*

6 Requirements for Multi-fuel stations

6.1. Review of potential risks

6.1.1. Risks associated to hydrogen refuelling stations

As illustrated by the Figure 58, the risks associated to HRS are mainly related to the flammable properties of hydrogen and the high pressure of storage and dispensing equipment.

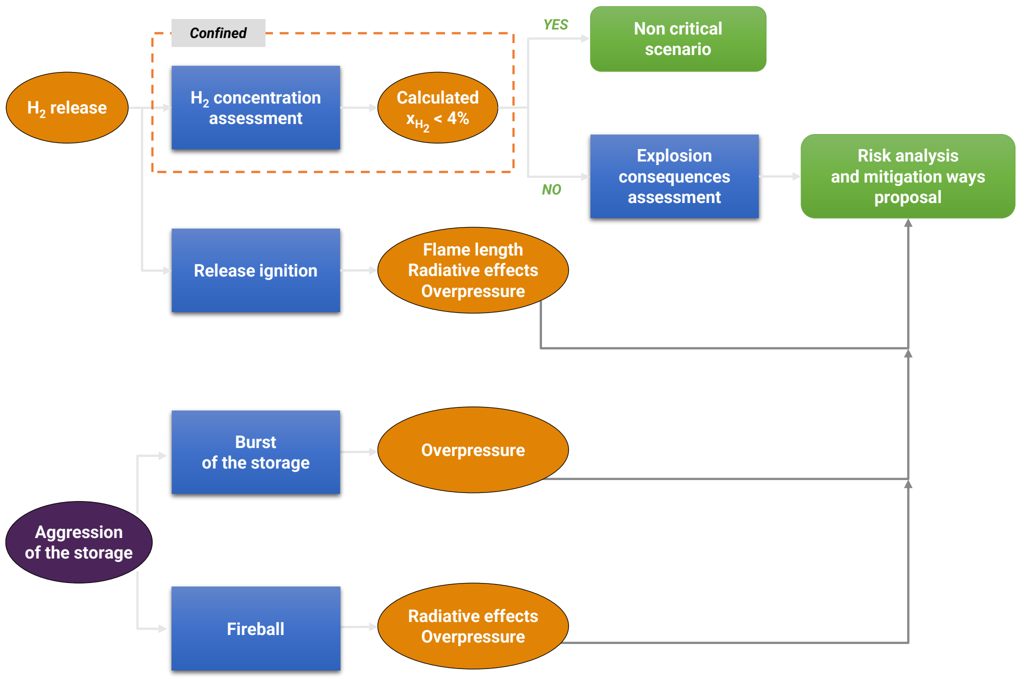


Figure 58 - Accidental events and associated consequences for hydrogen applications.

Should a leak from the H_2 equipment occur, hydrogen would be released and can generate:

- a jet fire, in case of immediate ignition, leading to radiative effects
- an unconfined vapour cloud explosion (UVCE), in case of late ignition, leading to overpressure effects
- a confined explosion, in case of late ignition in a closed space (e.g. container, building) leading to overpressure effects

Regarding the hydrogen storage, in addition to the previous scenarios, external aggression (e.g. fire or mechanical aggression) could generate a catastrophic rupture with the followings dangerous phenomena:

- a burst of the storage leading to overpressure effects
- a fire ball due to a massive release with instantaneous ignition of the hydrogen stored leading to radiative effects
- an unconfined explosion (UVCE), in case of late ignition of the previous instantaneous release, leading to overpressure effects

For example, the main scenarios identified in the deliverable 3.2 “State of the art - Risk assessment methods” are the following:

- a leak on piping or valve form H_2 HP storage leading to thermal and/or overpressure effects,
- a leak on dispenser system leading to thermal and/or overpressure effects,
- a leak on compressor leading to thermal and/or overpressure effects.

6.1.2. Risks associated to conventional refuelling stations

This paragraph gives a brief overview of major Health, Safety, Security and Environment (HSSE) risks and associated risk control and mitigation methods at conventional refuelling stations, i.e. public refuelling stations dispensing commercially-available gasoil and gasoline type of fuels for automotive application. The information is structured and represented in line with the so-called bowtie methodology. A bowtie is essentially a graphical representation of hazard[10] release scenarios, i.e. a representation of cause-to-consequence threat lines indicating realistic causes of an unwanted event (so-called top event), the potentially resulting consequences and how these consequences can be controlled and/or mitigated. Top events can generally be summarized as loss of control and more specifically for retail sites:

- loss of containment (manifested in product leaks or spills),
- loss of control of moving objects / objects at height (manifested in vehicle-vehicle or vehicle-equipment collision, falling objects, slips, trips and falls),
- loss of security (manifested in vandalism, physical / verbal aggression, robbery, etc.).

Bowties addressing loss of security will not be discussed in more detail, since this study essentially focusses on technical aspects. Potential consequences of remaining top events can be summarized as:

- harm to people (injury/death) resulting from ignition of leaked / spilled flammable product or utilities (e.g. gasoline pool fire, vapour cloud explosion), collisions, falling objects, slips, trips or falls,
- asset damage resulting from ignition of leaked / spilled flammable product or utilities (e.g. gasoline pool fire, vapour cloud explosion), collisions, falling objects,
- environmental impact resulting from noise, product or utility spill or leaks to air/soil/water,
- community impact (e.g. public concern).

The generic bowties with all major hazard scenarios for conventional refuelling stations[11] are shown in Figure 59 to Figure 62 hereafter.

[10] *Hazard: An agent that has the potential to cause harm to People, damage to Assets, impact on the Environment or Community.*

[11] *Shell retail bowtie for frontline engagement, 2017*

The intrinsic risk of relevant hazards, i.e. the likelihood of occurrence and the potential maximum severity of unmitigated consequences on basis of historic data[12] are listed in Table 9 below. Hazards that are not specific to refuelling stations, such as electrical hazard, are not within scope.

Table 9 - Intrinsec/unmitigated risk per hazard.

Hazard	People		Asset		Environment	
	Severity	Likelihood	Severity	Likelihood	Severity	Likelihood
Gasoline	permanent total disability or up to three fatalities	>1/yr in the industry	costs between US $10000 and US $100000	>1/yr in the industry	extensive measures required to restore beneficial uses of the environment	>1/yr in the organization
Gasoil	no injury	-	costs between US $10000 and US $100000	>1/yr in the organization	minor, no lasting effect	>1/yr in the organization
Lube oil, hydraulic oil, grease	no injury	-	0		minor, no lasting effect	>1/yr in the organization
Equipment under pressure	permanent total disability or up to three fatalities	>1/yr in the industry	costs less than US $10000	>1/yr in the industry	0	-

Please note, that the actual residual risk is reduced to tolerable level and ALARP (As Low As Reasonably Practicable) by means of design (barriers and procedures) and assured by the so-called Hazard and Effects Management work process entailing risk identification and assessment, gap closure, barrier maintenance and effectiveness audits.

[12] *HER: Hazard and Effects Register, i.e. a list of the Hazards that are associated with an activity (here: conventional refuelling stations), together with their potential Effects and assessed Risks.*

Figure 59 - Retail security bowtie for frontline engagement.

