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1 Acronyms

ADR	Accord européen relatif au transport international des marchandises Dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
ARPA	Agenzia Regionale Protezione Ambiente (Regional Environmental Protection Agency in Italy)
ASL	Azienda Sanitaria Locale (Local Health Service in Italy)
ASME	American Society of Mechanical Engineers
ATEX	Potentially Explosive Atmospheres (“ATmosphères EXplosibles”) (EU)
ATR	Auto Thermal Reforming
BP	Boiling Point
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardisation)
CGA	Compressed Gas Association (USA)
CNG	Compressed Natural Gas
CGH2	Compressed Gaseous Hydrogen
DDSC	Direction de la Défense et de la Sécurité Civile (Directorate for Civil Security and Defence in France)
DRIRE	Directions Régionales de l’Industrie, de la Recherche et de l’Environnement (French Regional Industry, Research and Environment Agency, F)
EIGA	European Industrial Gases Association
ERP	Emergency Response Plan
ESD	Emergency ShutDown
FDIS	Final Draft International Standard
GH2	Gaseous Hydrogen
GVB	Gemeentevervoerbedrijf (Municipal Transportation Company Amsterdam, NL)
H2	Hydrogen
HB	Handbook
HHV	Higher Heating Value
HRS	Hydrogen Refuelling Station
HSS	Hydrogen Storage System
ICPE	Installation Classée pour la Protection de l’Environnement (Installation classified for Environment Protection in France)
IEC	International Electrotechnical Commission

ISO	International Organization for Standardisation
ISPESL	Istituto Superiore Prevenzione e Sicurezza sul Lavoro (Italian National Institute of Occupational Safety and Prevention)
L/D	Length to internal Diameter
LEL	Lower Explosivity Limit
LFL	Lower Flammability Limit
LH2	Liquid Hydrogen
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAWP	Maximum Allowable Working Pressure
NBP	Normal Boiling Point
NFPA	National Fire Protection Agency (USA)
NPT	Normal Pressure and Temperature
NWP	Nominal Working Pressure
OEM	Original Equipment Manufacturer
PED	Pressure Equipment Directive
PLC	Programmable Logic Controller
PRD	Pressure Relief Device
PSD	Process ShutDown
QRA	Qualitative or Quantitative Risk Assessment studies
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
RD	Reference Document
SCBA	Self Contained Breathing Apparatus
TPED	Transportable Pressure Equipment Directive
UV	Ultra-Violet

2 Executive Summary

Increasingly, national and local governments all over the world are confronted with challenges like security of supply, harmful emissions, climate change, and increasing costs arising from the use of oil based transport fuels. Besides the need to use hydrocarbon-based fossil fuels more effectively, hydrogen, preferably produced from renewable energy sources, has been recognized by many public and private organisations as an alternative for fossil fuels in future transport applications. All major car manufacturers, for instance, have developed hydrogen and fuel cell prototype vehicles that are currently being tested in everyday conditions. Most leading energy companies, normally with the support of gas supply companies, have been operating hydrogen refuelling stations (HRS's) as a necessary learning step towards a future, which may include a widespread hydrogen distribution network. Some of these HRS's are integrated with the common liquid and gaseous fuels into Multi-fuel Refuelling Stations. In addition to economic motivators, this assists in supporting the public perception of hydrogen as a full-status motor fuel. Commercial hydrogen vehicles are expected to enter the market by 2015. The European Union (EU) has set a target for the use of hydrogen in the total transport fuel mix for 2020. The founding documents of the European Hydrogen and Fuel Cell Technology Platform (HFP - established in 2003 by the EC) provide a "Snapshot 2020" in which it is estimated that between 800,000 and 1.2 million cars fuelled by hydrogen will be on the European roads by 2020.

In agreement with the expectations of HFP, the HyWays project [www.hyways.de], finalised in summer of 2007, the conclusion is that by 2020 1 million hydrogen-fuelled road vehicles will be on the European roads through strong policy support and accelerated learning, and even 5 million in case of very strong policy support and accelerated learning. For 2030, HyWays estimated these numbers to be 15 and 50 million respectively.

In order to support these numbers of vehicles all over Europe, HyWays estimated that the following numbers of hydrogen refuelling stations across Europe would be required:

- For an introductory "lighthouse project" phase (2010-2015) some 400 stations in selected urban centres and some 500 stations on selected inter-connecting highways between these urban centres;
- For the phase of developing demand (2015-2025) between 13,000 and 20,000 stations;
- For the massive rollout phase after 2025 the same station patterns as today for conventional fuels will be reached.

In order to facilitate the introduction of hydrogen road vehicles into the market, in October 2007 the European Commission decided to support the formal approval of a regulation on motor vehicles using liquid or compressed gaseous hydrogen. This regulation will lay down common rules on the construction of these vehicles to ensure a smooth functioning of the internal market, high levels of public safety and the possibility of more sustainable forms of transport in the future.

The use of hydrogen as a transport fuel requires a regulatory framework to ensure that hydrogen transport applications are introduced in a coordinated fashion, complying with the highest safety standards. The HyApproval project, sponsored by the

European Commission within the Sixth Framework Programme (FP6), was aimed at developing a universal Handbook (HB) to facilitate the approval process of hydrogen refuelling stations (HRS's) in Europe. The 24 month project started in October 2005 and was terminated in September 2007. It was performed by a balanced partnership of 25 partners from industry, SMEs and research institutes providing the critical mass and required knowledge. Many partners already have extensive expertise in developing HRS's all over the world. Key partners from China, Japan and USA have provided an additional liaison to international regulations, codes & standards activities.

HyApproval Project Goals

The goals of HyApproval were to provide a Handbook of technical and regulatory requirements to assist authorisation officials, companies and organisations with the implementation and operation of an HRS, to finalise the HRS technical guideline started under the EU project EIHP2 and to contribute to the international standards under development at ISO TC197, particularly to WG11 “Gaseous hydrogen – Fuelling stations” ISO/DTS 20012.

The HB should be based on best practices reflecting the existing technical knowledge and regulatory environment and should allow new technologies and design to be introduced at a later stage. In 5 EU countries (F/D/I/E/NL) and in China the HyApproval process included a review of an early version of the HB by country authorities to pursue “broad agreement” and to define “approval routes”. After finalising the HB process the developed requirements and procedures to get “Approval in Principle” were expected to be sufficiently advanced in order to seek HRS approval in any European country without major modifications. Approving authorities, HRS operators / owners, engineering firms, as well as the EU as a whole will benefit from the HB as it is expected to facilitate the safe implementation of a hydrogen infrastructure.

Safety Considerations

In the HyApproval project the following three stages (hierarchy) of safety assurance were identified:

- *Prevention of accidents* by application of state of the art technology, by following technical standards and by displaying simple handling procedures to users and operators, designing the user-machine-interfaces in a straight forward manner and emphasise training of personnel.
- *Mitigation*, e.g. creation of safety zones and safety distances.
- Structured and effective *emergency response*.

Prevention of accidents is by far the best way to assure safety. It is aimed at avoiding accidental hydrogen releases resulting from e.g. hardware failures, software failures, operational errors or external impact, which may be caused by factors such as incorrect system or equipment design, incorrect system specifications, inadequate maintenance, inadequate operating procedures, or insufficient training of personnel. Preventive measures cover the technical system (the hardware), maintenance, operations, good housekeeping, and fire prevention.

If, in spite of the preventive measures taken, a hydrogen leakage does occur, the formation of an explosive air-gas mixture is the major concern. Creating sufficient distance between the hazard source and vulnerable targets is an effective way to limit the consequences of an explosion. Zoning aims to create such safety distances, thereby taking both people on site (personnel and customers) and off-site (the general public) into account.

Finally, well prepared emergency response services may further reduce consequences if people were to be affected by an accident on an HRS.

To evaluate the effectiveness and to determine the requirements of the safety assurance system a risk assessment is often performed. A risk assessment process (e.g. for the approval of an HRS) may comprise of several components, as shown below. With increasing severity of hazards and consequences more and more rigorous and elaborate methods will be applied.

In the HyApproval project the use of such methods for the approval process of an HRS was demonstrated.

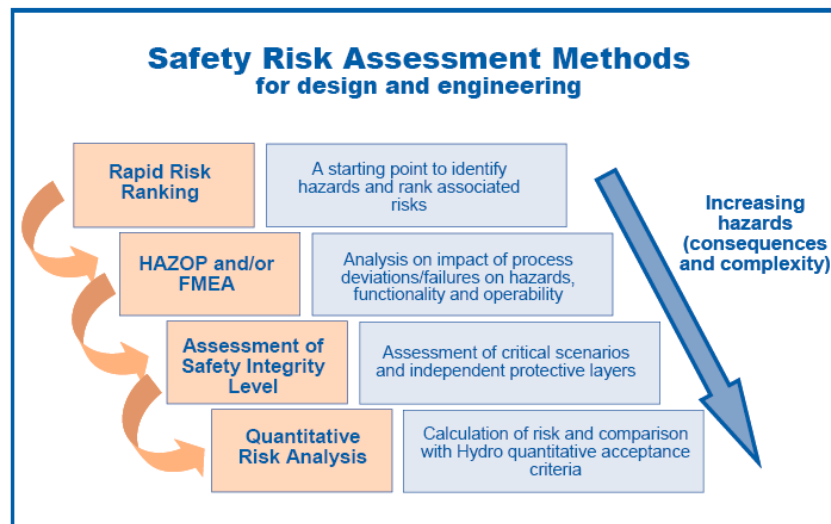


Figure 1: Safety Risk Assessment Methods

3 Introduction

The HyApproval project is aimed to develop a uniform approach to the installation and approval of Hydrogen Refuelling Stations (HRS's) throughout Europe, essentially by attempting to define a typical “European” (reference) refuelling station, which could be installed in most of the EU27 countries.

The CUTE project had clearly shown the need for harmonization of safety requirements and the permitting process as the various national authorities that were involved with the approval process for the HRS's had many different demands. This has made it difficult for the companies tasked with designing and building the HRS to propose one standard and cost effective for hydrogen refuelling station sites. The HyApproval HRS Handbook is expected to address this issue.

In order to move towards the goal of enabling the development of cost effective hydrogen refuelling stations, subject to harmonized requirements, an “EU wide” approach needs to be implemented. As a first step, an EU draft guideline was initiated during the EIHP2 project. The HyApproval Handbook builds on this project by compiling recommendations, best practices (from this guideline and if necessary augmented with others), and applying these to a reference station, also designed during the HyApproval project.

The main goals of the Handbook are:

- To serve as a working document assisting and supporting authorities to issue permits to install and operate HRS in Europe
- To finalize the technical guideline started under EIHP2 and contribute to the international standard under development
- To contribute to the safe implementation of a hydrogen infrastructure by addressing key safety issues like best available (safest) technology, definition of safety distances and best practices for operation and maintenance
- To assist companies and organisations in the implementation and operation of hydrogen refuelling stations

Therefore the target audience of the HB are mainly the authorities, regulators and the hydrogen refuelling station owners.

This document should also avoid that companies tasked with the design and construction of HRS's need to develop specific standards and site designs in the future. Instead it should be possible to use and promote EU uniform HRS layouts.

The present Handbook has been written as a standalone document. It is based on best practices reflecting the existing technical knowledge and regulatory environment, but it also includes flexibility to allow new technologies and designs to be introduced at a later stage. Along the 2-year development phase an early version of the HB was reviewed by authorities in 5 EU countries (France, Germany, Italy, Spain and The Netherlands) and in China to achieve “broad agreement” and to define “approval routes”.

The Handbook provides recommendations for a EU27 uniform approval process for HRS. The Handbook is divided into two main parts:

- Part I: “Guidelines for design, operation & maintenance of a Hydrogen Refuelling Station” provides technical guidelines and best practices related to

construction and operation of a hydrogen refuelling station. It includes the properties of hydrogen, and the list of regulations, codes and standards related to HRS. It also presents the methodologies for a risk assessment in the framework of a HRS approval.

- Part II: “Permitting process” proposes an approval route, which could be applicable all over Europe. It also highlights the HRS approval process differences between France, Germany, Italy, Spain, The Netherlands and China. It identifies the gaps between the various national processes. A feedback from the authorities is also included.

As hydrogen refuelling stations are still largely built as demonstration facilities, making allowance for further technological development and future innovations, is necessary. The safety of these HRS’s can be addressed by the application of relevant risk assessment methodologies as described and demonstrated in the Handbook. As HRS’s develop towards a commercial market further harmonisation can be achieved as technology becomes more mature and procedures more widely implemented and accepted.

Disclaimer

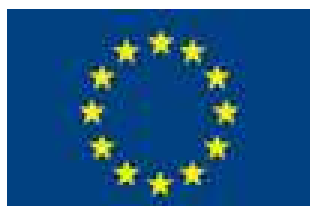
The handbook is based on best knowledge and experiences of 2007 available in the HyApproval consortium. The design and system solutions presented in this document are selected on the basis of practice prior to 2007 and should not be understood as mandatory.

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The partners involved in the HyApproval project were:

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4 Recommendations for an EU27 uniform approval process for hydrogen refuelling stations

4.1 Current situation

Hydrogen refuelling stations are currently subject from one country to another, or even, from one station to another within the same country, to very disparate requirements and permitting procedures. These are often complex and lengthy, with a highly uncertain outcome.

This results from a combination of two factors:

- The regulatory framework for Fuelling stations is still mostly determined at national level
- Due to the absence of specific requirements and regulation, there is significant variability with regards to the technical and regulatory references that will be invoked, as well as to how exactly they will be applied (as these did not specifically consider hydrogen refuelling stations when created)

Due to the range of issues that may be considered for permitting, the multiplicity of actors involved, and the absence of pre-defined requirements, the duration, the cost, and the prospect of success of a permitting procedure for a hydrogen fuelling station are very unpredictable (see Figure 2).

Such a situation constitutes an obstacle to the deployment of the network of hydrogen refuelling stations that is required for introducing hydrogen fuelled vehicles.

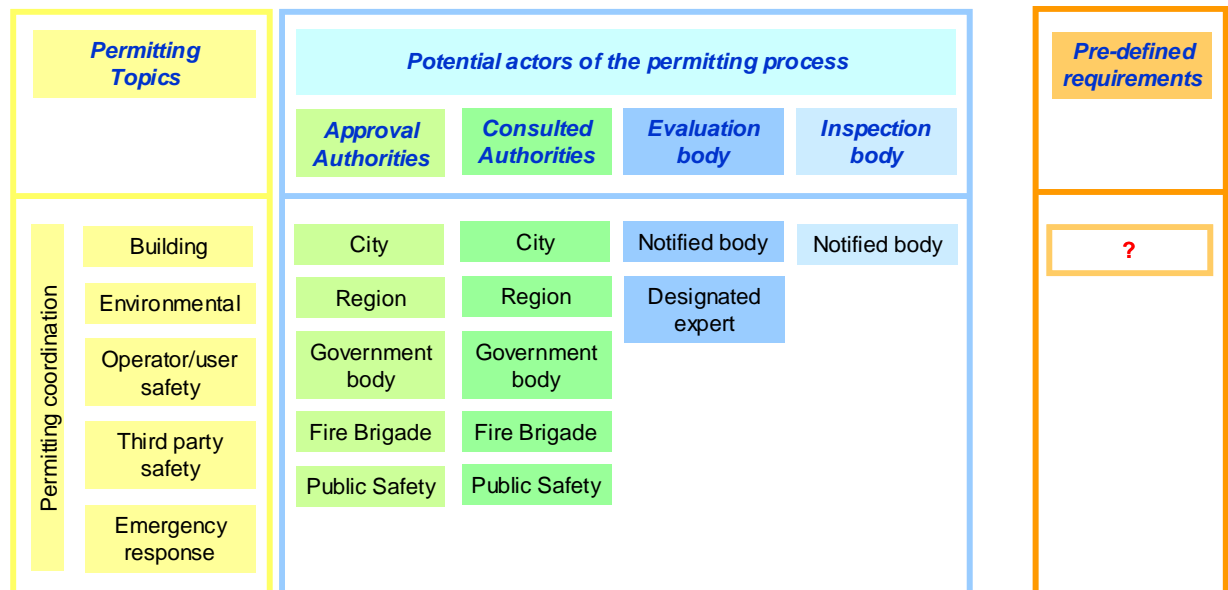


Figure 2: Potential permitting process complexity

Efforts towards developing a regulatory framework for hydrogen vehicles (EC type approval) must therefore be accompanied by similar efforts regarding the hydrogen fuelling stations.

4.2 Recommendations

The key recommendation is to develop an EC regulatory framework for hydrogen refuelling stations based on the proven combination of Essential requirements, Harmonized standards, and Notified bodies. This could be most efficiently achieved through the development of an EC Regulation (as opposed to an EC Directive).

Such a framework, which allows to address the key safety issues without impeding continued technological development, would establish a very streamlined EU 27 uniform permitting process (see Figure 3).

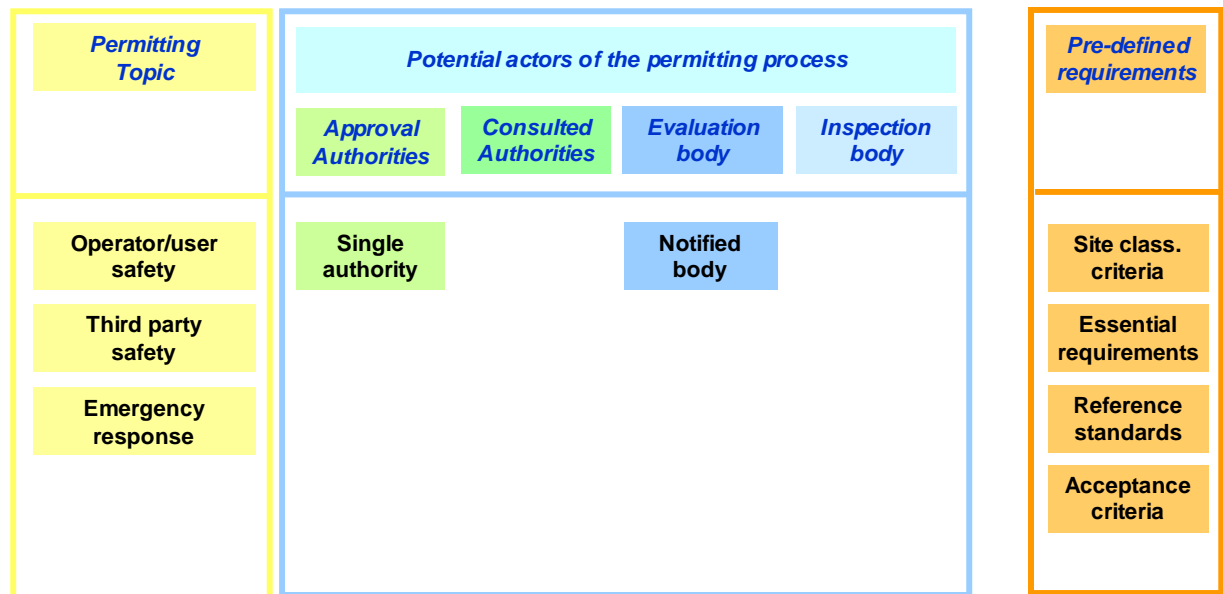


Figure 3: EU27 uniform permitting process

Going a step further, such a framework would allow for a mechanism of **fuelling station “type approval”** (similar to that of road vehicles), allowing a given station design to be approved for deployment in number in all EU 27 countries.

Until such a framework is fully established at EC level, national authorities are encouraged to adopt a permitting process structured similarly: one single authority, relying on the evaluation of one expert body, and referring to pre-established set of requirements and approval criteria.

International standards (ISO, IEC), developed considering the essential requirements set out in regulation, are the framework of choice for developing and providing fuelling station design rules and criteria allowing to meet regulatory and permitting requirements.

Whereas as regulation is developed at the initiative of the concerned EC regulatory bodies, standards are developed mostly through the contribution of industry. **However, due to the link between regulation and standards that needs to be established, a key feature of the proposed regulatory framework, close cooperation between actors of both worlds is necessary.**

Finally, in parallel to the development of the adequate regulatory framework, **guidance and support needs to be provided to the stakeholders** regarding the applicable standards and regulation, explaining how to apply these as well as providing the underlying knowledge base.

Providing this type of guidance is a key objective of the HyApproval handbook, which, as such, will need to be continuously updated.

Part I: Guidelines for design, operation & maintenance of a Hydrogen Refuelling Station

5 Properties of hydrogen

This chapter presents properties of hydrogen. For further information on this topic reference is made to ISO/TR 15916.

Physical properties

Hydrogen is the first element in the periodic table. It is the lightest and most abundant element in the universe.

The main physical properties of molecular hydrogen are summarized in the table below:

Property	Unit	
Molecular weight	g/mol	2.016
Boiling point (BP)	K	20.27
Melting point	K	14.01
Triple-point temperature	K	13.8
Triple-point pressure	kPa	7.2
Critical temperature	K	33.25
Critical pressure	MPa	1.297
Density of gas @ NTP	kg/m ³	0.08376
Density of liquid @ NBP	kg/m ³	70.78

Table 1: Main physical properties of Hydrogen

A phase diagram of hydrogen is shown in the figure below:

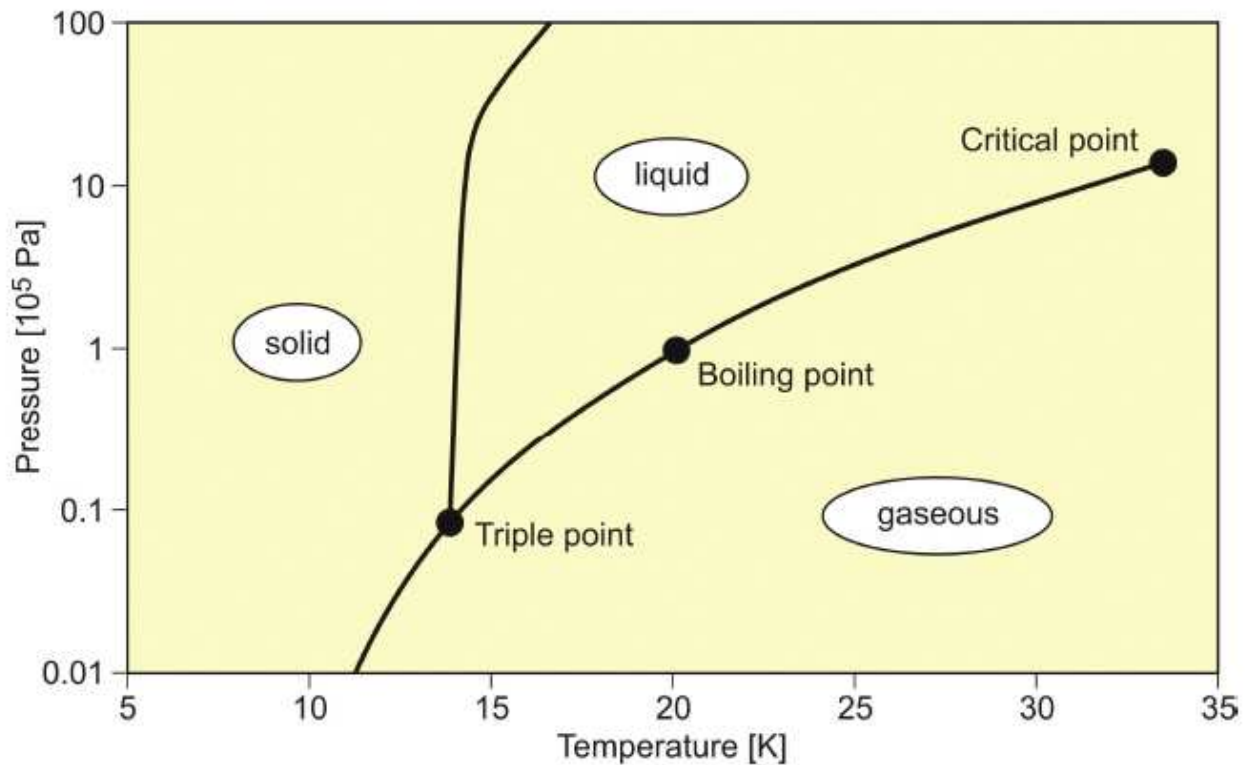


Figure 4: Simple phase diagram for hydrogen

Under standard conditions (i.e. 100 kPa (1 bar) and 273.15 K (0 °C)) hydrogen is in a gaseous state. Furthermore hydrogen is in a gaseous state under all normally occurring conditions on earth. At atmospheric pressure hydrogen is liquid at 20.3 K (– 252.9 °C) (boiling point), having the second lowest boiling point of all the elements after helium. The boiling point of hydrogen is increased with the application of pressure, up to its critical point of 33.2 K (– 240 °C) at 1.3 MPa. Hydrogen solidifies at 13.8 K (– 259.3 °C) (melting point).

Hydrogen has a very low density, both as a gas and as a liquid. In the gaseous state its density is 7% of the density of air. As a liquid its density is 7% of the density of water. For comparison, the density of typical fuels is shown in the table below:

Fuel	Gas/Vapour @ 293.15 K and 0.101 MPa			Liquid @ BP and 0.101 MPa		
	Absolute (kg/m ³)	Relative to hydrogen	Relative to air @ NTP	Absolute (kg/m ³)	Relative to hydrogen	Relative to water @ NTP
Hydrogen	0.09	1.0	0.07	70.8	1.0	0.07
Methane	0.65	8.13	0.57	423	6.0	0.42
Propane	1.88	20	1.4	582	8.2	0.57
Gasoline	4.4	55	3.85	700	9.9	0.69

Table 2: Density of fuels in gaseous and liquid state

Comparison with other fuels

The heating values of some commonly used fuels are summarized in the table below:

Fuel	HHV [MJ/kg]	LHV [MJ/kg]	State (@ 298.15 K, 0.101 MPa)
Hydrogen	141.86	119.93	gas
Methane	55.53	50.02	gas
Propane	50.36	45.6	liquid
Gasoline	47.5	44.5	liquid
Diesel fuel	44.8	42.5	liquid
Methanol	19.96	18.05	liquid
Coal	36.00	31.00	solid
Wood	16.00	13.00	solid
Biodiesel	37.00	35.00	liquid
Biogas	27.00	25.00	gas

Table 3: Heating values of fuels in gaseous and liquid state

Compared with other conventional fuels, hydrogen has the highest mass energy density, at least 2,5 times higher than that of other fuels (see the figure below).

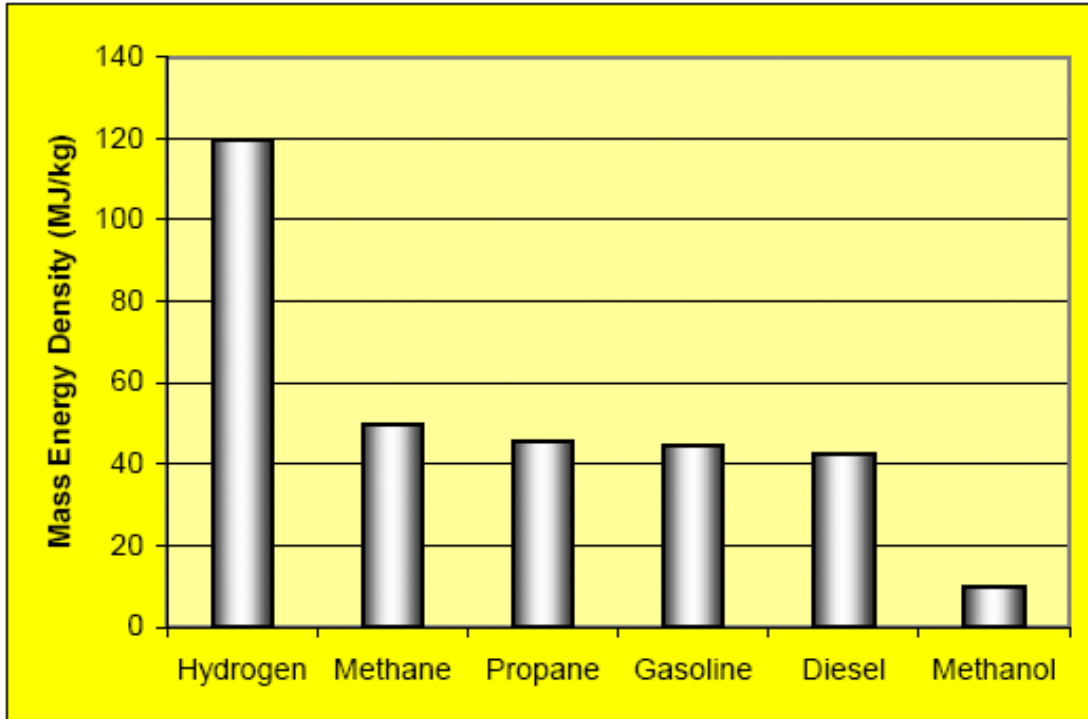


Figure 5: Mass energy density of fuels (based on LHV)

Therefore, on a weight basis, the amount of fuel required to deliver a given amount of energy is significantly reduced when hydrogen is utilized. This is especially important for aerospace applications. However, more importantly for road transportation applications, hydrogen has the lowest volumetric energy density. The volumetric energy densities of various fuels, including hydrogen, are summarized in the table below:

Fuel	LHV [MJ/m ³]	gaseous state conditions	State
Hydrogen	10.7	@ 288.15 K, 0.101 MPa	gas
	1852	@ 288.15 K, 20 MPa	gas
	4500	@ 288.15 K, 69 MPa	gas
	8491		liquid
Methane	32.56	@ 288.15 K, 0.101 MPa	gas
	6860	@ 288.15 K, 20 MPa	gas
	20920		liquid
Propane	86.67	@ 288.15 K, 0.101 MPa	gas
	23489		liquid
Gasoline	31150		liquid
Diesel fuel	31436		liquid
Methanol	15800		liquid
Coal	24800		solid
Wood	7800		solid
Biodiesel	30800		liquid
Biogas	18.00	@ 288.15 K, 0.101 MPa	gas

Table 4: Volumetric energy density of fuels

And in the figure below:

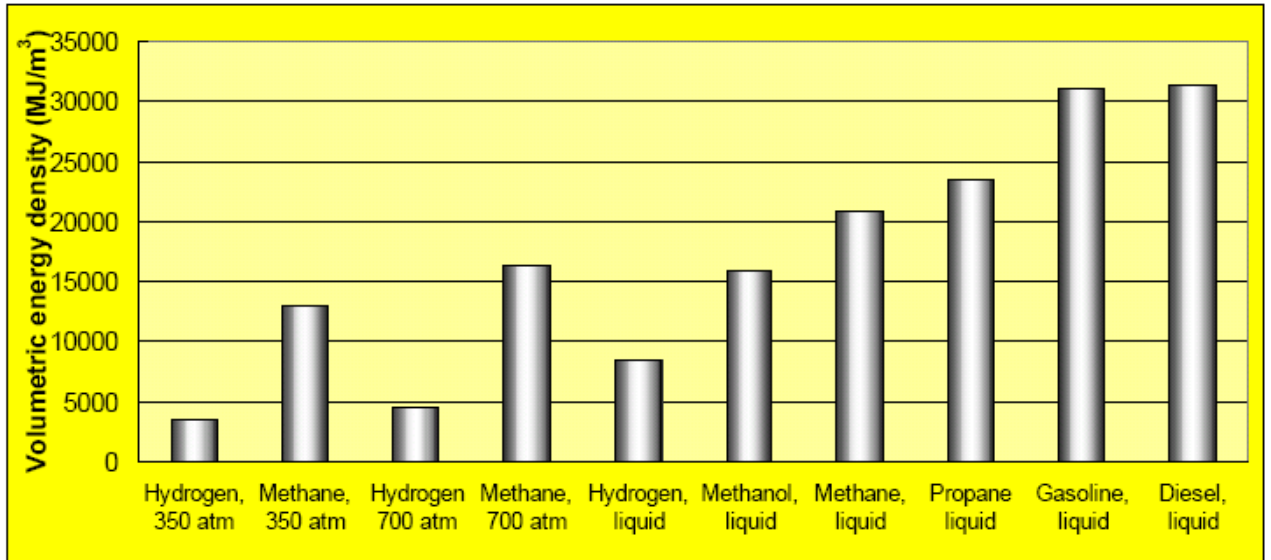


Figure 6: Volumetric energy density of typical fuels (based on LHV)

To put these figures in perspective, a 50 l gasoline tank is equivalent on an energy basis to a 460 l tank of compressed hydrogen at 35 MPa, or a 340 l tank of compressed hydrogen at 70 MPa, or a 185 l tank of liquid hydrogen.

In the future, hydrogen on-board storage could make use of chemical compounds containing hydrogen to improve the energy density while avoiding high pressure or low temperature storage requirements (reference to ISO/TR 15916:2004(E) Annex D).

5.1 Gaseous Hydrogen

Other key physical properties of gaseous hydrogen are:

- Specific Volume: 11.9830 m³/kg at 294.15 K (21 °C)
- Water solubility: 0.0016 g/l

5.2 Liquid Hydrogen

Liquid hydrogen is colourless and odourless. Its density is one fourteenth that of water. Liquid hydrogen is extremely cold -and except for helium- has the lowest boiling point of all gases.

Hydrogen consists of ortho-hydrogen and para-hydrogen. These forms have differences in physical but not in chemical properties. At the temperature of liquid hydrogen ortho-hydrogen tends to convert into para-hydrogen. This conversion liberates heat, which encourages evaporation. However, commercial liquid hydrogen mainly consists of para-hydrogen.

The main physical properties of liquid hydrogen are summarized in the table below:

Property	Unit	
Critical temperature	K	33.2
Boiling point @ 0.101 MPa	K	20.3
Density of cold gas @ NBP	g/m ³	1340
Relative density of cold gas GH ₂ @ BP, air @ NTP	air = 1	1.11
Density of LH ₂ @ NBP	g/litre	70
Relative density of LH ₂ LH ₂ @ NBP, water @ NTP	water = 1	0.07
Volume ratio GH ₂ /LH ₂ GH ₂ and LH ₂ @ NBP	litre/litre	52
Volume ratio GH ₂ /LH ₂ GH ₂ @ NTP, LH ₂ @ NBP	litre/litre	845

Table 5: Physical properties of liquid hydrogen

The relative density of cold hydrogen gas is higher than 1, so that gas generated from liquid hydrogen spreads first in a more or less horizontal direction. With progressive warming the gas becomes lighter than air. Liquid hydrogen is a very light liquid with a density much lower than that of the water. When released to the atmosphere liquid hydrogen evaporates very quickly. The level of a liquid hydrogen pool decreases by 25 to 50 mm/min due to evaporation. The evaporation of 1 litre of liquid hydrogen yields roughly 50 litre of cold gas, when the gas warms up to ambient temperature (NTP), its volume increases to about 830 litres.

5.3 Safety-relevant properties

The properties of hydrogen that are particularly relevant to safety are summarized in the table below:

Property	Unit	Fuel			
		Hydrogen	Methane	Propane	Gasoline
Lower Flammability Limit	% volume	4.0	5.3	1.7	1.3
Lower Detonation Limit	% volume	18.3	6.3	3.1	1.1
Upper Detonation Limit	% volume	59	13.5	9.2	3.3
Upper Flammability Limit	% volume	75	17	10.9	6.0
Autoignition temperature	K	858	810	723	488
Minimum ignition energy	mJ	0.017	0.274	0.240	0.240

Table 6: Safety-relevant properties of hydrogen and other common fuels at 298.15 K and 0.101 MPa

The data given in the above table are not well-defined, absolute physical properties but are measurement-dependent properties that are determined according to certain standard procedures (reference to ISO/TR 15916:2004(E)). Therefore, these data serve for comparison purposes only. They should not simply be adopted for the design of HRS or components, or for the definition of safety requirements.

In most cases hydrogen displays extreme characteristics, either very low or very high, as compared to other fuels. The figures below show this comparison in the case of

density, buoyancy in air, diffusion coefficient in air, ignition energy at stoichiometric ratio, flammability range, velocity of laminar burning at stoichiometric ratio, heat of combustion and detonation sensitivity. These figures are given for normal conditions of pressure and temperature.