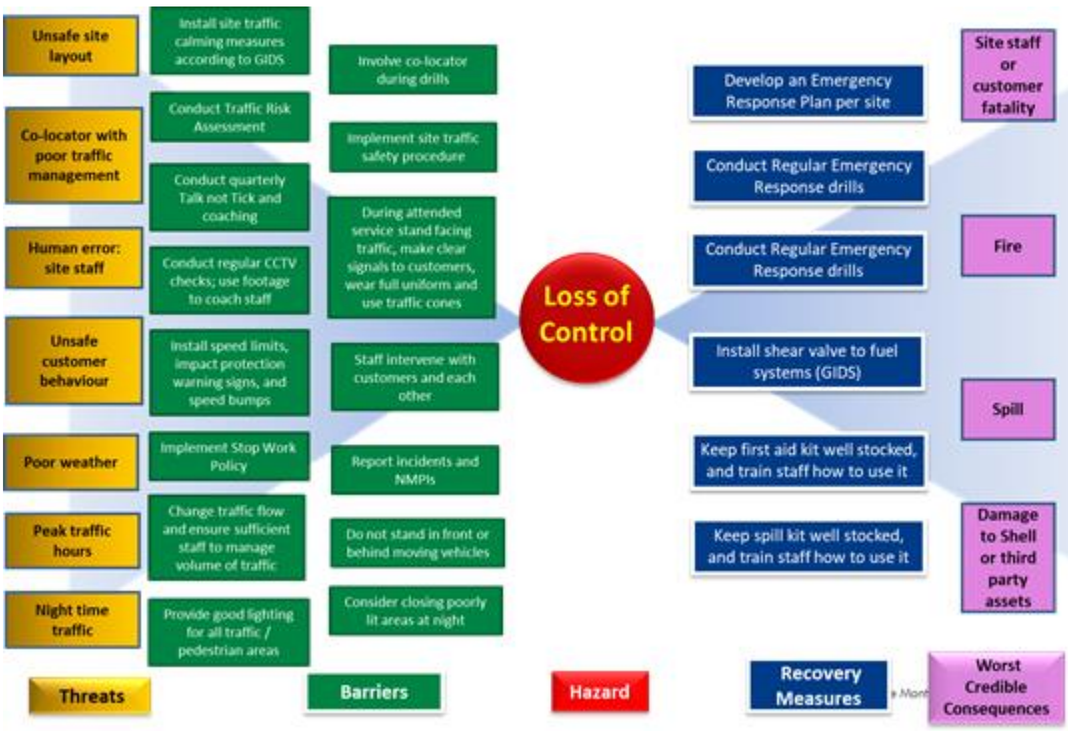


Figure 60 - Retail forecourt traffic bowtie for frontline engagement.

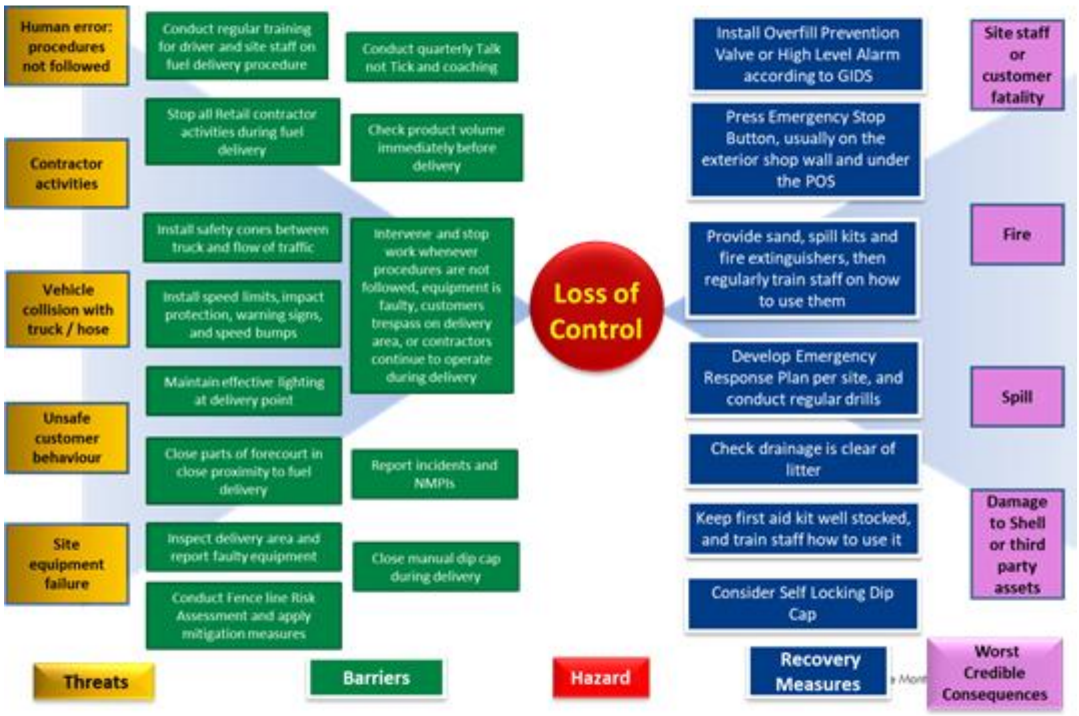


Figure 61 - Retail fuel delivery bowtie for frontline engagement.

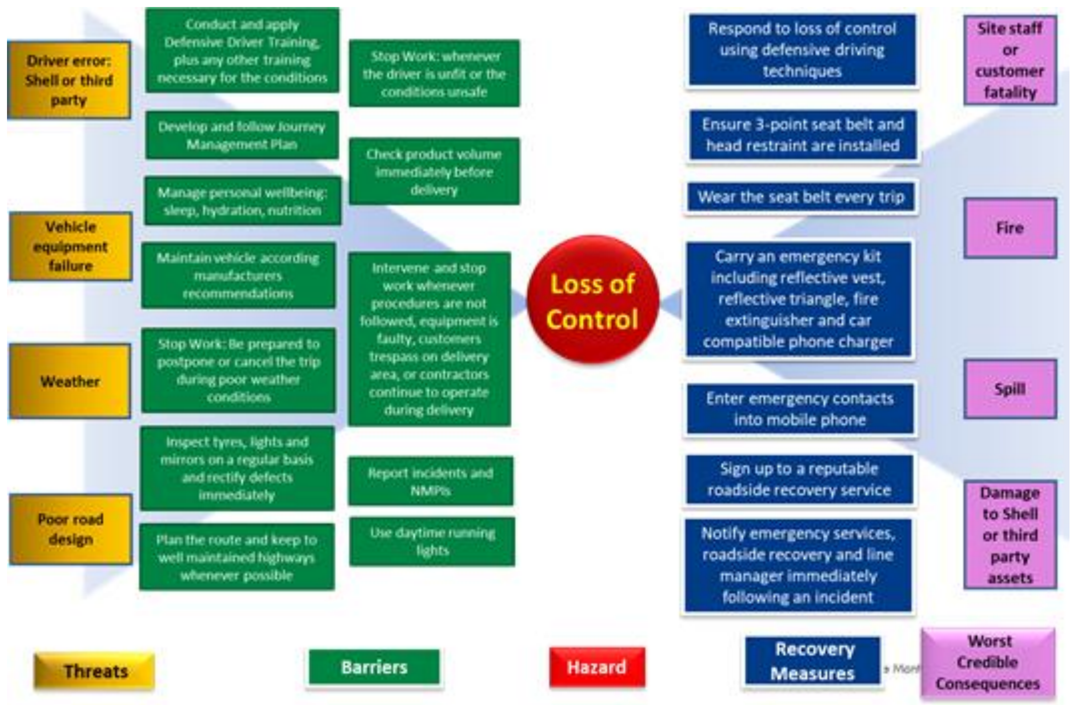


Figure 62 - Retail road driving bowtie for frontline engagement.