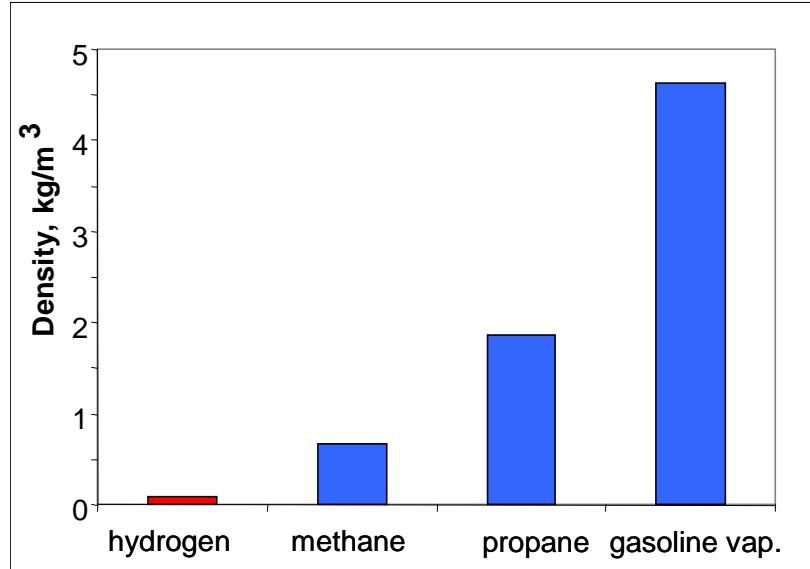


Figure 7: Density of hydrogen vs. other common fuels (source: FZK)

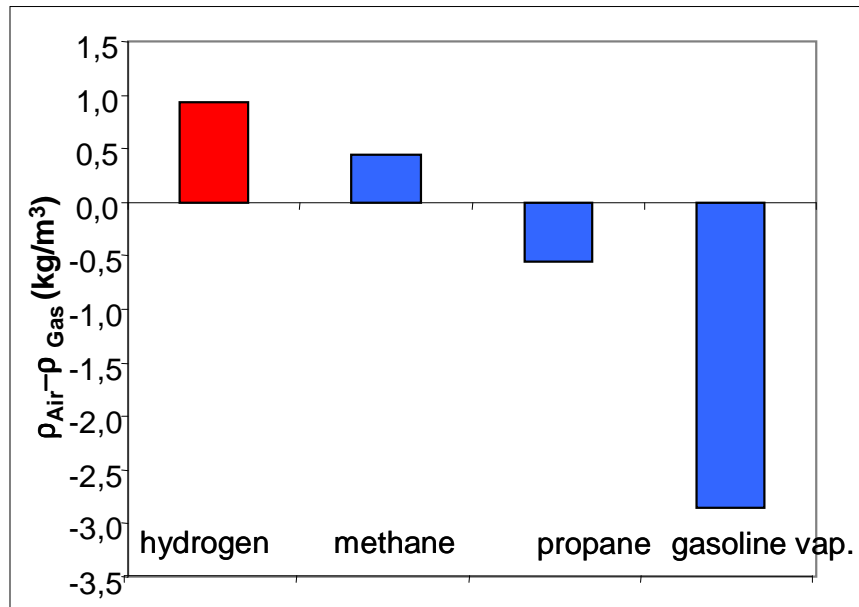


Figure 8: Buoyancy in air of hydrogen vs. other common fuels (source: FZK)

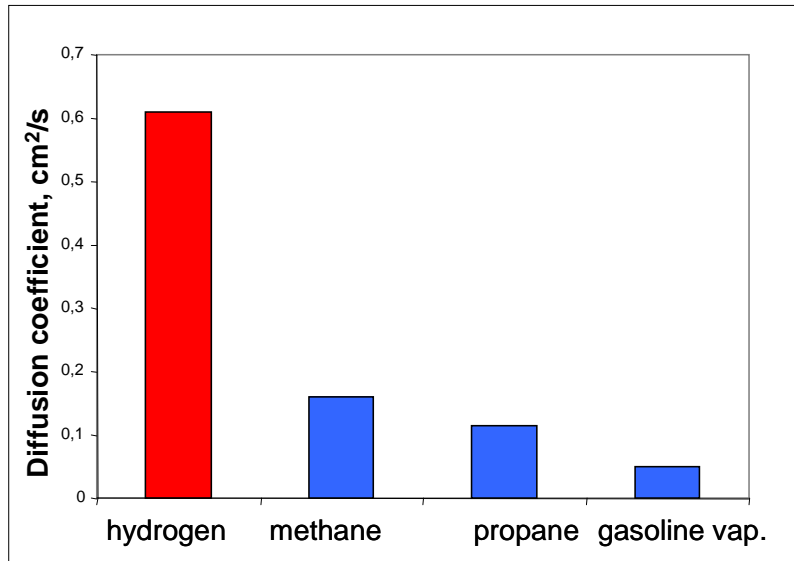


Figure 9: Diffusion coefficient of hydrogen vs. other common fuels (source: FZK)

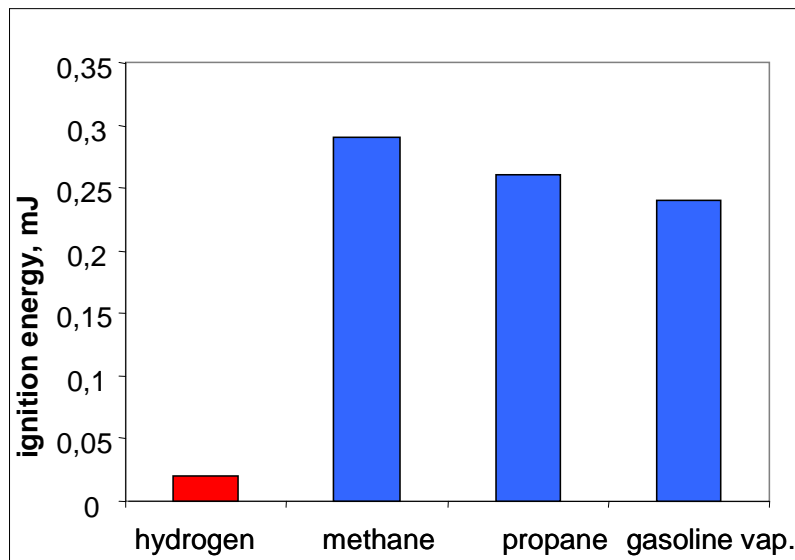


Figure 10: Ignition energy at stoichiometric ratio of hydrogen vs. other common fuels (source: FZK)

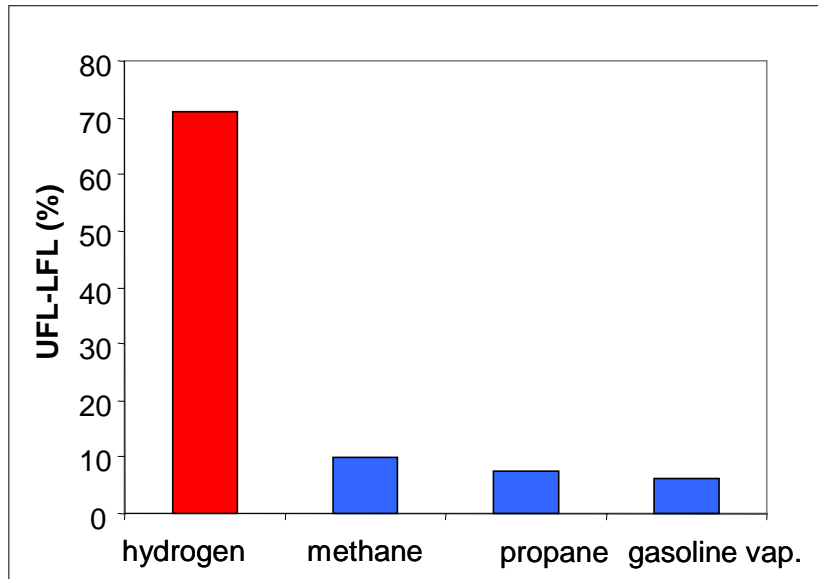


Figure 11: Flammability range of hydrogen vs. other common fuels (source: FZK)

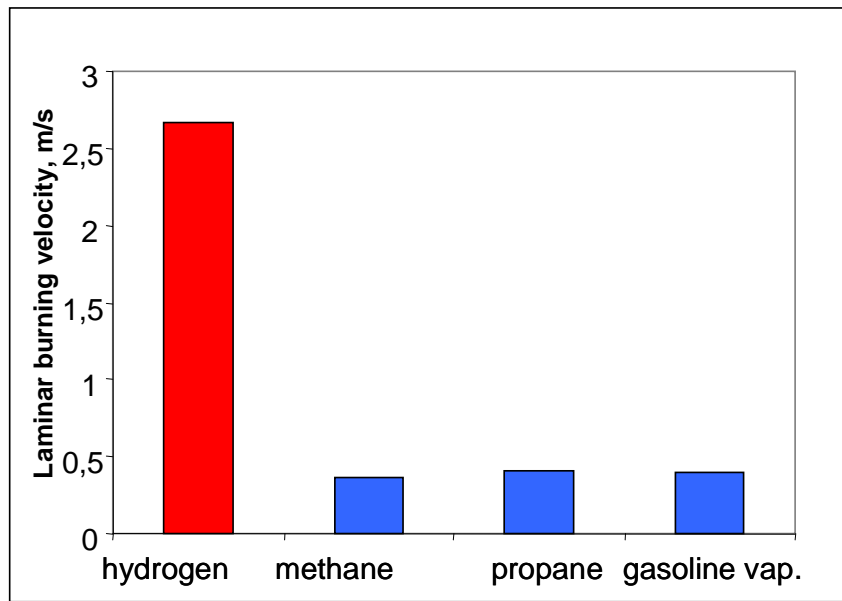


Figure 12: Laminar burning velocity at stoichiometric ratio of hydrogen vs. other common fuels (source: FZK)

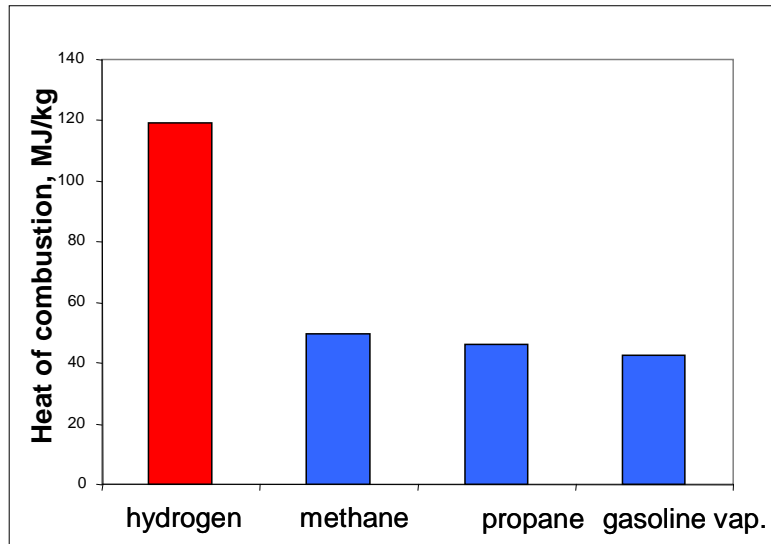


Figure 13: Heat of combustion of hydrogen vs. other common fuels (source: FZK)

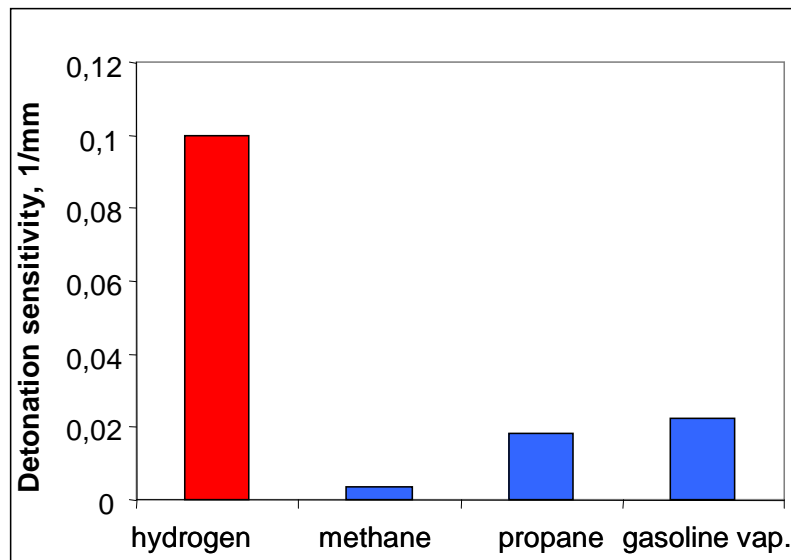


Figure 14: Detonation sensitivity at stoichiometric ratio of hydrogen vs. other common fuels (source: FZK)

Some of these extreme characteristics are due to the fact that hydrogen has the lowest atomic weight of any substance and the smallest molecular size compared to other gases. The effects of these extreme characteristics on safety may counteract each other. For example, the small molecular size that increases the likelihood of a leak also results in very high buoyancy and diffusivity. So indoors a leak could result in the accumulation of hydrogen but hydrogen, leaked outdoors, rises and becomes diluted quickly without accumulating. The resulting region of flammability is localized and disperses quickly, reducing the risk of a fire or an explosion.

The primary risk with hydrogen is through fire and explosion. Hydrogen is extremely flammable in air with very wide flammability limits, indicatively from 4% to 75% in

volume in air. Actual flammability limits vary with pressure, temperature, ignition energy and water vapour content. For a flammable mixture to exist, a concentration three times higher is required for gasoline, yet hydrogen dissipates about ten times faster than gasoline vapour. Similar comparisons are true for methane and propane versus hydrogen. Hydrogen has a low ignition energy, i.e., as little as 0.017 mJ at 30% volume concentration in air, in contrast to 0.25 mJ for other hydrocarbon fuels. However, at their lower flammability limits (4% to 5% in air), methane and hydrogen have very similar ignition energies of about 10 mJ (see the figure below).

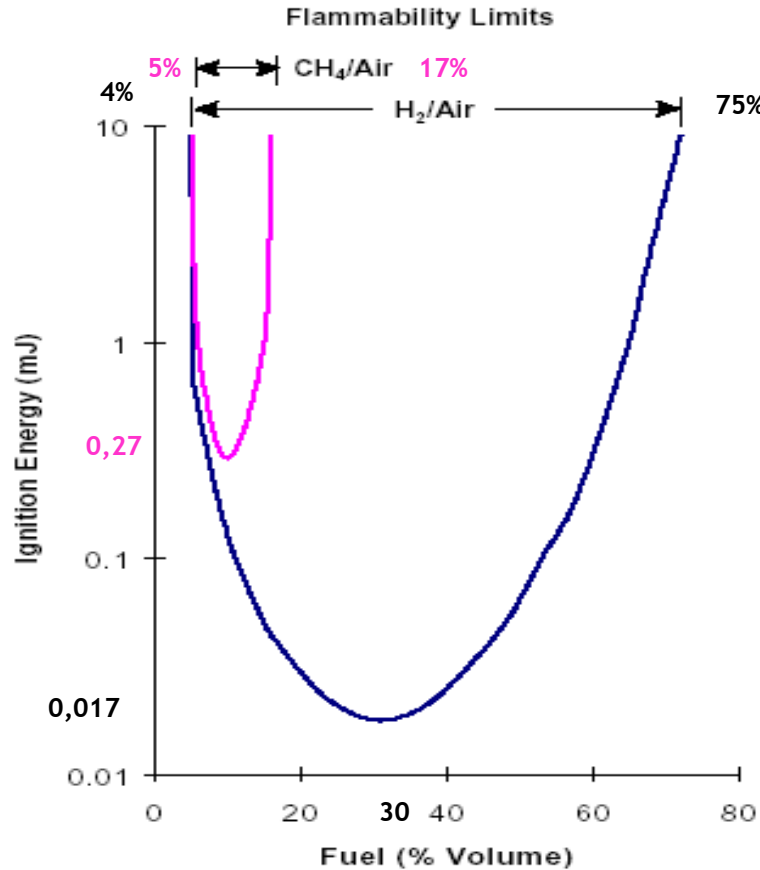


Figure 15: Ignition and flammability of hydrogen and methane

Specific thermo-physical properties of cryogenic liquid hydrogen that are relevant for safety consideration include the density (see Table 1 and Table 5), the coefficient of thermal expansion, the equivalent volume of gas generated by evaporation and the heat capacity.

The coefficient of thermal expansion of liquid hydrogen at NBP is 23 times greater than that of water at ambient conditions. Cryogenic storage vessel should have sufficient vacant space to accommodate the expansion of the liquid in case of addition of heat. Insufficient vacant space can lead to an over pressurization of the vessel or entrainment of the liquid into transfer and vent lines.

A considerable increase in volume results from the phase change of liquid hydrogen to gaseous hydrogen, and another gradual volume increase occurs when gaseous hydrogen warms up from the NBP to NTP. The volume ratio for the whole transition

is 845 (see Table 5). If the gaseous hydrogen is completely confined in a fixed volume, this transition can result in a final pressure of 172 MPa starting with an initial pressure of 0.101 MPa.

The specific heat at constant pressure of liquid Para hydrogen is 9.688 kJ/kg·K, i.e., more than double that of water.

The Safety Data Sheets for gaseous hydrogen and refrigerated hydrogen are provided in Appendix I.

6 Basics of hydrogen dispensing

By the end of 2006 about 160 Hydrogen Refuelling Stations were installed worldwide. Currently about 60% have on-site production with electrolysis or small-scale reforming and 40% are supplied with trucked in hydrogen gas (or liquid). The number of HRS with electrolyzers and small-scale reformers is about the same but the relative share of small-scale reformer based HRS has been increasing. (<http://www.h2stations.org/>).

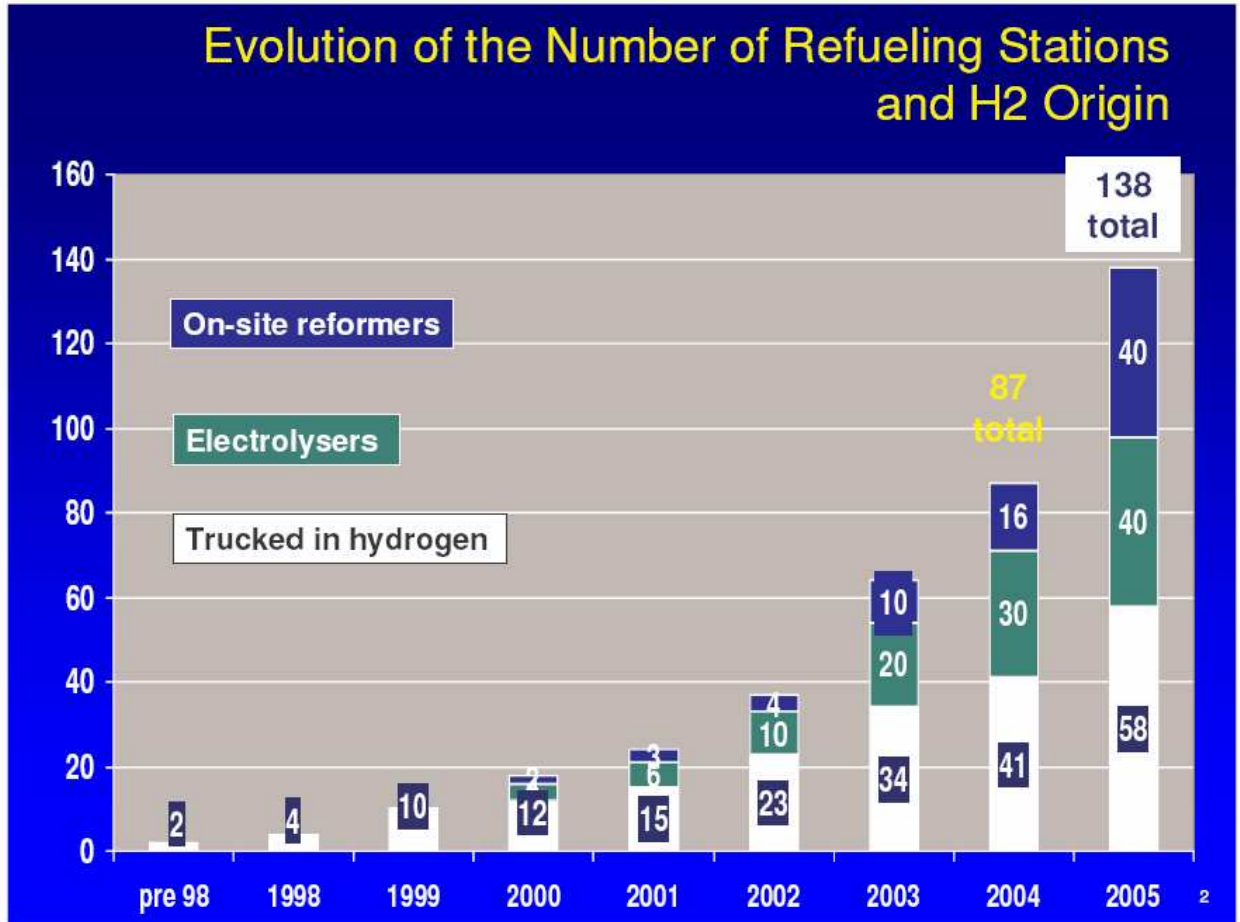


Figure 16: World-wide population of HRS and share of supply options

A typical process flow diagram of a HRS is shown in the next figure:

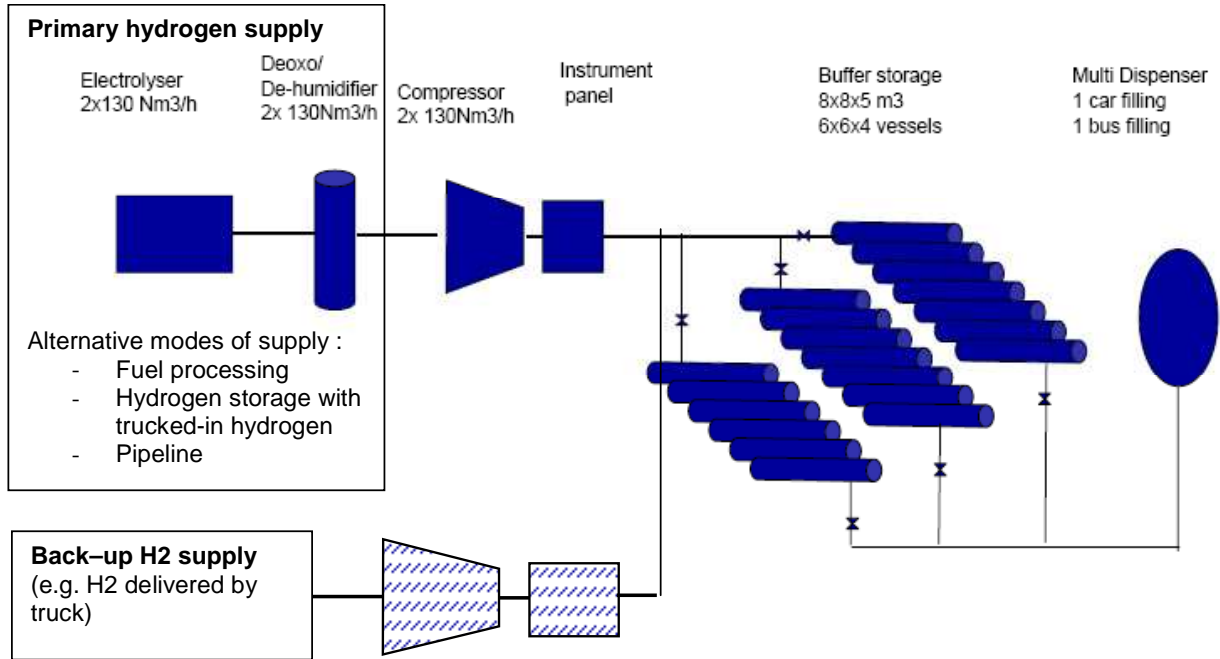
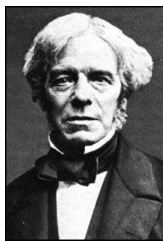


Figure 17: Typical layout of Hydrogen Refuelling Station with on-site production

6.1 On site production techniques

The purpose of producing hydrogen on site is to reduce storage required on-site and the amount of hydrogen delivered by truck. Two techniques are currently available: electrolysis and steam-reforming.

6.1.1 Hydrogen production by water electrolysis

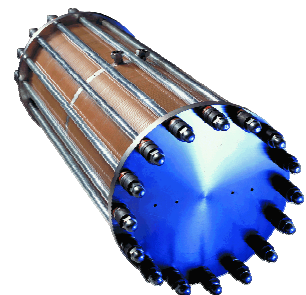


Michael Faraday first formulated the principle of electrolysis in 1820. Electrolysis is the process of generating hydrogen and oxygen from water.

The first large installation of an electrolyser for hydrogen production was by Norsk Hydro in 1927 in Norway. It was a bi-polar, filterpress water electrolyser for use in the Company's own ammonia plants.

In 2001, the world production and use of hydrogen was around 500 billion Nm³/a. Most of the hydrogen is used for the ammonia synthesis (main product NH₃), the methanol synthesis (CH₃OH) and the petrochemical hydration of fuels etc. Around 1% of this yearly amount was produced by water electrolysis.

Large electrolysis plants can reach capacities up to 100.000 Nm³/h but one single electrolysis unit produces around 500 Nm³/h. Large-scale electrolysis is mainly carried out where the electricity price is low. Two types of electrolysers are common, the atmospheric electrolysers and the electrolysers based on pressurized electrolysis. Today, atmospheric electrolysers with capacities of 50-485 Nm³/h and pressurized electrolysers with a capacity range of 1-65 Nm³/h are standard products.

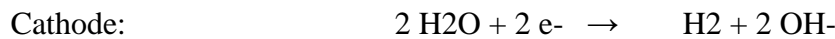
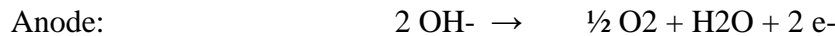


In the water electrolysis process the hydrogen is produced by electrochemically splitting water molecules into their constituents hydrogen H₂ and oxygen O₂. The main inputs to the process are therefore feed water and electricity.

The basic process of water electrolysis takes place in the electrolysis cells (see picture). In most of the cases, the cells are circular in shape and pressed together between two end frames. Such assembled cells are called a cell package.

In the water electrolysis cell, the two electrodes are plunged into the electrolyte. This electrolyte is water mixed with a substance to optimize the electrical conductivity. An aqueous alkali solution, usually 30% potassium hydroxide (KOH), is used in conventional electrolysis. The anode and cathode regions are separated by a gas-tight diaphragm that allows ions to pass but prevents a mixing of the gases. The diaphragm also contributes to equalizing the current.

DC voltage passes through the two electrodes, a potential is applied and the following reactions take place in the electrolysis cell:



The decomposition of the water results in gaseous H₂ at the negative cathode and O₂ at the positive anode. The hydrogen production can take place at ambient or increased pressures.

An electrolyser can directly deliver pressurized H₂ up to 2.5 MPa (25 bar), which leads to a more economic operation as the first stage of the compressor may not be necessary at all or at least parts of the compression-work which would be consumed by a separate compressor might be saved.

Electrolysers for hydrogen refuelling stations are commonly medium pressure or high pressure electrolysers. The typical capacities are from 50 Nm³/h up to 100 Nm³/h. Atmospheric electrolysers can supply up to 500 Nm³/h but are not well suited to on-site production on HRS due to large footprint.

New developments will improve electrolyser technology and capacities up to 500 Nm³/h and with discharge pressures up to 3 MPa (30 bars) will be on the market from 2007.

Typical characteristics are:

Capacity:	130 Nm ³ /h
Footprint:	2 x 1.5 x 2 meters
Electricity consumption:	4.8 kWh per Nm ³ of hydrogen
Operating range:	5 – 100%
Operating pressure	3 MPa

6.1.2 Hydrogen production by steam-reforming of natural gas

Several vendors are offering compact small – scale reformer units comparable to medium pressure electrolyzers.

Typical characteristics are:

Capacity:	100 Nm ³ /h
Footprint:	3.8 x 2,6 meters
Efficiency (HHV)	70%
Operating range:	40 – 100%
Operating pressure:	0.8 MPa



Figure 18: Compact reformer and compressor, 100 Nm³/h (source: Osaka Gas)

6.2 Hydrogen storage system

There are several options of storing hydrogen. Either in cryogenic liquid state (LH₂) at deep temperatures (-253 °C) or as pressurized gas (CGH₂ = compressed gaseous hydrogen) at high pressure.

6.2.1 Compressed gaseous hydrogen storage

Because H₂ is produced at low pressures (around 1 MPa), it needs to be compressed with a compressor to pressure levels up to 85 MPa in order to be stored at that elevated pressure before being dispensed into the vehicle tank. The storage tanks are located either above or below ground. Solutions with canopy-mounted storage cylinders are under discussion and could become a preferred solution, as the space

requirement is rather small. In Argentina this kind of installation is very common for Natural Gas storage and they sometimes include even the whole compressor units.

An example of CGH2 storage cylinders is presented hereafter.



Figure 19: CGH2 Storage cylinders (35 MPa) in Hamburg (CUTE Project, source: <http://www.h2stations.org/>)

6.2.2 Liquid hydrogen storage system

A cryogenic storage tank consists typically of an inner and outer vessel, separated by a vacuum to minimise heat ingress by conduction. Inside the vessel the product will exist in both liquid and gaseous phases.

Cylindrical vessels can be built either vertically or horizontally. Design should ensure minimum heat leak into the vessel and minimise boil off. Heat transfer could occur as radiation, convection or conduction depending on the installation chosen.

6.3 Comparison to other gaseous fuels

Hydrogen has different properties compared to natural gas (CNG) and Liquid Petroleum Gas (LPG).

LPG is used as a vehicle fuel in many countries and is offered at service stations. LPG is stored at 0.8 MPa (8 bar) in liquid phase. The gas is heavier than air and this can be a safety challenge as the gas can sink to the ground level and underground, in enclosed areas, if a leakage occurs. Another challenge with LPG is varied specifications available in terms of gas composition. LPG is a product name for a relatively wide gas specification with propane and butane mixtures. In the Nordic countries LPG typically means more than 90% propane while in southern Europe LPG can be 60/40 propane/butane. This provides a challenge in maintaining the performance and fuel consumption of an engine.

CNG is closer to hydrogen in its characteristics and the dispensing equipment required is also similar. Natural gas is lighter than air and dispensed at a high pressure – above 20 MPa (200 bar). For natural gas systems, equipment ventilation is

important, in order to avoid gas build up in enclosed areas. This is also the case for hydrogen.

Hydrogen has other safety challenges when compared with natural gas (CH₄), which are:

- Ignition energy is 1/10 of methane (CH₄) (see Figure 10)
- The flammability range is wide (see Figure 15)
- Flame speed of hydrogen-air mixture is higher (see Figure 12) and more sensitive to congestion and turbulence, potentially resulting in higher explosion over-pressure

General safety advantages are (as with CH₄):

- Hydrogen is much lighter than air and will disperse quickly and dilute out of the flammability range
- Hydrogen is a non- toxic gas (but is an asphyxiant)

6.4 Hydrogen dispensing techniques

6.4.1 Gaseous dispensing

Dispensing of gaseous hydrogen is by a nozzle that is fixed to the vehicles before pressurisation. The filling process is done automatically when the vehicle and nozzle are coupled together. The hydrogen refuelling is done by fast filling, with a filling time ranging from 12 minutes for large vehicles down to 2-3 minutes for smaller vehicles.

The manual operations are the connection and the disconnection of the nozzle with the vehicle. During the actual filling period no manual operation is required.



Figure 20: Filling of gaseous hydrogen

Three technical options are available for transferring the hydrogen into the vehicle tank:

- Pressure difference from a gaseous pressure vessel, brought to site (tube trailer or cylinder pack)
- Pressure difference from a high pressure gaseous buffer previously filled by compressing hydrogen from a source at lower pressure (e.g. tube trailer or on-site production)
- Direct compression from a low pressure source without use of gaseous hydrogen buffers

The above hydrogen buffers typically store hydrogen at 40-50 MPa (400-500 bar) for 35 MPa (350 bar) refuelling and 85-100 MPa (850-1000 bar) for 70 MPa (700 bar) refuelling. Buffer systems are made up of pressure vessels at different pressures in order to optimise efficiency (cascade filling: dispensing starts with low pressure source and finishes with the highest pressure source).

Hydrogen trailers and cylinder packs used to supply such dispensing systems typically store hydrogen at 20 MPa (200 bar).

All of the above mentioned pressure storage media are considered safe when used correctly and most are commercially available.

6.4.2 *Liquid dispensing*

Dispensing of liquid hydrogen is performed by an automotive coupling that is fixed to the vehicles before refuelling (see Figure 21).

The filling process is done automatically and including different safety procedures.

The normal filling time for a 8 kg storage size is about 5 minutes.

Manual operations are the connecting and the disconnecting of the nozzle to the vehicle. During the actual filling period no manual operation is required.



Figure 21: Filling coupling for liquid hydrogen (source: LINDE)

The stationary liquid storage tank can be arranged as a vertical or horizontal column tank above or beneath ground. Typical tank storage conditions are 0.2 MPa and approximately 25 K. The liquid hydrogen is supplied directly from the liquid storage to the dispenser by the use of a transfer pump. This pump will raise the pressure from the tank to a refuelling pressure of approximately 0.5 MPa. Typical maximum flow capacity of the pump is around 0.05 kg/s.

7 Regulations, standards and codes of practice affecting the design, installation, operation and maintenance of a hydrogen refuelling station

7.1 Introduction

Existing HRS's have been built to a number of different codes and standards, primarily based on a mix of national and specific local requirements. Some of the codes and standards applied have been derived from experiences within the CNG industry. Hydrogen specific international codes and standards (e.g. as developed within ISO/TC97) are still, currently, under development.

The purpose of regulations, standards and codes are to ensure the safe and reliable design and operation of a product or facility. The qualities of the regulations, standards and codes documents can differ considerably.

Authorities, e.g. local, national, or international governments, provide compelling regulations to protect the public, workers, and environment from dangers and hazards. A European Community Directive is an example of a regulation. This is a collective legislative act requiring member states to achieve a particular result without dictating the means of achieving that result. In addition to the EC directives the European countries typically have their own national or local regulations for producing parts, e.g. pressurised equipment and equipment intended for use in explosive atmospheres, applicable to a HRS. National or local regulations for the use of such equipment may also apply.

Codes (also referred to as codes of practice) and standards serve as guidelines and characteristics developed by interested parties to support the free exchange of goods and services, and to promote safety and common understanding. These interested parties are typically companies and associations. While standards are developed by standardisation organisations, through thorough development processes, involving workgroups put together by a wide range of interested parties, codes may be developed by a few or only a single company or association. Due to their more extensive development process, standards generally have a wider acceptance than codes.

The notion "Code" is unfortunately used differently in USA, where it refers to a standard or collection of rules made binding by a local or national government. In this handbook the European definition is used.

Standards and codes, unlike regulations, are not legal documents, yet standards may be included or referred to in regulations and, through the regulation, may be made legally binding. In this case the standard is said to be harmonised with the regulation and becomes a harmonised standard. CEN and CENELEC, the European counterparts to the international standardisation organisations ISO and IEC, have adopted international standards and harmonised these with a range of the European directives. The reason for the parallel structure is that the European standards can have a legal force in Europe as opposed to the international standards. References of Harmonised European Standards for European directives can be found on the European Commissions web pages:

http://ec.europa.eu/enterprise/newapproach/standardisation/harmstds/index_en.html

In addition to the European and international standardisation bodies there are national bodies such as the US National Fire Protection Association, NFPA, which are relevant for the construction and operation of a HRS. Depending on the national and local regulations the European and International standards may be sufficient for approving a HRS. Otherwise standards from national or local standardisation organisations or appropriate codes have to be applied. In this chapter the EC regulations and the European (CEN, CENELEC) and International (ISO, IEC) standards will be discussed together with the most commonly used codes (EIGA, NFPA, etc...) and national standards. The intention of this chapter is to give an overview of the relevant regulations, standards and codes affecting the design, installation, operation and maintenance of a HRS. However the regulations, standards and codes discussed are, in general, not developed exclusively for this purpose and therefore some parts or articles may not be applicable.

An overview of the international work, relating to the standardisation of hydrogen related equipment and technologies, is shown in Figure 22.