6.1.3. Risks associated to LNG/CNG refuelling stations

Natural gas as compared to gasoline and diesel is non-toxic, lighter than air, and can dissipate quickly when released in open space. Natural gas is odorized to have a distinctive smell that is easy to recognize.

Until recently there were few specific regulations for hydrogen refuelling stations in most European countries, many HRS were established with reference to regulations for natural gas refuelling stations. At least for CNG refuelling stations, the description of events and consequences in Figure 58 p 53 can be applied analogously.

Additional risks arise for cryogenic storage of LNG (as well as for LH_2):

- Cold exposure/freezing/cold fire/undercooling
- Cold impact resistance of components
- Reduction in cross-section/blockage of vent pipes due to ice formation from ambient air
- Possible formation of ice in the environment
- In the case of cryogenically stored hydrogen and liquefied natural gas, hydrogen or liquefied natural gas can move towards the ground after leaving the blow-off stack in certain weather conditions
- When storing cryogenic hydrogen and liquefied natural gas, there is a “boil off”, i.e. a technically induced evaporation of hydrogen or liquefied natural gas in the tank, which can either be collected and used or released into the air via a suitable chimney. If the vacuum insulation of the storage tank fails, a considerably increased amount of boil-off must be expected. This quantity must be taken into account in the design of the chimney and the pressure relief valves.
- When a large amount of LNG spills to the bottom, there is a period of intense boiling at the beginning followed by a rapid decrease in the rate of evaporation. At the beginning, the gas produced by evaporation has almost the same temperature as the LNG (around -160°C). This gas first spreads out in a layer on the ground (heavy gas) until it warms up by absorbing heat from the air.

In principle, the very same risks[13] have to be taken into account, when natural gas is not only stored in liquid phase but also refuelled as liquid, cryogenic fuel to the vehicle (see section 0 p 38, “L-CNG” vs LNG). In the area of heavy duty mobility, first LNG truck refuelling stations had been established. Some OEMs are planning LH_2 storage on-board of their “long haul” trucks, so that liquid hydrogen refuelling station will be constructed in mid-term.

[13] *informative: for LH_2 also condensating air and oxygen shall be considered*

6.2. Consequences in terms of global risk and safety distances

As described in the previous sections, hydrogen similarly to conventional fuels can lead to thermal and overpressure effects in case of leak on equipment followed by ignition.

The flammable properties of the fuels, the inventory of the storages and the operating pressure have influence on the severity of the scenarios. Also, the consequences of the related fires and explosions on the public and equipment will depend on the environment of the equipment where the leak occurs and the configuration of the refuelling station.

In order to reduce the effects of these scenarios on the public and on the near environment, some separation distances exist between fuel storages and site boundaries. In order to avoid escalation effects from a storage to a dispenser, recommendations for separation distances are established as well.

Nevertheless, in a multi-fuel context, recommendations for separation distances have not been established. Thus, it will be important to take it in consideration and avoid escalation effects between H_2 facilities and conventional fuel facilities. The risks related to conventional refuelling station should not be increased by H_2 facilities and the same for the risks related to hydrogen refuelling station which should not be increased by the conventional refuelling equipment.

7 Topics to be addressed in the project

7.1. Multi-fuel station configurations to be evaluated

Taking into account the state-of-the art review conducted in the context of this deliverable, the current technological and regulatory status of hydrogen used in mobility, its supply chain – from hydrogen production to distribution – and taking into account, as much as possible, actual and future needs, three configurations of hydrogen-based stations have been selected to be evaluated in terms of risk, keeping in mind feasibility and relevance.

As previously described, several options are available to design a hydrogen-based station and must be selected according to:

- the targeted end-users of the station (i.e. light and/or heavy duty vehicles) to be linked with the capacity of the station (H_2 t.day^{-1}) and its set-up environment,
- the hydrogen sourcing of the station and the storage characteristics (stationary refilled or mobile swapped storage, on-site production, feeding by pipeline) to be linked with its capacity, the hydrogen availability and mode of production,
- the maturity level of the technologies,
- the potential interactions with the existing private and public infrastructures, the relevancy of co-activities.

As a brief summary, because already described in more details previously, the different options available for the main requirements of a station are:

- hydrogen sourcing and storage,
    - gaseous, liquid
    - refilling of a stationary storage, swapping of mobile hydrogen storage, pipelines, on-site production
- station capacity and end-uses
    - for light and/or heavy duty,
    - filling pressure, filling flow rate…
- co-activities
    - other fuels available,
    - location environment

*Note that hydrogen storage and station capacities are linked. Thus in order to be able to anticipate potential delivery issues, a rule of storing the double of the station capacity was applied.

Taking the considerations above into account the proposed configurations are the following:

- **Configuration #1 – Ready-to-deploy multi-fuel station**
    - Based on existing, « simple » and already used technologies
- **Configuration #2 – On-site H_2 production multi-fuel station**

    - Based on on-site hydrogen production and associated requirements
- **Configuration #3 – High capacity & High filling multi-fuel station**
    - Based on future large needs of hydrogen for mobility

These configurations are detailed in the sub-sections of this chapter.

Many other aspects such as dispenser location or pipe work offer different options that are anticipated to influence the risk linked with the refuelling station. These different options were spread over the 3 configurations in order to capture a maximum scope and enlarge the analysis which will be conducted by this project. These different options and their spread in the different configurations are summed up in Table 10 p 69.

7.1.1. Configuration #1 – Ready-to-deploy multi-fuel station

For the configuration #1 "ready-to-deploy", the guideline is to refer to existing and already deployed technologies, with the objective to provide hydrogen for light and heavy-duty vehicles with a satisfying hydrogen availability (e.g. back-to-back refuelling of the vehicles, i.e. without time required between two refuellings), a relatively limited footprint of the station and considering a suburban (and maybe urban) location.

The characteristics of this configuration (e.g. in terms of hydrogen sourcing, station capacity, etc…) are:

- **Refuelling station capacity**
    - **500 $kg.day^{-1}$**

- **H_2 sourcing**
    - **Gaseous** supply chain
        - **Swap** → full versus empty packaging
          No stationary storage before compressor; tanks are removed from the station when they are empty and replaced by full packages

- **H_2 storage and inventory**
    - The total amount of hydrogen stored on the station site is fixed at **1 t-H_2**
    - Hydrogen will be stored – as commonly and mainly done up to now – thanks to:
        - Containerized H_2 trailers – from 200 type-I tubes up to 600 bar type-IV cylinders
            - 200 bar tube-trailer capacity: around 400 kg-H_2
            - "High capacity" trailers capacity: up to 1 t-H_2 according to the storage pressure (300-635 bar)

- and/or H_2 bundles – 200 bar type-I cylinders
  - assembly of 50 L type-I cylinders; number depending on the need

- **From storage to dispenser**
  - "Classic" process skid(s) for gaseous hydrogen feeding, including
    - Compression – two stages (around 400 and 900 bar)
    - High pressure buffers (type II, around 50 L each) – up to 900 bar
      - **100 kg-H_2** at **500 bar** (3 m^3); **multiple** (around 60 x 50-L cylinders)
      - **300 kg-H_2** at **900 bar** (6 m^3); **multiple** (around 50 x 123-L cylinders)
    - Chiller for H_2 cooling
    - Heat exchanger inside the dispenser
    - Process area enclosed by walls (3-m high) and partially covered by a canopy-like to limit sound and visual pollution
  - Pipework
    - Underground, buried
    - Pipe maximum diameter: 9/16''