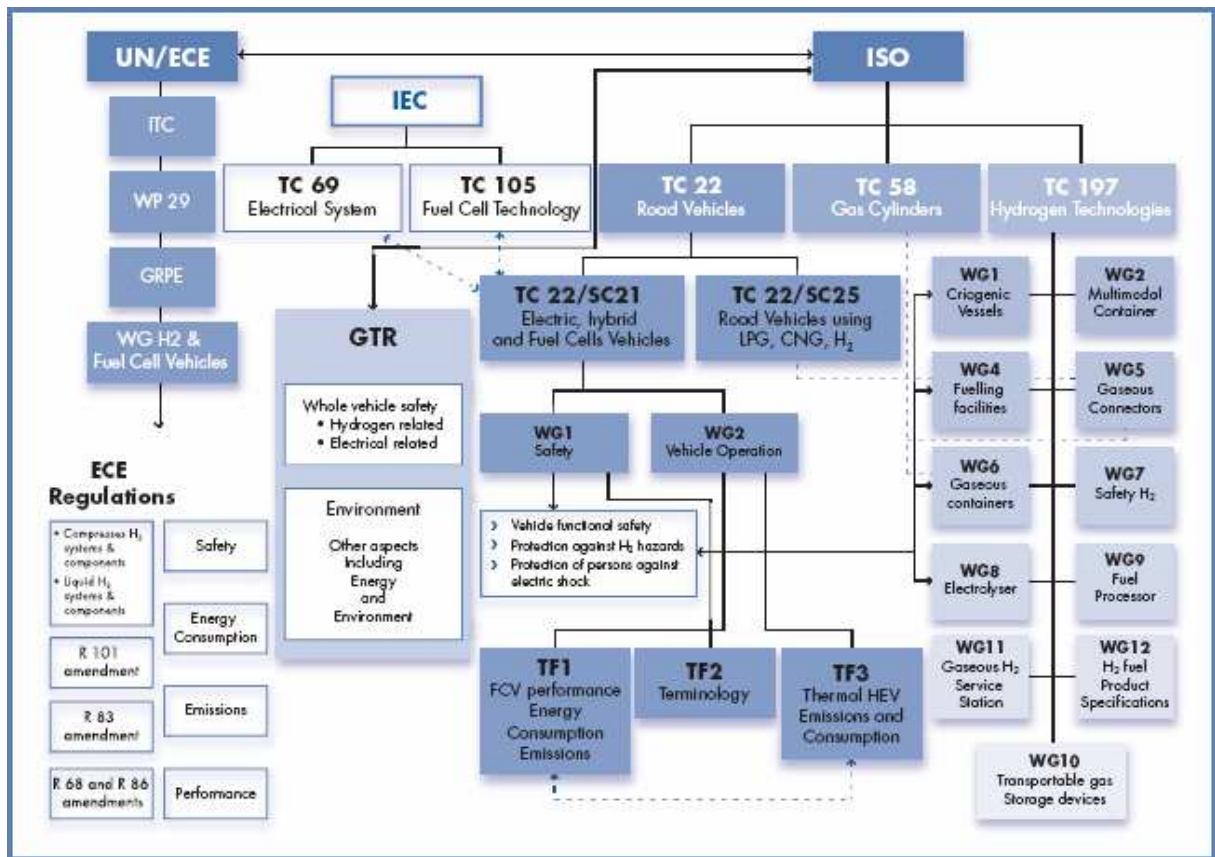


Figure 22: Overview of the international work on standardisation of hydrogen equipment and technologies. (Source: "Introducing Hydrogen as an energy carrier" by the European Commission)

7.2 Generally applicable regulation, standards and codes of practice

A HRS is roughly divided in three sections including; 1) supply of hydrogen, 2) storage facilities, and 3) dispensing facilities. Regulations, codes and standards applicable to all sections are discussed in this chapter. The section-specific documents are discussed in the following subchapter.

The most specific European legislations with regards to a HRS are those commonly known as the Pressure Equipment Directive, PED, Transportable Pressure Equipment Directive, TPED, the ATEX Product Directive (also known as ATEX 95 and ATEX 100), and the ATEX User Directive (also known as ATEX 137). When considering a HRS, it is important to differentiate between the regulations for entire systems and the regulations for system parts. An example is the ATEX directives where the product directive regulates the design and manufacturing process of equipment developed for use in explosive atmospheres in order to ensure proper quality standards, while the user directive is focusing on the risk to the health and life of the workers at a facility where explosive atmospheres may occur. The list of applicable EC directives is presented in § 7.4.1.

ISO has issued a technical report, ISO/TR 15916:2004, which is a guideline for the use of hydrogen in its gaseous and liquid forms. The report identifies the basic safety concerns and risks, and describes the properties of hydrogen that are relevant to safety. Currently ISO is also developing a technical specification ISO/TS 20012 on gaseous hydrogen service stations.

Several standards are developed for explosion prevention and protection. Part 1 of EN 1127 covers the basic concepts and methodology. The determination of explosion limits and auto ignition temperatures of gases and vapours are covered by EN 1839 and EN 14522, and the determination of explosion pressure, and the rate of explosion pressure rise are covered by EN 13673 part 1 and 2. The general principles for a leak detection system is covered by EN 13160 part 1. Performance requirements and test methods, for a stationary hydrogen detection apparatus designed to measure and monitor hydrogen concentrations, are covered by ISO 26142.

Equipment for use in potentially explosive atmospheres is covered by both the European and the international standardisation organisations. CEN covers the non-electrical equipment with part 1 of the standard EN 13463, and has developed terms and definitions for equipment and protective systems intended for use in explosive atmospheres, EN 13237. Electrical apparatus to be placed in an explosive atmosphere is covered by the international standard IEC 60079 and the equivalent CENELEC standard EN 60079. The 60079 standards are divided in several parts. The most relevant parts cover general requirements – part 0, classification of hazardous areas – part 10, electrical installations in hazardous areas (other than mines) – part 14, inspection and maintenance of electrical installations in hazardous areas (other than mines) – part 17, and repair and overhaul for apparatus used in potentially explosive atmospheres (other than mines or explosives) – part 19. A wide range of equipment specific ATEX harmonised standards and a list of all standards related to the ATEX product directive, sorted on equipment can be found through the following links:

<http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist/atex.html>
<http://www.newapproach.org/Directives/ProductFamilies.asp?94/9/EC>

The CEN standard EN ISO 4126 (based on ISO 4126) is a standard harmonised with the PED, and covers a variety of safety devices for protection against excessive pressure. A wide range of equipment specific PED harmonised standards and a list of all standards related to the pressure directive, sorted on equipment or materials type can be found through the following links:

http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/index_en.html

<http://www.newapproach.org/Directives/ProductFamilies.asp?97/23/EC>

The classification of areas where explosive atmospheres may occur are also covered in the EIGA code IGC 134/05, which was developed to facilitate and harmonize the interpretation and implementation of the required assessments according to the ATEX user directive.

7.3 Section specific regulations, standards and codes of practices

7.3.1 Hydrogen supply modes

7.3.1.1 On site production

When dealing with gaseous or liquefied hydrogen under pressure the PED is applicable. The ATEX directives are applicable due to the potentially explosive atmosphere.

The final draft ISO 16110-1 and committee draft ISO/CD 16110-2 cover safety requirements and test methods for performance, respectively, with regards to hydrogen generation using fuel-processing technologies. These drafts apply to hydrogen generation systems with a capacity less than 400 m³/h at 0 °C and 101,325 kPa, which convert fossil or biomass fuel to a hydrogen rich stream of a composition and conditions suitable for use in, for example, a hydrogen compression, storage and delivery system.

The committee draft international standard ISO/FDIS 22734-1 and committee draft ISO/CD 22734-2 is evaluating industrial and commercial applications, and residential applications of hydrogen generators using a water electrolysis process. The documents define the construction, safety and performance requirements of integrated, packaged hydrogen gas generation appliances using electrochemical reactions to electrolyse water to produce hydrogen and oxygen gas.

7.3.1.2 Pipeline interface

According to article 1 part 3.1 pipelines comprising piping or a system of piping designed for conveyance of any fluid or substance to or from an installation are excluded from the scope of the PED.

CGA G-5.4 is an American standard for hydrogen piping at consumer locations. The publication is a guide to the selection of materials and components for a safe and effective hydrogen supply system at a consumer site. It covers the system criteria, cleaning, installation, testing, operation, maintenance and repair.

The code ASME B31.3 on process piping applies to all fluids including cryogenic. The code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. A new code, ASME B31.12, specifically on hydrogen piping and pipelines is currently under

development. This code will cover both liquid and gaseous hydrogen and is intended to include a part on pipeline and distribution systems.

7.3.1.3 Gaseous delivery

The TPED applies to the equipment used to transport gases, compressed or liquefied. In the case of transport by rail the RID is applicable. The ADR is applicable when transported by road when the tanks or tank containers have a total capacity exceeding 3000 litres.

The standards ISO 11114-1 deal with metallic materials relating to transportable gas cylinders and the compatibility of cylinder and valve materials with gas content. It is a guide to the selection and evaluation of compatibility between metallic gas cylinder and valve materials, and the gas content. Seamless and welded gas cylinders used to contain compressed, liquefied and dissolved gases, are considered.

7.3.1.4 Liquid delivery

The TPED is applicable to transport of liquefied gas under pressure.

7.3.2 Hydrogen storage

When dealing with gaseous or liquefied hydrogen under pressure the PED is applicable. The ATEX directives are applicable due to the potentially explosive atmosphere.

Several European standards covering cryogenic vessels are harmonized with PED. EN 1252 on materials, EN 1626 on valves for cryogenic service, EN 1797 on gas/material compatibility, and EN 13648 on safety devices for protection against excessive pressure.

The EIGA code of practise IGC 06/02 on safety in storage, handling and distribution of liquid hydrogen describes certain rules and precautions related to liquid hydrogen. The code includes (1) features for layout and design e.g. safety distances and suitable mechanical and electrical equipment, (2) notices, instructions and customer information in order to facilitate control of an emergency, (3) testing, operations and maintenance of equipment, (4) training and protection of personnel.

Gaseous hydrogen, compression, purification, and filling into containers and storage installations at a consumer site are covered by the EIGA code of practise IGC 15/06. The code shall serve as guidance to designers and operators of gaseous hydrogen stations and reflect the best practices currently available. It includes issues such as safety of personnel, operations instructions, protection, and emergency situations.

The US standard NFPA 55 applies to the design and location of both gaseous and liquefied hydrogen systems at consumer sites. The standard covers operation, maintenance, and fire protection at a hydrogen refuelling station. NFPA 55 superseded and amended the NFPA 50A and NFPA 50B standards, which applied to gaseous and liquefied systems respectively.

7.3.3 *Dispensing facility*

When dealing with gaseous or liquefied hydrogen under pressure the PED is applicable. The ATEX directives are applicable due to the potentially explosive atmosphere.

The ISO 17268:2006 standard deals with design, safety and operation verification of refuelling connection devices for a Compressed Hydrogen Surface Vehicle, CHSV. It applies to nozzles and receptacles which (1) prevent hydrogen fuelled vehicles from being refuelled by dispenser stations with working pressures higher than the vehicle; (2) allow hydrogen vehicles to be refuelled by dispenser stations with working pressures equal to or lower than the vehicle fuel system working pressure; (3) prevent hydrogen fuelled vehicles from being refuelled by other compressed gas dispensing stations; and (4) prevent other gaseous fuelled vehicles from being refuelled by hydrogen dispensing stations.

The standard ISO 13984:1999 applies to the design and installation of liquid hydrogen fuelling and dispensing systems. It specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refuelling procedure. It aims to provide a reasonable level of protection from loss of life and property.

7.4 **Reference list for regulations, standards and codes of practice applicable to a European HRS**

7.4.1 *European Directives*

67/548/EEC

- *Title:* Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances
- *Relevance to:* Dangerous substances
- *Status:* Published. Amended seven times and latest by the Council Directive 92/32/EEC of 30 April 1992.
- *Application:* The directive deals with the notification of substances, exchange of information on notified substances, and the assessment of the potential risk to the public and the environment of notified substances, as well as the classification, packaging and labelling. It is not applicable for the carriage of substances.

73/23/EEC – Low Voltage Directive, LVD

- *Title:* Council Directive 73/23/EEC of 19 February 1973 on the harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits.
- *Relevance to:* General safety, Equipment certification and conformity
- *Status:* Published
- *Application:* Applies to electrical equipment designed for use with a voltage rating of between 50 and 1 000 V for alternating current and between 75 and 1

500 V for direct current. **It is not applicable to electrical equipment used in an explosive atmosphere.** The directive's scope includes the protection against hazards from electrical equipment and correct marking of electrical equipment and packaging thereof.

80/779/EEC

- *Title:* Council Directive 80/779/EEC of 15 July 1980 on air quality limit values and guide values for sulphur dioxide and suspended particulates
- *Relevance to:* Environmental protection, Sulphur dioxide
- *Status:* Published
- *Application:* Fix limit and guide values for sulphur dioxide and suspended particulates in the atmosphere and the conditions for their application in order to improve the protection of human health and the environment.

89/336/EEC – Electromagnetic Compatibility Directive, EMC

- *Title:* Council Directive 89/336/EEC of 3 May 1989 on the approximation of the laws of the Member States relating to electromagnetic compatibility
- *Relevance to:* General safety, Equipment certification and conformity
- *Status:* Published
- *Application:* Applies to apparatus liable to cause electromagnetic disturbance or where the performance of this apparatus is liable to be affected by such disturbances. Apparatus includes all electrical and electronic appliances together with equipment and installations containing electrical and/or electronic components. The directive's scope includes the protection against electromagnetic disturbance from electrical apparatus and certification of such equipment.

89/391/EEC

- *Title:* Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers in the workplace
- *Relevance to:* Safety of workers at work, General
- *Status:* Published
- *Application:* To introduce measures to encourage improvements in the safety and health of workers in the workplace. It contains general principles relating to the prevention of occupational risks, the protection of safety and health, the elimination of risk and accident factors, the informing, consultation, balanced participation in accordance with national laws and/or practices and training of workers and their representatives, as well as general guidelines for the implementation of said principles. It shall apply to all sectors of activity, both public and private. A worker is any person employed by an employer, including trainees and apprentices but excluding domestic servants.

89/654/EEC

- *Title:* Council Directive 89/654/EEC of 30 November 1989 concerning the minimum safety and health requirements for the workplace (first individual directive within the meaning of Article 16 (1) of Directive 89/391/EEC)
- *Relevance to:* Safety of workers in the workplace, HSE
- *Status:* Published
- *Application:* Protection of workers from risks to their safety and health at the workplace. It shall apply to all sectors of activity, both public and private. A worker is any person employed by an employer, including trainees and apprentices but excluding domestic servants.

89/655/EEC

- *Title:* Council Directive 89/655/EEC of 30 November 1989 concerning the minimum safety and health requirements for the use of work equipment by workers in the workplace (second individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC)
- *Relevance to:* Safety of workers in the workplace, Work equipment
- *Status:* Published
- *Application:* Protection of workers from risks to their safety and health due to the use of work equipment in the workplace. It shall apply to all sectors of activity, both public and private. A worker is any person employed by an employer, including trainees and apprentices but excluding domestic servants.

91/271/EEC

- *Title:* Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment
- *Relevance to:* Environmental protection, Waste water
- *Status:* Published
- *Application:* Concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors.

93/68/EEC – CE Marking Directive

- *Title:* Council Directive 93/68/EEC of 22 July 1993 amending Directives – among others – EMC and LVD. The initial Machinery Directive, directive 89/392/EEC, was also amended, but this was later amended by the directive 98/37/EC.
- *Relevance to:* General safety, Equipment certification
- *Status:* Published

- *Application:* Added two Annexes to the LVD regarding CE conformity marking and international production control. Amendments to Annex I of the EMC regarding CE conformity marking.

94/9/EC – ATEX Product Directive (also known as ATEX 95 and ATEX 100)

- *Title:* Directive 94/9/EC of the European Parliament and of the Council of 23 March 1994 on the approximation of the laws of Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.
- *Relevance to:* Equipment certification, Explosive atmosphere
- *Status:* Published
- *Application:* Applies to equipment and protective systems intended for use in potentially explosive atmospheres. Such equipment and systems also include safety devices, controlling devices and regulating devices intended for use outside potentially explosive atmospheres but required for or contributing to the safe functioning of equipment and protective systems with respect to the risks of explosion.

94/55/EC – ADR

- *Title:* Council Directive 94/55/EC of 21 November 1994 on the approximation of the laws of the Member States with regard to the transport of dangerous goods by road
- *Relevance to:* Hydrogen supply, Transportation
- *Status:* Published
- *Application:* Not directly applicable to a HRS but to a possible way of fuel supply.

96/49/EC – RID

- *Title:* Council Directive 96/49/EC of 23 July 1996 on the approximation of the laws of the Member States with regard to the transport of dangerous goods by rail
- *Relevance to:* Hydrogen supply, Transportation
- *Status:* Published
- *Application:* Not directly applicable to a HRS but to a possible way of fuel supply.

97/23/EC – Pressure Equipment Directive, PED

- *Title:* Directive 97/23/EC of the European Parliament and of the Council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment.
- *Relevance to:* Pressure equipment, Fixed

- *Status:* Published
- *Application:* Applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure PS greater than 0.05 MPa (0.5 bar). Pressure equipment includes vessels, piping, safety accessories and pressure accessories. Where applicable, pressure equipment also includes elements attached to pressurised parts such as flanges, nozzles, couplings, support, lifting lugs, etc.

98/24/EC

- *Title:* Council Directive 98/24/EC of 7 April 1998 on the protection of the health and safety of workers from the risks related to chemical agents at work (fourteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)
- *Relevance to:* Safety of workers at work, Chemical agents
- *Status:* Published
- *Application:* Protection of workers from risks to their safety and health arising, or likely to arise, from the effects of chemical agents that are present at the workplace or as a result of any work activity involving chemical agents. It shall apply to all sectors of activity, both public and private. A worker is any person employed by an employer, including trainees and apprentices but excluding domestic servants.

98/37/EC – Machinery Directive, MD

- *Title:* Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery.
- *Relevance to:* General safety, Equipment certification and conformity
- *Status:* Published
- *Application:* Applies to machinery and lays down the essential health and safety requirements therefore. It shall also apply to safety components placed on the market separately. Machinery is an assembly of linked parts or components, at least one of which moves, joined together for a specific application. Safety component should fulfil a safety function when in use and the failure or malfunctioning of which endangers the safety or health of exposed persons.

1999/36/EC – Transportable Pressure Equipment Directive, TPED

- *Title:* Council Directive 1999/36/EC of 29 April 1999 on transportable pressure equipment
- *Relevance to:* Pressure equipment, Transportable
- *Status:* Published

- *Application:* Enhance safety with regards to transportable pressure equipment approved for inland transport of dangerous goods by road and by rail and to ensure the free movement of such equipment within the EU, including placing on the market and repeated putting into service and repeated use aspects. The term “transportable pressure equipment” shall include receptacles and tanks used for the transport of Class 2 substances in accordance with the Annexes to the RID and ADR treaties. Class 2 substances include gases, compressed, liquefied or dissolved under pressure. The ADR and RID treaties are covering the transport of dangerous goods by road and rail respectively. *However ADR shall not apply to substances of Class 2 in tanks or tank containers of a total capacity exceeding 3000 litres or deeply refrigerated liquefied gases.*

1999/92/EC – ATEX User Directive (also known as ATEX 137)

- *Title:* Directive 1999/92/EC of the European Parliament and of the Council of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. (15th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)
- *Relevance to:* Safety of workers at work, Explosive atmosphere
- *Status:* Published
- *Application:* The ATEX user directive is an individual amendment of the council directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work. It is focusing specifically on workers potentially at risk from explosive atmospheres. The directive shall apply to all sectors of activity, both public and private, and the term “worker” shall include any person employed by an employer, including trainees and apprentices but excluding domestic servants.

7.4.2 ISO standards, drafts, reports and specifications

ISO 11114-1

- *Title:* Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents – Part 1: Metallic materials
- *Relevance to:* Hydrogen supply, gaseous transport
- *Status:* Published standard
- *Application:* Guidance in the selection and evaluation of compatibility between metallic gas cylinder and valve materials, and the gas content. Seamless and welded gas cylinders used to contain compressed, liquefied and dissolved gases, are considered.

ISO 11114-4

- *Title:* Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement

- *Relevance to:* Hydrogen supply, gaseous transport
- *Status:* Published standard
- *Application:* Applies to seamless steel gas cylinders and specifies test methods and the evaluation of results from these tests in order to qualify steels suitable for use in the manufacture of gas cylinders (up to 3 000 l) for hydrogen and other embrittling gases.

ISO 13984:1999

- *Title:* Liquid hydrogen – Land vehicle fuelling system interface
- *Relevance to:* Dispensing facilities, Liquid hydrogen
- *Status:* Published standard
- *Application:* Applies to the design and installation of liquid hydrogen fuelling and dispensing systems, and specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refuelling procedure and in order to provide a reasonable level of protection from loss of life and property.
- *Corresponding standards:* SAE J2783 (under development)

ISO 13985:2006

- *Title:* Liquid hydrogen – Land vehicle fuel tanks
- *Relevance to:* On-board hydrogen storage, Liquid hydrogen
- *Status:* Published standard
- *Application:* specifies the construction requirements for refillable fuel tanks for liquid hydrogen used in land vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided.

ISO/DIS 15869

- *Title:* Gaseous hydrogen and hydrogen blends – Land vehicle fuel tanks
- *Relevance to:* On-board hydrogen storage, Gaseous hydrogen
- *Status:* Under development
- *Application:* This International Standard specifies the requirements for light-weight refillable fuel tanks intended for the onboard storage of high pressure compressed gaseous hydrogen or hydrogen blends on land vehicles. This International Standard is not intended as a specification for fuel tanks used for solid or liquid hydride hydrogen storage applications.

ISO/TR 15916:2004

- *Title:* Basic considerations for the safety of hydrogen systems
- *Relevance to:* General safety
- *Status:* Published standard
- *Application:* Providing guidelines for the use of hydrogen in its gaseous and liquid forms. It identifies the basic safety concerns and risks, and describes the properties of hydrogen that are relevant to safety.

ISO 16110-1

- *Title:* Hydrogen generators using fuel processing technologies – Part 1: Safety
- *Relevance to:* Hydrogen supply, fossil fuels
- *Status:* Under development
- *Application:* Applies to hydrogen generation systems with a capacity less than 400 m³/h at 0 °C and 101,325 kPa, which convert fossil or biomass fuel to a hydrogen rich stream of composition and conditions suitable for, for example, a hydrogen compression, storage and delivery system.

ISO/CD 16110-2

- *Title:* Hydrogen generators using fuel processing technologies – Part 2: Procedures to determine efficiency
- *Relevance to:* Hydrogen supply, fossil fuels
- *Status:* Under development
- *Application:* covers operational and environmental aspects of the performance of hydrogen generators described in ISO 16110-1.

ISO 17268:2006

- *Title:* Compressed hydrogen surface vehicle refuelling connection devices.
- *Relevance to:* Dispensing facilities, Compressed gas
- *Status:* Published standard
- *Application:* Applies to design, safety and operation verification of Compressed Hydrogen Surface Vehicle, CHSV, refuelling connection devices. Applies to nozzles and receptacles which (1) prevent hydrogen fuelled vehicles from being refuelled by dispenser stations with working pressures higher than the vehicle; (2) allow hydrogen vehicles to be refuelled by dispenser stations with working pressures equal to or lower than the vehicle fuel system working pressure; (3) prevent hydrogen fuelled vehicles from being refuelled by other compressed gases dispensing stations; and (4) prevent other gaseous fuelled vehicles from being refuelled by hydrogen dispensing stations.
- *Corresponding standards:* SEA J2600 (published standard)

ISO/TS 20012

- *Title:* Gaseous Hydrogen – Service Stations
- *Relevance to:* General safety
- *Status:* Under development
- *Application:* Applies to non-residential, pure hydrogen refuelling stations, and will address separation distances.

ISO/DIS 22734-1

- *Title:* Hydrogen generators using water electrolysis process – Part 1: Industrial and commercial applications
- *Relevance to:* Hydrogen supply, electrolysis
- *Status:* Under development (Draft International Standard)
- *Application:* This standard defines the construction, safety and performance requirements of integrated, packaged hydrogen gas generation appliances using electrochemical reactions to electrolyse water to produce hydrogen and oxygen gas.

ISO/CD 22734-2

- *Title:* Hydrogen generators using water electrolysis process – Part 2: Residential applications
- *Relevance to:* Hydrogen supply, electrolysis
- *Status:* Under development
- *Application:* As part 1, for residential applications

ISO 26142

- *Title:* Hydrogen detector
- *Relevance to:* General safety
- *Status:* Under development
- *Application:* Defines the performance requirements and test methods of stationary hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations.

7.4.3 CEN standards

EN 1127-1:1997

- *Title:* Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology
- *Relevance to:* Protection systems

- *Status:* Published standard

EN 1252-1:1998

- *Title:* Cryogenic vessels – Materials – Part 1: Toughness requirements for temperatures below – 80 C
- *Relevance to:* On-board hydrogen storage, Liquid hydrogen
- *Status:* Published standard

EN 1626:1999

- *Title:* Cryogenic vessels – Valves for cryogenic service
- *Relevance to:* On-board hydrogen storage, Liquid hydrogen
- *Status:* Published standard

EN 1797

- *Title:* Cryogenic vessels – Gas/material compatibility
- *Relevance to:* On-board hydrogen storage, Liquid hydrogen
- *Status:* Published standard

EN 1839:2003

- *Title:* Determination of explosion limits of gases and vapours
- *Relevance to:* Risk assessment
- *Status:* Published standard

EN 4126-1, 2, 3, 4, 5, 6, 7

- *Title:* Safety devices for protection against excessive pressure
- *Relevance to:* Non-electrical equipment
- *Status:* Published standard

EN 13160-1:2003

- *Title:* Leak detection systems – Part 1: General principles
- *Relevance to:* Detection systems
- *Status:* Published standard

EN 13237:2003

- *Title:* Potentially explosive atmospheres – Terms and definitions for equipment and protective systems intended for use in potentially explosive atmospheres
- *Relevance to:* Protective systems
- *Status:* Published standard

EN 13463:2001

- *Title:* Non-electrical equipment for potentially explosive atmospheres – Part 1: Basic method and requirements
- *Relevance to:* Non-electrical equipment and installations
- *Status:* Published standard

EN 13648-1, 2, 3

- *Title:* Cryogenic vessels – Safety devices for protection against excessive pressure
- *Relevance to:* Non-electrical equipment, Liquid hydrogen
- *Status:* Published standard

EN 13673-1:2003

- *Title:* Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours – Part 1: Determination of the maximum explosion pressure
- *Relevance to:* Risk assessment
- *Status:* Published standard

EN 13673-2:2005

- *Title:* Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours – Part 2: Determination of the maximum rate of explosion pressure rise
- *Relevance to:* Risk assessment
- *Status:* Published standard

EN 14522:2005

- *Title:* Determination of the auto ignition temperature of gases and vapours
- *Relevance to:* Risk assessment
- *Status:* Published standard

7.4.4 IEC standards

IEC 60079-0

- *Title:* Electrical apparatus for explosive gas atmospheres - Part 0: General requirements
- *Relevance to:* Electrical equipment and installations
- *Status:* Published standard
- *Application:* Specification of general requirements for construction, testing and marking of electrical apparatus and components intended for use in explosive gas atmospheres. Electrical apparatus complying with this standard is intended for use in hazardous areas in which explosive gas atmospheres, caused by mixtures of air and gases, vapours or mists, exist under normal atmospheric conditions.
- *Corresponding standards:* EN 60079-0 by CENELEC (published standard)

IEC 60079-10

- *Title:* Electrical apparatus for explosive gas atmospheres – Part 10 : Classification of hazardous areas
- *Relevance to:* Electrical equipment and installations
- *Status:* Published standard
- *Application:* Classification of hazardous areas where flammable gas or vapour risks may arise, in order to permit the proper selection and installation of apparatus for use in such hazardous areas.
- *Corresponding standards:* EN 60079-10 by CENELEC (published standard)

IEC 60079-14

- *Title:* Electrical apparatus for explosive gas atmospheres - Part 14: Electrical installations in hazardous areas (other than mines)
- *Relevance to:* Electrical equipment and installations
- *Status:* Published standard
- *Application:* Specification of requirements for the design, selection and erection of electrical installations in explosive gas atmospheres. These requirements are in addition to the requirements for installations in non-hazardous areas. Applies to all electrical equipment and installations in hazardous areas, and at all voltages.
- *Corresponding standards:* EN 60079-14 by CENELEC (published standard)

IEC 60079-17

- *Title:* Electrical apparatus for explosive gas atmospheres - Part 17: Inspection and maintenance of electrical installations in hazardous areas (other than mines)
- *Relevance to:* Electrical equipment and installations
- *Status:* Published standard
- *Application:* Intended to be applied by users, and covers factors directly related to the inspection and maintenance of electrical installations within hazardous areas only.
- *Corresponding standards:* EN 60079-17 by CENELEC (published standard)

IEC 60079-19

- *Title:* Electrical apparatus for explosive gas atmospheres - Part 19: Equipment repair, overhaul and reclamation
- *Relevance to:* Electrical equipment and installations
- *Status:* Published standard
- *Application:* Gives instructions, principally of a technical nature, on the repair, overhaul, reclamation and modification of a certified equipment designed for use in explosive atmospheres.
- *Corresponding standards:* EN 60079-18 by CENELEC (published standard)

7.4.5 CENELEC standards

EN 60079 – Part 1, 10, 14, 17, 19

- *Title:* Electrical apparatus for explosive gas atmospheres
- *See corresponding IEC standards*

7.4.6 EIGA standards

IGC 06/02

- *Title:* Safety in storage, handling and distribution of liquid hydrogen
- *Relevance to:* Hydrogen storage, Liquid hydrogen
- *Status:* Published code of practice
- *Application:* Describes certain rules and precautions related to liquid hydrogen. The code includes (1) features for layout and design, e.g. safety distances and suitable mechanical and electrical equipment, (2) notices, instructions and customer information in order to facilitate control of an emergency, (3) testing, operations and maintenance of equipment and (4) training and protection of personnel.

IGC 15/06

- *Title:* Gaseous hydrogen stations
- *Relevance to:* Hydrogen storage, Gaseous hydrogen
- *Status:* Published code of practice
- *Application:* The code shall serve as guidance for designers and operators of gaseous hydrogen stations and reflect the best practices currently available. It includes issues such as safety of personnel, operations instructions, protection, and emergency situations.

IGC 23/00

- *Title:* Safety training of employees
- *Relevance to:* Safety of workers at work, General
- *Status:* Published code of practice
- *Application:* Serve as a guideline for training programs for employees dealing with industrial gases such as hydrogen. The guideline includes a safety training checklist and information about the hazards related to the various gases.

IGC 75/07

- *Title:* Determination of safety distances
- *Relevance to:* General safety, Risk management and mitigation
- *Status:* Published code of practice, Revision of IGC 75/01
- *Application:* Establishing the basic principles for calculating appropriate safety distances for the industrial gas industry. It is intended to be an aid to writing and revising codes and practices, which involve specifying separation distances for safe equipment layout. It applies to equipment required for the storage and processing of industrial, medical and speciality gases.

IGC 121/04

- *Title:* Hydrogen transportation pipelines
- *Relevance to:* Dispensing facilities, Compressed gas
- *Status:* Published code of practice
- *Application:* Contains a summary of current industrial practices related to metallic transmission and distribution piping systems carrying pure hydrogen and hydrogen mixtures.

IGC 122/00

- *Title:* Environmental impacts of hydrogen plants
- *Relevance to:* Environmental protection, Operation

- *Status:* Published code of practice
- *Application:* Concentrates on the environmental impacts of hydrogen and carbon monoxide production, and shall provide a guideline for identifying and reducing the environmental impacts of such facilities. This document is relevant for sites which produce hydrogen by electrolysis or chemical processes and covers principal impacts and impacts due to compression, desulphurising, reforming, maintenance and storage.

IGC 134/05

- *Title:* Potentially explosive atmosphere – EU directive 1999/92/EC
- *Relevance to:* Safety of workers at work, Explosive atmosphere
- *Status:* Published code of practice
- *Application:* To facilitate and harmonize the interpretation and implementation of the required assessments and specifically the classification of areas where explosive atmosphere may occur according to the ATEX user directive

IGC 137/06

- *Title:* Environmental aspects of decommissioning
- *Relevance to:* Environmental protection, Decommissioning
- *Status:* Published code of practice
- *Application:* Providing guidance to the identification and management of environmental risks associated with decommissioning.

7.4.7 NFPA standards

NFPA 50A – Superseded by NFPA 55

- *Title:* Standard for Gaseous Hydrogen Systems at Consumer Sites
- *Relevance to:* Hydrogen storage, Gaseous hydrogen
- *Status:* Published standard
- *Application:* Present requirements for designing systems including container locations, safety devices, marking, piping, venting, and other components.

NFPA 50B – Superseded by NFPA 55

- *Title:* Standard for Liquefied Hydrogen Systems at Consumer Sites
- *Relevance to:* Hydrogen storage, Liquid hydrogen
- *Status:* Published standard
- *Application:* Present requirements for designing systems including container locations, safety devices, marking, piping, venting, and other components.

NFPA 52

- *Title:* Vehicular Fuel Systems Code, 2006 Edition
- *Relevance to:* Hydrogen fuelled engines
- *Status:* Published standard
- *Application:* Presents the latest fire safety rules for hydrogen as well as CNG and LNG fuel systems on all vehicle types plus their respective compression, storage, and dispensing systems.

NFPA 55

- *Title:* Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks
- *Relevance to:* Hydrogen storage, Gaseous and Liquid hydrogen
- *Status:* Published standard
- *Application:* Present requirements for designing systems including container locations, safety devices, marking, piping, venting, and other components. Incorporates the standards NFPA 50A and NFPA 50B.

NFPA 221

- *Title:* Standard for High challenge Fire Walls, Fire Walls, and Fire Barrier Walls
- *Relevance to:* General safety
- *Status:* Published standard
- *Application:* Addressing the requirements for fire walls and fire barriers.

7.4.8 Other standards and codes

CGA G-5.4

- *Title:* Hydrogen Piping at Consumer Locations
- *Relevance to:* Hydrogen supply, Pipeline interface
- *Status:* Published standard
- *Application:* Serve as a guide for materials and components selection to assist in installing a safe and effective hydrogen supply system at a customer's site.

CGA G-5.5

- *Title:* Hydrogen Vent System
- *Relevance to:* General safety
- *Status:* Published standard
- *Application:* Presents design guidelines for hydrogen vent systems for gaseous and liquid hydrogen installations at consumer sites, and provides

recommendations for their safe operation. Intended to be a useful reference for personnel who design, install, and maintain hydrogen vent systems.

CGA H-3

- *Title:* Cryogenic Hydrogen Storage
- *Relevance to:* Hydrogen storage, Liquid hydrogen
- *Status:* Published standard
- *Application:* Contains the suggested minimum design and performance requirements for shop-fabricated, vacuum-insulated cryogenic tanks (vertical and horizontal) intended for aboveground storage of liquid hydrogen.

ASME B31.3

- *Title:* Process piping
- *Relevance to:* Hydrogen supply, Pipeline interface
- *Status:* Published standard
- *Application:* Contains requirements for piping covering materials and components, design, fabrication, assembly, erection, examination, inspection, and testing. This Code applies to piping for all fluids including cryogenic fluids.

ASME B31.12

- *Title:* Hydrogen piping and pipelines
- *Relevance to:* Hydrogen supply, Pipeline interface
- *Status:* Under development
- *Application:* Contains requirements specific to hydrogen service in power, process, transportation, distribution, commercial, and residential applications.

8 HRS design and construction recommendations

8.1 General recommendations for Hydrogen plants

8.1.1 General design

The hydrogen systems shall be designed, fabricated and tested in accordance with recognized national pressure vessel and piping codes (PED for Europe, ASME for USA) and where appropriate, in accordance with statutory requirements. Electrical and mechanical installation in classified areas shall be certified according to ATEX (for Europe).

Particularly the safety considerations of ISO15916 should be addressed.

Hydrogen fuelling facilities shall be designed so that, in the event of a power or equipment failure, the system shall go into a fail-safe condition.

Equipment and pipeline systems shall be earthed and bonded to give protection against the hazards of stray electrical currents and static electricity. Resistance between equipment and ground shall be less than 10 Ohms.

Means shall be provided to protect storage tank, transfer pump and dispenser as well as connecting piping and wiring against physical damage. General layout of the equipment shall consider risk of collision by a vehicle entering the facility.

Lighting shall be provided of adequate intensity for all buildings and working areas so that, at all times operations can be carried out in safety. The lighting equipment in classified areas shall be suitable to meet the requirements of these areas (e.g. Ex-protection).

The installation should be clearly identified as containing hydrogen/flammable gas and that smoking and other naked flames should be prohibited within hazard zones.

8.1.2 Hydrogen quality

Preliminary specifications for H₂ gas purity are given by ISO 14687-2 or SAE 2719.

There shall be a 5 µm filter installed to protect the vehicle from particles in the hydrogen flow bigger than 10 µm.

The refuelling station must include a means of preventing oil, graphite entry or any other impurity into the gas stream in the event of any process equipment defect or malfunction.

The sampling of H₂ gas shall be done at the point of discharge to the vehicle using a sampler functionally comparable to the “Hydrogen Quality Sampling Adapter” described in the CaFCP Hydrogen Quality Guideline.

Filling station owner/provider shall have the delivered H₂ gas analysed at sufficient frequency to demonstrate the gas composition is reliably controlled to the requirements.

8.1.3 Piping

Aboveground pipelines for gaseous and liquid hydrogen shall be clearly identified by means of colour coding and/or labels.

Isolation valves shall be provided so that the hydrogen source can be shut off safely¹ in the event of an emergency. This is particularly important where hydrogen pipelines enter buildings or enclosures. Type and position of isolation valves shall be such that they remain operational and can be safely operated (manually or remotely) in the event of an emergency (e.g. fire).