- **H_2 dispensing, dispensing island and forecourt**
  - "Classic" **dual** dispenser – 350 and 700 bar
    - **For car** – pressure: **700 bar**, maximum flow rate: **60 $g.s^{-1}$** peak flow
    - **For buses and heavy duty vehicles** – pressure **350 bar**, maximum flow rate: **120 $g.s^{-1}$** peak flow
    - Simultaneous fillings
  - Multi-fuel dispensers
    - For car dispensing conventional fuel, CNG and H_2
    - For HDV dispensing CNG and H_2
  - Multiple dispensing islands: one part dedicated to LDV, one part dedicated to HDV
  - Unique canopy covering the entire dispensing forecourt

- **Other fuels**
  - Conventional hydrocarbon fuel
  - CNG
  - Electric charging points

- **Location**
  - Urban environment considered
  - Footprint
    - Storage and process area: 15 x 20 m (300 m^2)
    - Dispensing forecourt: 300 m^2

A simplified PFD (Process Flow Diagram) is given in Figure 63 and an idea of how could be the layout of this station is presented in Figure 64.

These characteristics and organizations may be modified and adjusted according to the outputs of the other tasks and workstream undertaken by the project.

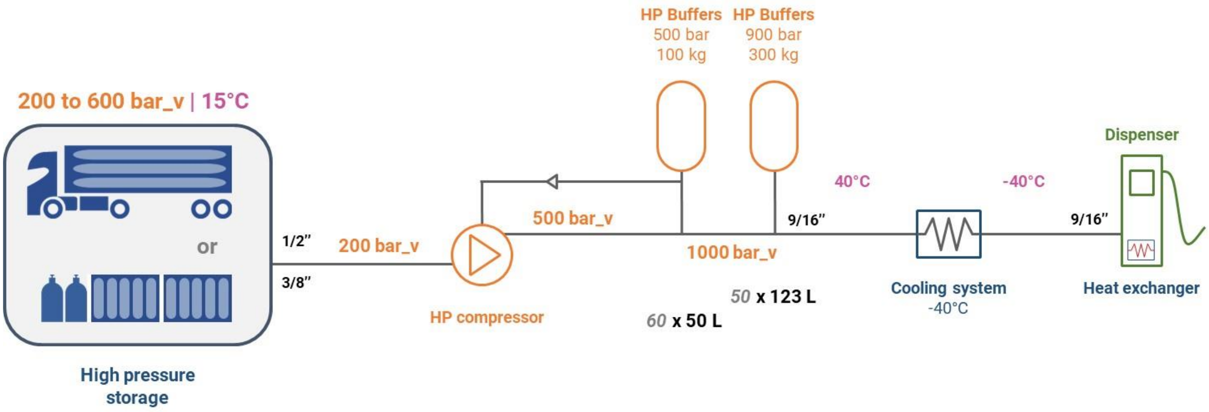


Figure 63 - Simplified PFD of "Ready-to-deploy"-station.
v: for gaseous

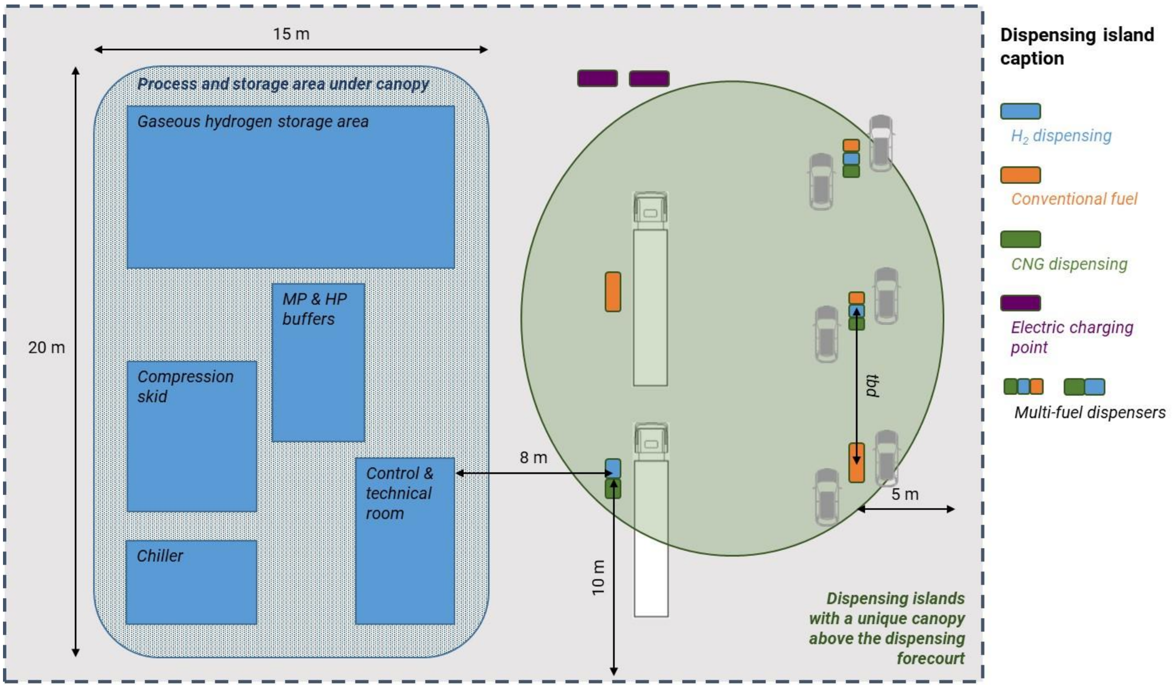


Figure 64 - Simplified and preliminary layout of "Ready-to-deploy"-station.

7.1.2. Configuration #2 – On-site H_2 production multi-fuel station

For the configuration #2 "On-site H_2", the guideline is to provide hydrogen for light and heavy-duty vehicles with an on-site green hydrogen production considering a suburban location.

In this way, choices have been done for hydrogen on-site production, station capacity, storage optimized solution, and are described hereafter:

- **Refuelling station capacity**
  - **1 t.day^{-1}**

- **H_2 sourcing**
  - **On-site gaseous H_2 production**
    - **PEM electrolysis** was chosen for its flexibility and maturity (fast start-up and no problems with frequent start/stop, and feasibility already demonstrated coupled with HRS and filling center)
      - Power: **3 MW** (adapted for targeted HRS capacity – 2000$^+$ FCEV)
      - H_2 outlet pressure: **30 bar**

H_2 storage and inventory

- The total amount of hydrogen stored on the station site is fixed at **2 t-H_2**
- Compression from 30 bar to 900 bar, with an intermediate pressure at 200 bar
- Hydrogen produced by the electrolyser will be stored in several stationary storages from 30 to 900 bar with a proposed distribution as follows:
  - **50 kg**-H_2 at **30 bar** (20 m^3); **single** storage
  - **1650 kg-H_2** at **200 bar** (110 m^3); **multiple** large volume storages (32 bundles of 68 x 50 L cylinders, or 50 x 2.235-m^3 tube cylinders vertically or horizontally set up)
  - **300 kg-H_2** at **900 bar** (6 m^3); **multiple** (4 bundles of 28 x 50-L cylinders)