Above ground or exposed pipe work shall be protected from corrosion, adequately supported and protected from mechanical damage.

Buried pipe work shall be continuously welded and protected with a system to prevent external pipe surface corrosion. The pipe work shall be laid at a depth to protect it against mechanical damage. The pipe work should be buried in trenches, which are at minimum 600 mm deep and/or subject to topographical investigation and/or local regulations. Warning tapes and/or protection slabs should be placed above the pipe work.

Any cathodic protection system should not cause interference to any other underground structure.

Where it is necessary to run hydrogen pipelines in the same duct or trench used for electrical cables and other pipelines, then all joints in the hydrogen pipelines in the ducted/trenched section shall be welded or brazed.

As good practice, a minimum separation distance of 50 mm from electrical cables and any other pipelines should be maintained.

The hydrogen pipeline should be run at a higher elevation than other pipelines, unless local requirements stipulate otherwise.

Liquid hydrogen piping

Isolation of liquid hydrogen piping should use double walled vacuum with multi layer insulation.

Cryogenic temperature potentially in contact with the ambient atmosphere may cause air liquefaction. As a consequence drops of liquid air, enriched in oxygen, may be present around the liquid hydrogen piping and may fall down on the floor. Therefore combustible material below a liquid hydrogen piping is forbidden.

Pressure relief devices shall be provided to prevent over pressure of blocked-in lines where this can occur.

8.1.4 Venting

8.1.4.1 Venting of hydrogen

The hydrogen gas shall be vented outdoors to a safe location. This means that the vented gas should be released at sufficient height so that the release is not a hazard for people or equipment in case of ignition. The vent outlet shall be located so that gas cannot accumulate in neighbouring structures (e.g. overhangs, roofs, building openings, ventilation inlets, etc ...).

¹ It is generally recommended that the term safe is defined by risk based criteria.

Means shall be provided to prevent water, ice and other debris from accumulating inside the vent pipe or obstructing the vent pipe. These means shall not limit or obstruct the gas flow.

Operational and emergency discharges of hydrogen should be disposed of through the vent system where, upon discharge, it is rapidly diluted with air to a concentration that is below the lower flammability limit. Flammable concentrations of hydrogen in air should not be allowed to reach an ignition source.

Operational venting

Procedures for the operation and maintenance of hydrogen supply systems require the discharge of hydrogen gas to the atmosphere. These discharges are characterized either by manual control or by automatic control devices such as back pressure valves. Typical discharges encountered are:

- Purge of refill hoses
- Boil off generated in liquid storage systems
- Depressurisation and purge of piping for maintenance of control components, safety devices, etc.

Emergency venting

Emergency venting can result from abnormal occurrences and malfunctions such as: exposure of the:

- Storage vessel to fire
- Loss of vacuum in liquefied storage vessels
- Pressure relief device actuation

Mechanical considerations

The vent pipe shall be properly supported. The vent structure shall be designed to withstand the forces generated by the exiting gas flow as well as environmental factors: ice, wind, and seismic loadings prescribed in the local building code.

Fire considerations

Hydrogen is flammable in air over a wide range of concentrations, and the ignition energy is very low. Therefore, the possibility of ignition always exists during the dilution process. The vent system shall be designed and its discharge point located so that burning the discharged hydrogen will proceed safely.

Design considerations

The size of a vent stack is normally determined by the available pressure drop that permits adequate flow of pressure relief devices and by the minimum exit velocity required for dispersion of the vent gases.

The vent system piping shall be sized so that the vent line pressure drop will not reduce the relieving capacity of the pressure relief device(s) connected to the venting system to an unacceptable level. The discharge line should be sized to ensure that a back pressure at the relief discharge does not exceed 10% of the relief device set pressure.

Some applications, e.g., venting through a manual valve, permit the sizing criteria to be based on high exit velocities for plume dispersion.

Interconnecting hydrogen vent sources to a common stack is permitted if the vent system is designed to handle the flow from all discharges without over pressurization of any portion of the vent system. Excess pressure in the vent system can cause failure of connected apparatus and can reduce flow capacity of the pressure relief devices that discharge into the vent system.

Separate vent systems should be used for high and low-pressure sources. Separate vent systems will avoid undesirable leakage from high to low pressure systems and will not reduce the venting capacity of the low-pressure device(s).

The vent system should be designed in accordance with the stress limits given in national and international standards for dead weight, ice, wind, earthquake, and other. These loads are not intended to act simultaneously.

Thermal contraction of the vent piping shall be accounted for in the design of vent systems that can discharge cold vapour.

Supersonic flows may require special considerations to predict the loading effects of shock waves on tees, elbows, and other fluid impingement points.

Hydrogen vent systems shall be designed by personnel competent and experienced in the design of hydrogen vent systems at the specific process conditions at the site.

Flow discharge considerations

To minimize the potential for hydrogen settling close to the ground in cloud form, discharge of hydrogen vapour at a temperature that is near its boiling point at atmospheric pressure should be avoided. Hydrogen clouds are hazards due to their ignition and asphyxiation potential. Personnel shall not enter into vapour clouds of any type. Exits of vent stacks for cold hydrogen gas releases should be at a height that is sufficient to avoid vapour clouds at ground level or at levels where people normally are present.

The exits of vent stacks shall be located so the concentration of vented gas at any point of personnel exposure is below the lower flammability limit. Exits of vent stacks shall be located outdoors and away from personnel areas, ignition sources, air intakes, building openings, and overhangs. The siting distances from exposures specified in NFPA55 or EIGA/IGC/15/06 or ISO15916 or local fire code requirements, as applicable, can be used as general guidelines to locate vent stacks for hydrogen consumer locations.

Vent exits should be cut at an angle along a plane facing upwards, in order to ensure that the gas is vented in an upwards direction.

Design pressure for deflagration and detonation

In theory, where the L/D ratio of any section is greater than 60:1 but less than 100:1 a deflagration of a contained air-hydrogen mixture is possible. Similarly, where the L/D ratio of any section is greater than 100:1, a detonation of an air-hydrogen mixture is possible.

However, hydrogen vent systems of facilities within the scope of this document are unlikely to sustain deflagrations or detonations, regardless of L/D ratios. The relatively simple geometry of the system (few turns, few tie-ins) and operating scenarios are not conducive to forming ignitable hydrogen-air concentrations within the system and limit potential ignition sources external to the stack discharge. Experience has shown that a venting system designed for 1030 kPa (150 psig) will sustain a potential flammable mixture ignition without bursting. When rupture disks are installed in a vent system, their design and construction should consider these conditions.

Materials

Single-wall, un-insulated piping should be used for warm and cold gaseous hydrogen venting. Cold vents accessible to untrained persons should have some form of personnel protection.

Piping, tubing, fittings, valves, accessory equipment, gaskets, and thread sealants shall be suitable for hydrogen service at the pressure and temperatures involved and shall maintain their integrity under the high temperatures of fire conditions.

Austenitic (300 series) stainless steel meeting the ASME Code requirements is the preferred choice for hydrogen vent systems. Type 304 stainless steel has well documented mechanical characteristics when exposed to fluctuations between ambient and liquid hydrogen temperatures and for corrosion resistance, which will minimize particulates within the vent system.

Low melting point materials such as aluminium, copper, brass, and bronze have reduced strength at elevated temperatures. Vent stack systems containing components made of low melting point material shall be:

- Suitably protected against external fire exposure, e.g. in accordance with ISO15916 Annex C or NFPA55, or local fire code requirements, as applicable
- Located so that any leakage resulting from failure would not unduly expose personnel, buildings, or structures; or
- Located where leakage can be readily controlled by the operation of an accessible and remotely located valve

Gray, ductile, or malleable iron shall not be used in a hydrogen vent system.

Plastic piping, tubes, fittings, or components of any kind shall not be used for pressure containment in hydrogen vent systems.

Components

Welded, screwed, or bolted components of a vent stack should comply with applicable ASTM or equivalent standards. System and components should be used in accordance with manufacturers' recommendations.

8.1.4.2 Venting of oxygen

If hydrogen is produced on-site by water electrolysis, venting of oxygen will most likely take place regularly. Oxygen is a highly reactive chemical and special consideration should be taken regarding venting of oxygen gas.

Piping, tubing, fittings, valves, accessory equipment, gaskets, thread sealants and other components shall be suitable for oxygen service at the pressures and temperatures involved.

Hydrogen and oxygen shall not be vented into the same system. Additionally, venting outlets of these systems shall be well separated to avoid oxygen-enriched hydrogen-air mixtures.

8.1.4.3 Venting of nitrogen

Nitrogen is often used for purging purposes. Nitrogen is hazardous due to its asphyxiation potential. Venting of nitrogen should be routed to locations where it is not allowed to accumulate and to reduce the oxygen content of the working atmosphere.

8.1.5 Pressure relief and venting discharge devices

Discharge relief valves shall be directed so as to minimize hazard to personnel and other equipment.

Pressure relieving safety devices shall be so arranged that the possibility of damage to piping or appurtenance is reduced to a minimum. The means for adjusting relief valve set pressure shall be sealed.

The vent discharge piping should be securely supported and designed for the pressure arising within the vent. Vent lines shall not be fitted with flame arresters, or any other restrictions that prevent the free release of hydrogen to the atmosphere.

Stainless steel is the preferred material to use for discharge vents to minimise the possibility of ignition due to atmospheric corrosion particles.

Bleed or vent connections shall be provided so that loading arms and hose can be drained and depressurised prior to disconnection if necessary. These bleed or vent connections shall lead to a safe point of discharge.

The vents of pressure relief devices shall be designed or located so that moisture or contaminants cannot collect and freeze in a manner that could interfere with the proper operation of the device.

Vents, including those of pressure relief devices, shall be arranged to discharge in a safe place in the open air so as to prevent impingement of escaping gas on to personnel or any structure, vessels, valves or fittings. Vents should be piped individually, manifolding is not recommended. Vents shall not discharge where

accumulation of hydrogen can occur, e.g. such as below the eaves of buildings, inside shelters, etc...

Pressure relief devices or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner that would interfere with proper operation of the device.

Pressure relief devices shall be provided in piping wherever liquefied hydrogen could be trapped between closures.

A thermal expansion relief valve shall be installed as required to prevent overpressure in any section of a liquid or cold vapour pipeline that can be isolated by valves.

Thermal expansion relief valves shall be set to discharge above the maximum pressure normally expected in the line but less than the rated test pressure of the line it protects.

Pressure relief devices should also be provided in piping etc. where gaseous hydrogen could be trapped, if thermal expansion of the gaseous hydrogen could give rise to hazardous overpressure.

8.1.6 Material selection criteria

All materials used shall be suitable for hydrogen service at design pressure and design temperature. Some of the considerations that are involved in selecting a material include:

- (low) temperature effects
- hydrogen embrittlement effects
- permeability and porosity
- compatibility of dissimilar metals when used together

Low temperature effects

Many materials change from ductile to brittle behaviour as their temperature is lowered. This change in behaviour can occur at temperatures much higher than cryogenic temperatures.

Two of the primary considerations in the selection of a material for liquid hydrogen service are low temperature ductility (low temperature embrittlement) and thermal contraction.

The temperature span from ambient to liquid hydrogen temperature is about 280 K. Such a large temperature decrease can result in significant thermal contraction in most materials. The design of equipment for low temperature service should account for the stress caused in components by thermal expansion or contraction.

Proper design should also accommodate the difference in thermal expansion of different materials involved.

Embrittlement and hydrogen attack

Hydrogen embrittlement is a serious concern for metals exposed to hydrogen. This phenomenon can cause a significant deterioration in the mechanical properties of metals.

Hydrogen embrittlement is fully described in EIGA document IGC15/06 Appendix 5.

Permeability and porosity

Hydrogen can diffuse rapidly through certain porous materials or systems with small openings, which would normally be gastight with respect to air or other gases.

Cast iron pipe and fittings shall not be used. The use of any casting is not recommended due to the permeability of hydrogen and the possibility of porosity in the casting.

Compatibility of dissimilar metals when used together

The use of dissimilar metals in tubing, fittings and other components should be avoided. Stainless steel fittings shall be compatible with metal tubing materials. Care shall be taken in contacts between dissimilar metals for corrosion protection. Special consideration shall be given to prevent contact between small components of less noble metal to larger more noble ones.

Note: “Dissimilar metals” can also include different alloys of stainless steel.

Further considerations

Pressure vessels, such as those used for buffer storage, that are made of materials that are subject to corrosion by atmospheric conditions, shall be protected by corrosion prevention methods.

Corrosion that can limit the working life of the cylinders and affect the fatigue characteristics in serious cases should be avoided. The implementation of good periodic preventative maintenance in anti-corrosion procedures is strongly recommended.

Where ammonia is likely to be present as an impurity or as an atmospheric contaminant, copper and copper/tin/zinc base alloys shall not be used for pipe or fittings since these materials is susceptible to be attacked by ammonia. Consideration should also be given to the possibility of other contaminants being present and adequate precautions should be taken.

Pipes and fittings shall conform to an established standard or specification for their manufacture.

Further detailed information on the selection of materials is found in ISO/PDTR 15916 App C and ISO/DIS 11114, Part 1 and 4.

8.1.7 Insulation

Insulation and piping systems used to convey cryogenic fluids shall be of non-combustible material and shall be designed to have a vapour-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation.

The insulation material and outside shield shall also be designed to prevent deterioration of the insulation due to normal operating conditions. Uninsulated piping and equipment that operates at liquefied hydrogen temperatures shall not be installed above asphalt or other combustible materials or surfaces in order to prevent the contact of liquid air with such materials.

Drip pans shall be allowed to be installed under uninsulated piping and equipment to retain and vaporize condensed liquid air.

8.1.8 Instrument

Instrumented process control systems and instrumented safety systems should be implemented for the on-site production facility and the dispenser. The main control system should handle all instrumented process control functions. A high integrity PLC should be installed to handle any dedicated safety instrumented systems according to safety integrity requirements.

The on-site hydrogen production process may be fully automated and unattended. In case of an automatic shut down (PSD² or ESD³) the process can be restarted from a remote control unit or from the main control panel. However, all alarms or trips should have to be cleared out locally prior to reset and restart. Manual emergency shutdown buttons should also be installed to facilitate shut down in case of an emergency.

Instruments and gauges shall be designed and located such that, in the event of a leakage or rupture, and possible subsequent fire, the risk to personnel is minimised. The use of safety glass and blow-out backs on pressure gauges is recommended. The control facilities should be designed so that, in the event of a power or equipment failure, the system will go into a fail-safe condition.

If hydrogen gas detection instruments are provided for detection of gas leaks or a hydrogen fire, the following guidance is given (see also ISO/PDTR 15916):

Fire detection

Off-loading site fire detection and fire protection shall be provided. The fire detection system shall be capable of detection at multiple locations beyond the full radius of the transfer hose, measured at each point of transfer and receipt of LH2.

Only UV based detection methods will indicate the presence of a hydrogen fire. However, if the detectors are located outdoors, they can easily be confused by the presence direct sun light or sun light reflections. Also welding activities, even at long distances, may cause false alarms. Infrared detection devices will not detect the existence of a hydrogen fire.

² [Process shutdown](#)

³ [Emergency shutdown](#)

Gas detection

Gas detectors do not detect hydrogen fires; they only detect or monitor the gas concentration at a particular location. Hence, the correct placement of a hydrogen gas detector is critical to its ability to detect a hydrogen leakage. Changing air currents within a room, or changing wind direction outdoors, may also affect its ability to detect the presence of hydrogen.

Fixed detectors may have a slow response; e.g. while 10% LEL is detected 100 % LEL may exist at the leakage. Hand held detectors are often needed to find leakages.

When selecting a hydrogen gas detector, potential interference with other gases should be considered.

8.2 Safety distances

8.2.1 Introduction

One of the possible measures to be taken to reduce the risk or potential consequences of an incident involving an HRS, is ensuring sufficient distance between the ‘source’ of hazard and the ‘target’ of this hazard. The distance referred to here is generally called the ‘safety distance’.

In Figure 23 the concept of safety distances is schematically illustrated. The distance indicated in these figure is just an example, as safety distances will be determined by local circumstances. In this paragraph a method will be proposed to calculate these safety distances.

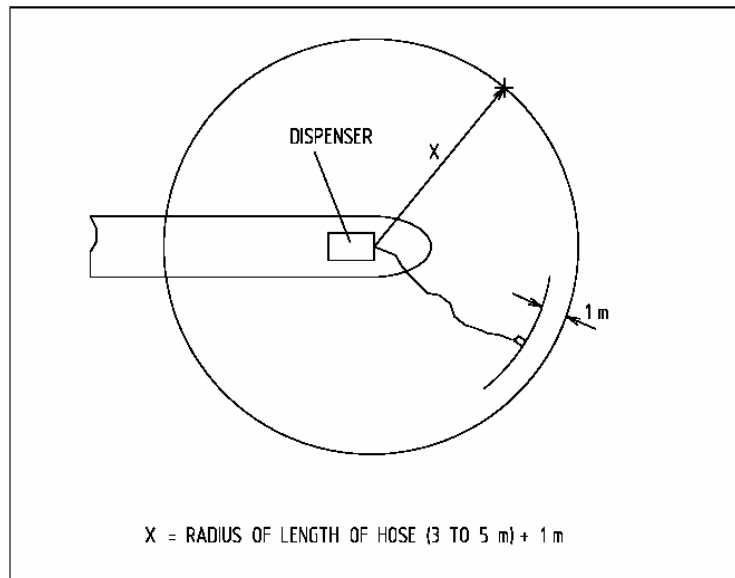


Figure 23: Safety distance of refuelling hose

For a common understanding of the concept of safety distance, a clear definition of this concept is required. An inventory among various parties and reference documents

has revealed that the word ‘safety distance’ may easily create misunderstandings. Depending on one’s comprehension, it may be understood as ‘how far should a person be from a hazard source in order to avoid getting hurt?’ or as ‘at which minimum distance should an activity be from a potential hazard source in order not to unleash this hazard?’.

For the determination of safety distances for hydrogen refuelling stations (HRS’s) in the scope of this Handbook, a concrete set or table of figures cannot yet be provided. It is recognised that concrete safety distances are reported in many standards and guidelines (see e.g. the overview given in HySafe document D26 as well as the more recent IGC Doc O6/02/E and IGC Doc 15/06/E). However, unless it can be demonstrated that the parameters and criteria used for the design and operation of an HRS fulfil the assumptions underlying safety distances as reported in these standards and guidelines, the suggested safety distances should be treated with great caution. As well established underlying design requirements are lacking at this stage and harmonisation still needs to be achieved, this may be difficult.