- **From storage to dispenser**
  - "Classic" process skid(s) for gaseous hydrogen feeding, including
    - Chiller for H_2 cooling under dispenser
    - Process area enclosed by walls (3-m high)
  - Pipework
    - Underground, in trench, gridded or accessible thanks to removable plates
    - Pipe maximum diameter: 9/16''

- **H_2 dispensing, dispensing island and forecourt**
  - "Classic" **dual**

  - For car – pressure: 700 bar, maximal flow rate: **60 g.s^{-1}** peak flow
  - For buses and heavy duty vehicles – pressure 350 bar, maximal flow rate: **120 g.s^{-1}** peak flow
  - Simultaneous fillings
- Multi-fuel dispensers
  - For car dispensing conventional fuel, CNG and H_2
  - For HDV dispensing CNG and H_2
- Multiple dispensing islands: one part dedicated to LDV, one part dedicated to HDV
- Multiple canopies with space between each island roof

- **Other fuels**
  - Conventional hydrocarbon fuel
  - L-CNG
  - Electric charging points

- **Location**
  - Suburban environment considered
  - Footprint
    - Storage and process area: 20 x 20 m (400 m^2)
    - Dispensing forecourt: 400 m^2

A simplified PFD is given in Figure 65 and an idea of how could be the layout of this station is presented in Figure 66.

These characteristics and organizations may be modified and adjusted according to the outputs of the other tasks and works provided by the project.

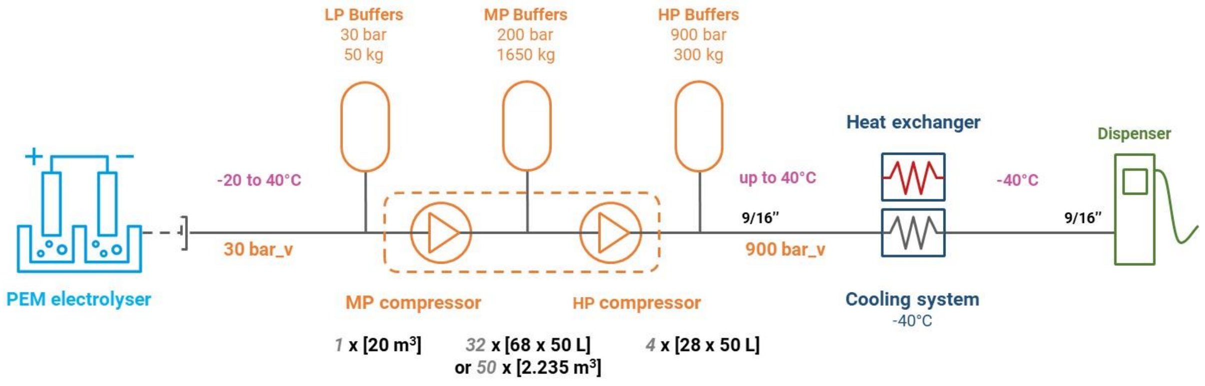


Figure 65 - Simplified PFD of "On-site H_2"-station.
v: for gaseous

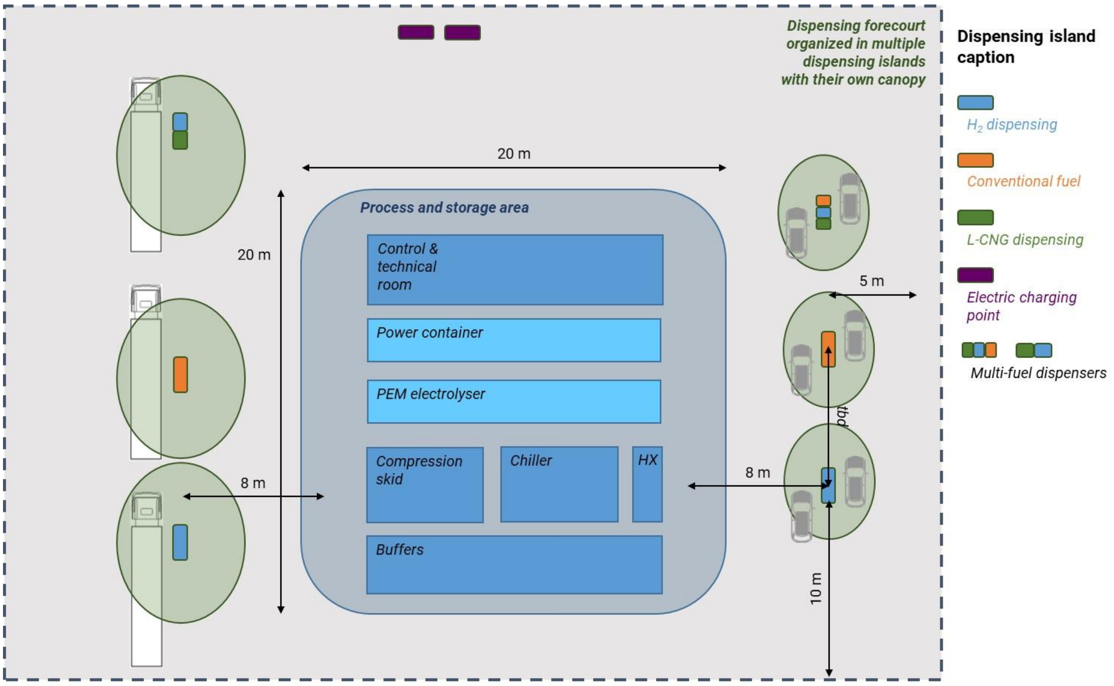


Figure 66 - Simplified and preliminary layout of "On-site H_2"-station.

7.1.3. Configuration #3 – High capacity & High filling multi-fuel station

For the configuration #3 "High capacity", the guideline is the availability of a large amount of hydrogen without increasing substantially the footprint of the station in order to provide hydrogen for heavy duty vehicles only, considering – as well – an acceptable filling duration for large capacity/autonomy vehicles. That is the reason why the station of the configuration #3 is based on a liquid hydrogen storage and the targeted location is in industrial area.

In this way, choices have been made for hydrogen sourcing, station capacity and characteristics, and are described hereafter:

- **Refuelling station capacity**
  - **2 t.day^{-1}**

- **H_2 sourcing**
  - **Liquid** supply chain
    - **Bunkering →** trans-filling in a stationary vessel

- **H_2 storage and inventory**
  - The total amount of hydrogen stored on the station site is fixed at **4 t-H_2**
  - Stationary liquid storage – medium pressure and cryogenic temperature

- Total volume required at 10 bar: 80 m^3; **multiple** storages (4 x 20-m^3 storages, or higher volume and less number of storages)
- Fully outdoor tanks

- **From storage to dispenser**
  - Process skid(s) for liquid hydrogen feeding, including
    - Liquid pumping
    - Vaporizer: tube-in-tube vaporizer, and atmospheric vaporizer to be investigated
    - High pressure buffers (type II) – **900 kg-H_2** at 900 bar (21 m^3); **multiple** (170 x 123-L cylinders)
    - Chiller for H_2 cooling
    - Process area enclosed by walls (3-m high)
  - Pipework
    - Aerial, elevated above the ground
    - Pipe maximum diameter: 1'', maybe higher (waiting for PRHYDE project feedback in order to adapt to high filling flow rate)

- **H_2 dispensing, dispensing island and forecourt**
  - "High flow" specific dispenser // **dual**
    - **High filling flow rate**: up to **300 $g.s^{-1}$** peak flow
    - Pressure: 350 bar (HDV), and potentially 700 bar (HDV)
    - No simultaneous fillings
  - No canopy

- **Other fuels**
  - Conventional hydrocarbon fuel
  - L-CNG

- **Location**
  - Industrial zone
  - Footprint
    - Storage and process area: 30 x 30 m (900 m^2)
    - Dispensing forecourt: 600 m^2

A simplified PFD is given in Figure 67 and an idea of how could be the layout of this station is presented in Figure 68.
These characteristics and organizations may be modified and adjusted according to the outputs of the other tasks and works provided by the project.

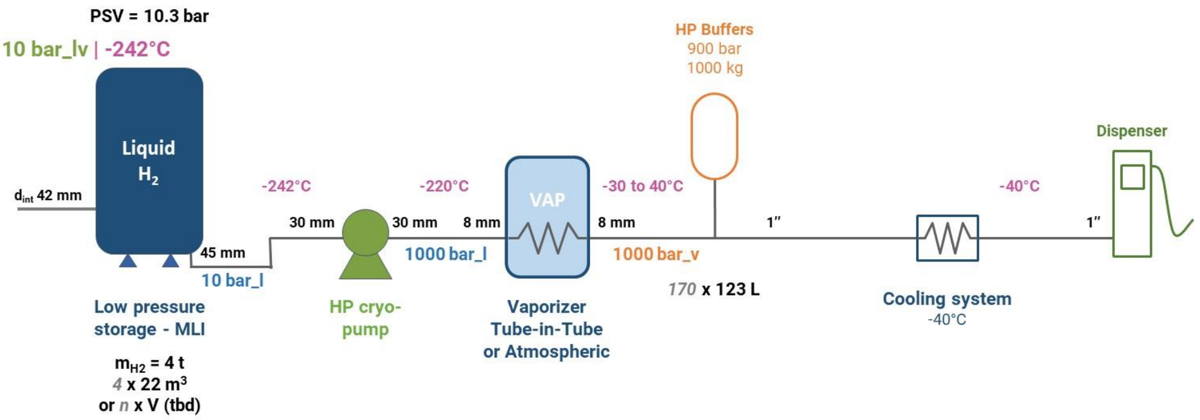


Figure 67 - Simplified PFD of "High capacity"-station. v: for gaseous, l: for liquid

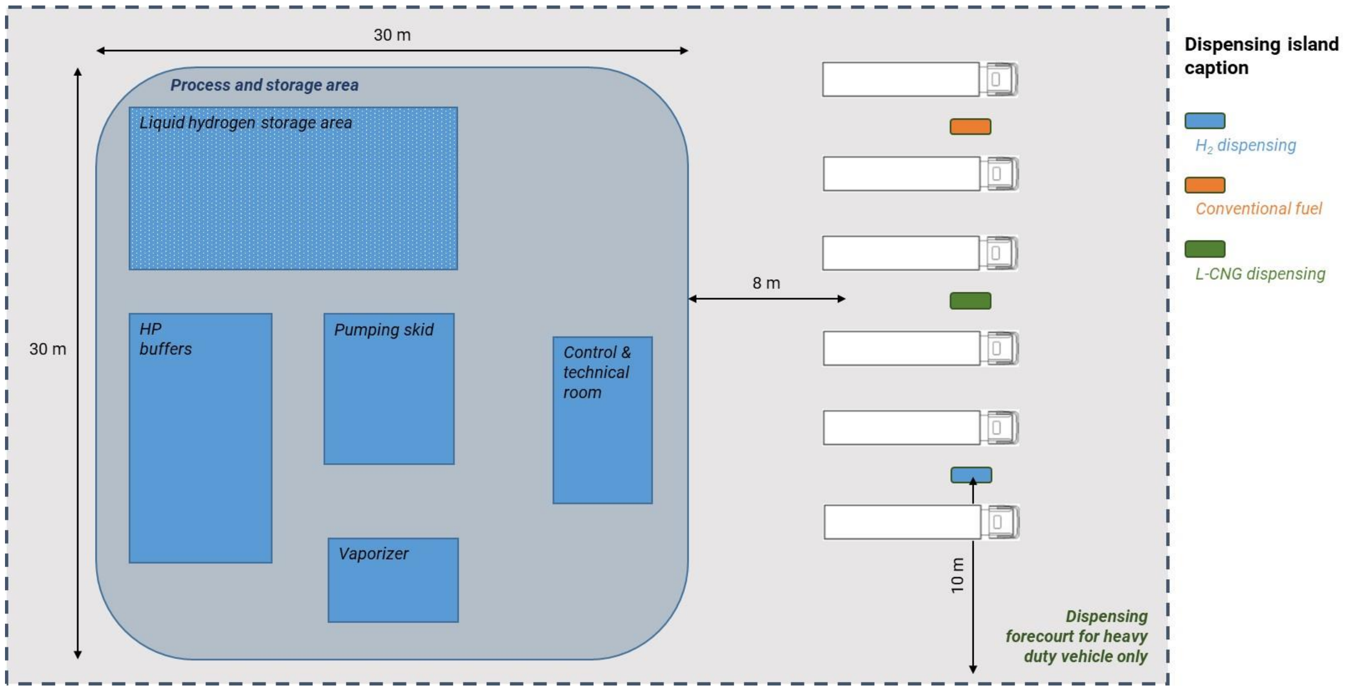


Figure 68 - Simplified and preliminary layout of "High capacity"-station.

7.1.4. Overview of the options

Regarding the configurations defined in the previous section, the Table hereafter summarizes the distribution of the studied options.

Table 10 - Sum-up of the different options spread into the 3 multi-fuel station configurations.

Topic	Option 1	Option 2	Option 3
H_2 source/supply	Liquid	Trucked in (tube trailer left on site)	Production on-site
Dispenser pressure	**700 bar**	**350 bar**	
Dispenser type	Single hose	dual hose (but NO simultaneous filling possible)	dual hose (simultaneous filling possible)
Peak dispenser flow	**60 g s^{-1}**	**120 g s^{-1}**	300 g s^{-1}
Pipe work	Underground (buried)	Underground (trench)	Above ground (elevated)
Canopy	Unique canopy covering the entire dispensing forecourt	Multiple canopies with space between each island roof	no canopy
HP storage location	containerized	outside in semi-confined compound (options blast wall / fire wall / other to be define later)	outside in open compound
Dispenser location	H_2 dispenser on same island than other fuel	H_2 dispenser on dedicated island	Multi-fuel dispenser fully integrating all fuel inclunding H_2
Heat exchanger	Inside dispenser	Next to dispenser on the island	
Vent lines	**on canopy roof**	from compound	

Config #1 – Ready-to-deploy	Config #2 – On-site H_2	Config #3 – High

When the same option is present in several configurations, the colour appears in the font and in the background of the cell

Note that for some options, the sensitivity of the studied parameter will be investigated.

7.2. Interconnections with other WPs

In Figure 69 an overview of MultHyFuel's workplan is represented, highlighting the strong interconnections between the different tasks, works and outcomes. WP3 is at the heart of the project and the three "multi-fuel station" configurations defined and described in this report are almost its starting point.

A brief overview of existing regulation and safety distances was necessary in order to help construct the preliminary layout of the three defined configurations, considering stand-alone fuel stations. WP1 will carry out a more in-depth analysis of applicable legislation and separation distances, which will be presented at a later stage in the project.

Configurations defined in this chapter will contribute to determine and perform relevant experimental and numerical simulations in the framework of WP2, aiming at answering the main knowledge gaps, and bring concrete solutions in terms of safety barriers if required, means to accurately assess safety distances and impact of the hazardous events considering a "multi-fuel" environment.

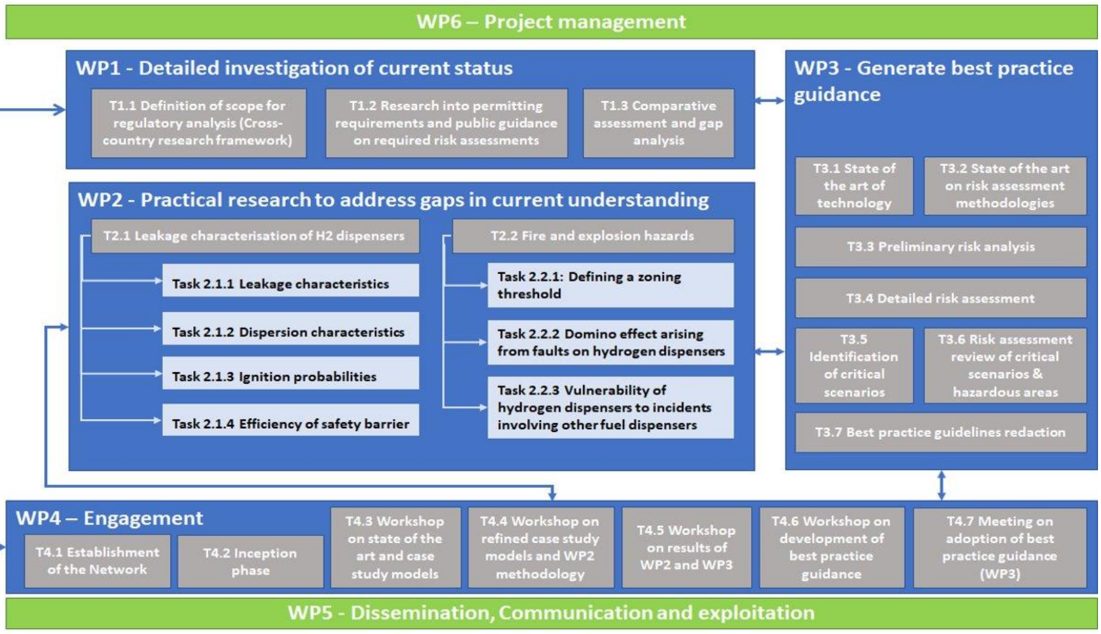


Figure 69 - Overview of MultHyFuel project organization and tasks for interconnections understanding.

In the next steps of WP3, the following studies are on-going or will be done:

- A benchmark of risk assessment methodologies (T3.2) used on refuelling stations,
- A preliminary and detailed risk assessment (T3.3 & T3.4) on case study models to identify the critical scenario to be studied during experimentation in WP2,
- Review of the critical scenarios with the inputs of WP2 to define separation distances and safety barriers requirements (T3.5 & T3.6).

Writing "Best Practice Guidelines for Multi-Fuels Stations" (T3.7) will be based on the WP3 findings to be used as a recommendation for standards elaboration regarding:

- The most appropriate approach(es) for risk assessment and addressing the permitting requirements,
- The most appropriate safe design(s) for hydrogen refuelling stations in a multi-fuel context (e.g. safety barriers identified in risk assessment tasks),
- Layout recommendations between the dispenser and the other components of the refuelling station (e.g. storage tanks, compressors, etc.),
- Recommendations about hazardous area around H_2 dispenser taking into account the other fuels.

8 Conclusions

A review of existing H_2 technologies and infrastructures – from the production to the dispensing of gaseous hydrogen at the refuelling station – is presented in this document.
Similar considerations, as applicable to other conventional fuels such as hydrocarbon liquids and LNG/CNG have been presented as well.

A brief review of existing regulation and safety distances has been made in order to bring more information for the potential layout of a multi-fuel station.

Regarding the available technologies and the safety aspects, three configurations have been defined taken into account:

- the targeted end-users of the station (i.e. light and/or heavy duty vehicles) to be linked with the capacity of the station (H_2 t.day^{-1}) and its set-up environment,
- the hydrogen sourcing of the station and the storage characteristics (stationary refilled or mobile swapped storage, on-site production, feeding by pipeline) to be linked with its capacity, the hydrogen availability and mode of production,
- the maturity level of the technologies,
- the potential interactions with the existing private and public infrastructures, the relevancy of co-activities…

Thus, the chosen configurations to be further studied in the MultHyFuel project are:

- **Configuration #1 – Ready-to-deploy multi-fuel station**
  - Based on existing, « simple » and already used technologies
- **Configuration #2 – On-site H_2 production multi-fuel station**
  - Based on on-site hydrogen production and associated requirements
- **Configuration #3 – High capacity & High filling multi-fuel station**
  - Based on future large needs of hydrogen for mobility

These configurations have been detailed in this document, and associated process flow diagrams and preliminary layouts have been provided.

Characteristics and organizations may be modified and adjusted according to the outputs of the other tasks and works that will be performed in the project.

A first important step will be the workshop organized – 2021.06.08 – with the Stakeholder of the project (in particular, HRS operators and makers) allowing to share information around these configurations and to validate them for the MultHyFuel project.

Appendix: Example Safety Distances For Hydrogen Fuelling Stations

1. General

ISO 19880-1, “Gaseous hydrogen - Fuelling stations - Part 1: General requirements”, includes requirements for, and additional guidance on, safety and risk assessment methodologies used at hydrogen fuelling stations. ISO 19880-1: 2020, Annex A, includes information on regional specific permitting guidance, in addition to methodologies for semi-quantitative and quantitative risk assessment for assessing hydrogen installation safety. ISO 19880-1: 2020, Annex A.2 provides examples of specific hydrogen fuelling station regulations, codes or guidance documents applicable in some countries/regions, which typically detail prescriptive requirements or recommendations to be followed in the design, installation or operation of a fuelling station. To supplement the content of ISO 19880-1: 2020, this document provides examples of safety distances sourced from countries involved in the preparation of the preceding document, ISO/TS 19880-1 (2016).

2. Example safety distances from different countries/regions

Below is a table of examples of safety distances meant to convey a status of country specific safety distances at the time of publication of the ISO/TS 19880-1 (2016). This table is not an inclusive list of values internationally. It demonstrates the wide range of results that can be found for similar equipment in similar environments around the world, and highlights the benefits of a quantitative or semi-quantitative risk assessment methodology, as discussed in ISO 19880-1. Table A.1 is not meant to be a recommendation for these applications and is subject to change from local regulations, codes and standards. Units are in metres unless otherwise noted.

Table A.1 - Examples of hydrogen fuelling station safety distances currently in use globally

			CA	CN	FR	DE	IT	JP	KR	SE	UK	US
RESTRICTION DISTANCES *The restriction distance is the minimum distance from, or area around, hydrogen equipment where certain activities are restricted or subject to special precautions*	Potential area of flammable / explosive atmosphere round compression unit	m				IEC 60079- 10		8	8		5	0 to 4,6 m Class1 Div2
	Potential area of flammable / explosive atmosphere around storage unit	m						8	8		5	0 to 4,6 m Class1 Div2
	Potential area of flammable / explosive atmosphere around dispenser	m		4,5				0,6			-	0 to 1,5 m Class1 Div2
	Sparking equipment, open flames, welding	m	7,6	20-40				8	8		5	10,7
	Outdoor discharge for relief valves or vents	m		3-10							-	1,5 m Div1 4,6 m Div2
INSTALLATION LAYOUT DISTANCES *The installation lay-out distance is the minimum distance between the various units of the main equipment of the hydrogen installation required to prevent units causing damage to one another in case of incidents.*	Between Sub-System / Equipment of any kind	m		3-15		1 m vessels without opening 0,5 m				1	-	
	Between H2 Storage and other Sub-System / Equipment	m		3-15					Max [1, (radius 1+ radius 2)/2]		-	
	Between Compressor and other Sub-System / Equipment	m		3-9							-	
	Between Equipment and barriers around the plant (access and circulation)	m		2-5 (walls)							0,6	
	Between hydrogen dispenser and other non hydrogen equipment except vehicle	m				2					-	
PROTECTION DISTANCES *The protection distance is the minimum distance required between the installation/equipment to be protected of the possible source of an external hazard (e.g. a fire) to prevent damage.*	Presence of (liquid) combustibles above ground (like gasoline storage or a tank truck)	m	7,6 to 15,2	18-35		5			8	50	8	
	Private or public road (Collision by a vehicle, either present at the fuelling station or passing by on a nearby road)	m		2-5				3	5	10	8	
		m		12-35		5				25	-	

CLEARANCE DISTANCES *The clearance distance is the minimum distance between the potentially hazardous installation /equipment and the vulnerable targets within the fuelling station. Here, the hydrogen installation is regarded to be the source, while the surrounding people /objects are considered to be the targets.*	Personnel of the HRS (1st party)	m									-	
	Users of the HRS (clients, 2nd party)	m					10				-	
	Public (Third party)	m									8	4,6
	Other fuelling facilities within the fuelling station, like delivery facilities.	m								12		
	Gasoline storage	m	3,1 to 7,6 (below ground)	3-8		3	10			25	8	4,6
	LPG storage	m	7,6 to 15,2 (above ground)			8	20			25	8	4,6
	CNG hazardous elements	m	7,6 to 15,2	5-12			15	6		12	5	4,6
	Bulk liquid oxygen storage	m	7,5 to 15			5		10	10 (5 if firewall)	12	5	
	Between H2 dispensing and others fuels (LPG, CNG, gasoline)	m		4			8				-	4,6
	Buildings inside the plant	m		5-15	8					12	-	
	Building of combustible material	m	15,2							12	8	4,6
	Building openings / windows / access doors	m	3,1 to 7,6							Same as for buildings in general	8	10,7
	Building non combustible material	m	1,5 (2 h) 7,6 (< 2 h)								-	1.6
	Air intakes / ventilation	m	15,2			Out of hazardous area				Outside of hazardous area	8	10,7
	Other	m	4,6 (haz. mat. piping)								-	

EXTERNAL RISK ZONE *The external risk zone is the distance (or area) outside the fuelling station which has to be protected against hazards caused by the hydrogen installation. Here, the H2 installation (i.e. dangerous units thereof) is clearly the hazard source, while people and constructions offsite are regarded to be the target(s).*	Lot line	m	1,5		8			8	10 (5 firewall)		8	10,7
	Public Road	m	4,6	5-15	8			8	5	10 (up to 50 km/h)	8	3 (Dispen-ser)
	Specific public buildings Houses	m							12-20		-	
	Parking	m	4,6							6	8	4,6
	School / Hospital Place of public assembly / Other	m	15.2	50					17-30	100 (exits from difficult to evacuate buildings)	-	
	High voltage line	m	15 tram, bus overhead 1,5 others overhead electrical	1.5 times of the height of the pole			30		5 (Rail 30)	15 (Valid for 12-72,5 kV)		4,6
Comments:									where "-" is un-specified			

NOTE:

CA: Sourced from CHIC, Canadian Hydrogen Installation Code, CAN/BNQ 1784-000/2007, Table 2, for gaseous hydrogen storage greater than 35 kg

CN: The values provided above for China have been derived from Chinese National Code GB 50516-2010: Technical code for hydrogen fuelling station.

FR: The values provided above for France have been derived from the specific French regulation "Arrêté du 12 février 1998 relatif aux prescriptions générales applicables aux installations classées pour la protection de l'environnement soumises à déclaration sous la rubrique n° 1416 (Stockage ou emploi de l'hydrogène) : for stored quantity of hydrogen between 100 kg and 1 T.

Values provided available for installations using gaseous hydrogen:

- Distance can be reduced to 5 m if located in a dedicated closed building
- Distance can be reduced to 3 m by installing a dedicated fire-resistance wall

DE: The values provided above for Germany have been derived from the VdTÜV-Merkblatt: Compressed gases 514: Requirements for hydrogen fuelling stations and other sources.

IT: The values provided above for Italy have been derived from the Italian Regulation of the 2006-08-31: Technical rule for the design, construction and exercise of hydrogen refuelling stations.

JP: The values provided above for Japan have been derived from High Pressure Gas Safety Law, Code of General High Pressure Gas Safety Article 7-3 Paragraph 2. These distances are applied for gaseous hydrogen systems (< 82 MPa) and liquid hydrogen storage (< 1 MPa).

KR: The values provided above for Korea have been derived from interpretation of the High Pressure Gas Safety Management Law and KGS FP216.

SE: Swedish distances are based on distances used for CNG-stations. They can be found in TSA 2015, "Anvisningar för tankstationer för metangasdrivna fordon", published by The Swedish Gas Association (Energigas Sverige).

Note that most of the values are valid for storage volumes larger than 4000 litres. Shorter distances are available in TSA for smaller volumes and for dispensers. Many of the distances may be halved with walls with 1 h fire resistance.

UK: The values provided above for the UK have been derived from interpretation of the published British Compressed Gases Association (BCGA) Code of Practice CP41, 2014 - The design, construction, maintenance and operation of filling stations dispensing gaseous fuels. These distances are based on those for bulk gaseous hydrogen storage published in BCGA Code of Practice CP33. Other distances may apply for smaller gaseous hydrogen storage systems, or for liquid hydrogen storage.

US: NFPA 2: Derived from National Fire Protection Association (NFPA) Code 2, for gaseous hydrogen systems of a pressure between 51,7 MPa to 100 MPa, and with a piping system of internal diameter 7,16 mm. (also NFPA 55: Compressed gases and cryogenic fluids code)

MultHyFuel

What is MultHyFuel?

The goal of MultHyFuel is to contribute to the effective deployment of hydrogen as an alternative fuel by developing a common strategy for implementing Hydrogen Refuelling Stations (HRS) in multi-fuel contexts, contributing to the harmonization of existing laws and standards based on practical, theoretical and experimental data as well as on the active and continuous engagement of key stakeholders.

MultHyFuel is a project funded by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU).

Further information can be found under https://www.multhyfuel.eu.

For feedback on the MultHyFuel project or the published deliverables, please contact info@multhyfuel.eu.

The MultHyFuel Consortium

Air Liquide creative oxygen

engie Lab CRIGEN

BESPOKE RESEARCH AND CONSULTANCY FROM HSE

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