Therefore, in this HyApproval Handbook we will discuss the concept of safety distances in some detail and we will suggest harmonisation in definitions and requirements and propose methods and tools to derive such distances in a transparent way. As an example, a calculation will be performed on how to calculate a safety distance, based on data from a Quantitative Risk Assessment (QRA) on the reference HRS and some Computational Fluid Dynamics (CFD) calculations performed within the context of the HyApproval project, as shown in chapter 12 and appendices IV and V. Any values given in this chapter are merely shown as an example. They don’t necessarily reflect the state-of-the-art for today’s HRS’s.

8.2.2 *Definition of safety distance*

As outlined above the term “safety distance” is used in different ways. We suggest using the definition and calculation method for safety distance as proposed by the European Industrial Gases Association, EIGA, in document DOC 75/07/E, as (1) the method is known and supported within the “gas branch”, and (2) the method is in good agreement with concepts and criteria more widely used in safety assessments of installations with dangerous substances.

In this document safety distance is defined as:

“The minimum separation distance between a hazard source and an object (human, equipment or environment) which will mitigate the effect of a likely foreseeable incident and prevent a minor incident escalating into a larger incident”.

Crucial in this definition is the recognition of the presence of two prerequisites: there is a **source** and there is an **object** (or better: a **target**). As will become clear in the following, particular objects may both be a source of hazard as well as a target of another hazard. Since these different positions will require different separation distances in order to mitigate effects, it is proposed to set distinctive definitions for each type of ‘safety distance’.

Also important is the notion that safety distances are a means (among others) to prevent escalation. This puts focus on initiating events, which are minor with regard to the feared consequences of an escalation, and where a safety distance is the most effective and efficient method to prevent this outcome. Some escalation scenarios are best prevented by other means.

8.2.2.1 Source and target

A hazard source is an object (installation, equipment, construction, machinery, etc) that may create a hazard to its surroundings due to:

- An incidental release of hazardous material;
- Mechanical impact to the installation whereby kinetic energy may affect the integrity of the installation resulting in physical effects such as fire and explosion;
- External heat sources, especially fires, affecting the integrity of surrounding objects.

A hazard target is an object (installation, person, construction, etc) that may be exposed to the physical effect created by the hazard source.

Example 1: A leak in a part of the HRS (e.g. the dispenser hose) may create an explosive atmosphere or a jet fire, which may engulf vehicles within the refuelling station in a fire in case of ignition. In this case, the hydrogen installation (i.e. the dispenser) is acting as the source, while the vehicle is the target.

Example 2: A fire of a pool of spilled gasoline from a vehicle may create heat exposure to the hydrogen installation due to which the HRS equipment may get damaged. In this case, the hydrogen installation is acting as the target, while the gasoline pool (or actually: the vehicle) is the source.

Example 3: A leak in a part of the equipment in the HRS (e.g. the dispenser hose) may create a jet fire, which is directed to another part of the equipment of the same installation (e.g. the storage of compressed gaseous hydrogen, CGH₂). In this case, the hydrogen installation itself acts both as the hazard source and as the target. The definition of safety distances shall then be on equipment scale.

8.2.2.2 Terms used in the context of safety distances

From the examples above it may be clear that:

- In a given situation, an object can act both as a hazard source and as a target;
- The distance required to mitigate or prevent the exposure of the target would differ depending on what is the source and what is the target;
- In some occasions, the assignment of ‘source’ or ‘target’ may be on macro-scale (e.g. installation, building, activity), but in others a definition on micro-scale is necessary (e.g. vessel, piping).

In various regulations and industrial practices, this distinction is well recognised, but it lacks from clear definitions or terminologies for each type. The term ‘safety distance’ is often considered to cover all types. The following terms are frequently encountered, although not all of them are considered to fit in the scope of purpose of this document:

A. Hazardous area or hazardous zone

Hazardous areas or hazardous zones are discussed in some detail in paragraph 8.3. Thus, they need no further introduction here⁴.

B. Protection distance

The protection distance is the minimum distance required between the installation/equipment to be protected and the possible source of an external hazard (e.g. a fire) to prevent damage.

Here, the hydrogen installation is regarded to be the target, while external objects/activities are the source. The source may be both within the establishment, as well as outside the site boundaries.

Examples of sources of hazard are mainly involving fire, like:

- Presence of (liquid) combustibles, like gasoline storage or a spill of gasoline from a tank truck;
- Nearby building, particularly of wooden construction;
- Dry vegetation;
- Storage of oxygen or oxidisers;
- Nearby storage of combustible material like timber, paper, chemicals, etc.

Also, sources of mechanical impact shall be considered, like:

- Collision by a vehicle, either present at the refuelling station or passing by on a nearby road;
- Falling objects, e.g. roof fragments or billboards present at the station, in case of storm.

This list, of course, is not exhaustive.

C. Clearance distance

The clearance distance is the minimum distance between the potentially hazardous installation / equipment and the vulnerable objects within the establishment required to prevent damage or harm.

⁴ As part of work package 12 of the EU founded project HySafe phase 2 development of a best practice methodology for determination of hazardous zones for hydrogen installation will be developed based on IEC/EN60070-10.

Here, the hydrogen installation is regarded to be the source, while the surrounding objects are the targets.

Examples of targets that may be exposed to the hydrogen hazards (fire, explosion, fragments), are:

- People, particularly personnel of the HRS (1st party) and users of the HRS (clients, visitors, 2nd party);
- Other fuelling facilities within the establishment, like gasoline tank truck, gasoline storage, delivery facilities;
- Buildings, like the shop and company offices.

D. Installation lay-out 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.

Here, the H₂ installation is regarded to be both source and target. The main equipment units distinguished here are: H₂ delivery or production, H₂ storage and dispenser. Additionally, piping, vent lines and stacks, etc. might need to be treated similarly.

E. External risk zone

The external risk zone is the distance (or area) outside the establishment which has to be protected against the 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). The extent of the external risk zone is often determined by local / national requirements with respect to risk acceptance criteria, and may be based on a probabilistic approach or a deterministic one. Usually Risk acceptance criteria will be stricter for offsite targets, and less frequent incidents will have to be included in the evaluation. Thus external safety should be evaluated in a QRA

Examples of off-site targets are:

- Public, residing near the HRS or passing by the establishment
- School, hospital, office
- Shopping centre, market
- Vulnerable infrastructure

The table below summarizes the various concepts.

	Characterisation of safety distance	Source	Target	Examples	Remark
A	Hazardous area	HRS under normal operation			Safety distance concept not applicable
B	Protection distance	External hazard	HRS	Source: pool fire; collision; fragments	Safety distance shall mitigate / prevent secondary effects
C	Clearance distance	HRS	Objects within establishment	Target: HRS personnel and clients; HRS shop; gasoline facilities	Safety distance shall mitigate escalation of H ₂ incident
D	Installation lay-out distance	HRS equipment	HRS equipment	Source: dispenser; target: storage, electrolyser unit	Safety distance shall mitigate escalation within HRS installation
E	External risk zone	HRS	Objects outside establishment	Target: public; office; school.	Zone size shall mitigate off-site risks, thereby complying with statutory requirements. Concept difficult to align with safety distance

Table 7: Various concepts of safety distances

8.2.2.3 Specification of the scope of “safety distances”

According to the approach in EIGA document DOC 75/07/E, only categories B, C and D above clearly fall within the definition of safety distance.

Hazardous areas (category A) do not specifically consider targets, and are sufficiently defined elsewhere.

External Risk Zones (category E) are dependent on many factors, more particularly on local or national regulations with respect to acceptance criteria and environmental legislation. Moreover, the calculation of External Risk zones requires the assessment of many location-specific, often time dependent, external variables, many of which are outside the control of the owner / operator of an HRS. This makes the calculation of a unique (external) safety distance difficult, if not impossible. It is also stated in IGC Doc 75/-7/E that “*The safety distance is not intended to provide protection against catastrophic events or major releases...*”. Such events or releases are almost always dominant for external risks. Finally the EIGA definition of safety distance is based on (harm) *effect* rather than *risk*, which is the decisive criterion for External Risk. We shall therefore leave the concept of External Risk outside the definition of safety distance, as treated in this chapter.

However, risk to external parties, either expressed in terms of risk or as an effect distance is of prime importance in the approval process for an HRS. An example of such an assessment is shown in the QRA in Appendix IV.

8.2.3 Determination of safety distances

The following is cited from EIGA document DOC 75/07/E:

“The safety distance from a piece of equipment is to provide a minimum separation which will mitigate the effect of any likely event and prevent it from escalating into a larger incident. The safety distance will also provide protection for the equipment from foreseeable external impacts (e.g. roadway, flare) or activities outside the control of operation.

The safety distance is a function of the following:

- *The nature of the hazard (e.g. toxic, flammable, oxidising, asphyxiant, explosive, pressure, etc);*
- *The equipment design and the operating conditions (e.g. pressure, temperature) and/or physical properties of the substance under those conditions;*
- *Any external mitigating / protection measures (e.g. fire walls, dikes, deluge system, etc.) which reduce the escalation of the incident;*
- *The ‘object’ which is protected by the safety distance, i.e. the harm potential (e.g. people, environment or equipment).”*

The number of parameters that influence the required safety distance is large. This inhibits the inclusion of a simple table of numbers and figures. As long as technical standards for the HRS do not exist, a situation specific evaluation will be required, probably in each case of a planned erection of an HRS.

The site-specific determination of required safety distances (categories B to D) involves the following steps:

- Identification of foreseeable events that may lead to a loss of containment from the HRS. This identification includes the internal and external causes and the available preventive devices and mitigating measures for each cause;
- Determination of the likelihood (frequency) of these events and decision whether the event should be included in any further analyses;
- Assessment of the potential effects of the defined event on the target, in terms of physical exposure (thermal load, overpressure, duration, etc), and in terms of damage or harm (injury, fatality, window or wall collapse, etc). In IGC Doc 75/07/E a number of damage / harm criteria are defined (see below);
- Determination of the (safety) distance at which this damage / harm occurs;
- If necessary, consideration of additional prevention / mitigation measures to reduce this distance followed by recalculation of safety distance.

8.2.3.1 Identification of hazards and prevention and mitigation measures

The identification of credible accidents includes, as a minimum, an agreed set of Loss of Containment events for the HRS and an evaluation of the mitigating measures (controls, alarms, barriers) already in place. An example of such a set of accident scenarios for an HRS is shown in Table 8.

Sub-System or process item	Deviation to be considered for safety distance	Hazard Targets (T)/ Hazard Sources (S)	Potential consequences	Safety distance to be considered	Examples of Prevention /mitigation measures allowing to reduce/ eliminate safety distance	Current Practice /Comments
Gaseous H2 Dispenser	Minor leak	T: User	Burn injury if ignition	Users kept away at x meters of connection when fuelling is underway Area subject to safety restrictions (e.g. no smoking)	Specific coupling design validation program Leak test prior to each fill Trained users	Hose and connection are recognised as critical items Measures indicated as examples are common practice Dispensers may be designed with user interface located away from connection.
	Large leak at coupling - Hose failure - Hose disconnection	T: User	Lethal burn (flash fire) if ignition	Between user and connection when fuelling is underway	Specific design validation of coupling and hose Automatic shut-off limiting quantity of H2 released Frequent inspection of hose and connector	Measures indicated as examples are common practice
		T: Other station customers	Burn injury if ignition	Separation between dispensing areas		
		T: Shop area, Offices, Buildings	Explosive atmosphere build-up in building Fire	Distance to openings and air intakes		Separation is normal practice
		T: Construction in combustible material	Fire	Separation to avoid propagation of H2 fire		Separation is normal practice
		T: Stock of combustible material	Fire	Separation to avoid propagation of H2 fire		Separation is normal practice
		T: Flammable liquid/gas storage above ground	Fire impingement menacing structural integrity	Separation to avoid potentially severe domino effect		Separation is normal practice
		T: Flammable liquid/gas storage below ground	Possibly no impact	None		Separation not needed if no impact
		T: Public sidewalks – people outside facility	Burn injury if ignition	Minimum distance to public sidewalk		Separation is normal practice
		T: Site boundary – people and property	Burn injury if ignition/fire propagation	Minimum distance to site boundary		Separation is normal practice
S: Vehicle impact	H2 release due to equipment rupture	Safety distance not most effective measure	Up-stream isolation when not in use Prevention of risk of impact by plant layout Prevention of consequences of impact			

Sub-System or process item	Deviation to be considered for safety distance	Hazard Targets (T)/ Hazard Sources (S)	Potential consequences	Safety distance to be considered	Examples of Prevention /mitigation measures allowing to reduce/ eliminate safety distance	Current Practice /Comments
Vents	Ignition	T: People, buildings and property	Fire	Distance from vent outlet to targets eliminating hazardous impact		Separation is normal practice
GH2/LH2 process equipment	Leak	T: People on site	Burn injury if ignition	Area of restricted access	Proven industrial technology GH2 : Leak-tightness check by process (no pressure drop)	Restricted access to “back-office” systems is common practice
		T: Shop area, Offices, Buildings	Explosive atmosphere in building Fire	Distance to openings and air intakes		Separation is normal practice
		T: Construction in combustible material	Fire	Separation to avoid propagation of H2 fire		Separation is normal practice
		T: Stock of combustible material	Fire	Separation to avoid propagation of H2 fire		Separation is normal practice
		T: Flammable liquid/gas storage above ground	Fire impingement menacing structural integrity	Separation to avoid potentially severe domino effect		Separation is normal practice
		T: Flammable liquid/gas storage below ground	Possibly no impact	None		Separation not needed if no impact
		T: Public sidewalks – people outside facility	Burn injury if ignition	Minimum distance to public sidewalk		Separation is normal practice
		T: Site boundary – people and property	Burn injury if ignition/fire propagation	Minimum distance to site boundary		Separation is normal practice
Hydrogen storage systems	Leak	Same Targets as H2 process systems	As above	As above	As above	As above
		S: Equipment prone to fire hazards	Menace to structural integrity in case of fire	To avoid excessive radiation in case of fire	Thermal Shielding GH2 : Release of pressure	Separation is normal practice
		S: Stock of combustible material	Menace to structural integrity in case of fire			
		S: Other (smaller) storage of combustible material	Menace to structural integrity in case of fire			

Table 8: Qualitative overview of incident scenarios of an HRS

8.2.3.2 Event and threshold frequency

In document IGC Doc 75/07/E EIGA suggests to exclude events with an expected frequency less than 3.5×10^{-5} /yr from inclusion in calculations. This is called the threshold frequency F_t . The expected annual frequency includes:

- Frequency of initial deviation (F_d) (like leakage, external impact, etc., including failure of preventive devices and presence of ignition sources)
- Probability of the effect reaching the target (P_g) (e.g. probability of a jet pointing towards the target)
- Probability of failure of mitigating measures (P_m)

Hence for events for which $F_d \times P_g \times P_m < F_t = 3.5 \times 10^{-5}$ /yr no safety distance is required.

8.2.3.3 Assessment of effects

An inventory of potential effects, given the activities within the establishment, threats from outside the establishment, and the overall site layout, as well as the existing protection layers (barriers, fire proof walls) already in place.

The effects of each relevant event have to be assessed (quantified) by means of consequence modelling. For the various elements of an HRS the relevant effects would be heat load from fires (pool, jet, construction) and explosion overpressure. Models for calculation of heat load, pool evaporation, gas cloud dispersion for estimating the extent of LEL (Lower Explosion Limit), explosive pressure effect, etc. are available for these assessments, e.g. EFFECTS by TNO or PHAST by DNV, although validation for use with hydrogen has not always been performed.

For indicative purposes, graphs may be developed for typical extents of the effects, as a function of HRS type and inventory. Specific site conditions (lay-out, obstacles, ventilation) may require more sophisticated tools, like numerical CFD models.

8.2.3.4 Definition of acceptance (or harm) criteria

An effect distance is the distance from the hazard source to a location where a certain effect (or damage), such as death of a person or burns, can occur. Beyond this distance the effects will be less severe. The effect can strike both workers and users of the HRS. In the event of fire or explosion (the prime concern for an HRS), the heat radiation may be lethal, may cause burns, or it may cause damage to nearby structures or equipment.

Some typical harm effect levels frequently used to assess the effect of a fire are shown in Table 9.

The severity of the consequences will depend on the time of exposure. The consequences for people shown in Table 9 are typical for exposure times around 20 seconds. Consequences will be less severe for shorter exposure times and more severe for longer exposure times. In case of a flash fire, for instance, it is assumed that only persons inside the flame will be affected i.e. lethally injured. For those being outside the flammable area, the short duration of exposure to thermal radiation will not result in lethal burns.

Heat intensity [kW/m ²]	Consequence to people	Consequence to installations or structures
Direct flame contact	100% fatalities	Integrity of unprotected installation may be lost
35	100% fatalities	Domino effects; combustible materials (e.g. wood) will catch fire
10	1% fatalities	Temperature increase of installation inventory, resulting in pressure increase and failure
4 – 5	1% first degree burns Fire brigade can operate, in protective clothing	Glass structures and windows will break
< 1	Safe area	Safe situation

Table 9: Typical heat load criteria and related consequences frequently used in consequence assessments

The consequences mentioned for structures and installations generally apply for a more prolonged exposure. Though the specific conditions have to be taken into account, one may generally assume exposures of several minutes up to one hour before the secondary effects (i.e. catching fire) occur.

Fire integrity of supporting structure or main equipment heavily depends on design and specific protection measures like e.g. heat insulation. Detailed structural integrity assessments can be performed to optimise design and use of passive fire protection on potentially exposed parts of structure or equipment, thereby reducing safety distances without increasing the risk of escalation of an initial event.

For the external consequence area, often the 1% lethality criterion is used. For 20 seconds exposure duration, the corresponding heat radiation level equals approx. 10 kW/m².

Also the pressure effect caused by an explosion should be taken into account. At pressures exceeding 0.1 bar structures may be severely damaged which may result in casualties amongst persons in or nearby such structures. Therefore the distance at which this pressure level will occur should also be considered.

In IGC Doc 75/07/E, two harm or effect criteria are used:

- A “harm criterion” (defined as 1% chance of individual risk of serious injury or fatality)
- A “no harm” effect criterion

The “harm” and “no harm” criteria used for the calculation of safety distances (and relevant for HRS’s) proposed in IGC Doc 75/07/E are shown in Table 10. As can be seen the “harm” criteria are in good agreement with those shown in Table 9.

hazard	target	“no harm criterion”	“harm criterion”
(Prolonged) fire (pool, jet or other type of fire)	people	1.6 kW/m ²	9.5 kW/m ²
	equipment	-	37.5 kW/m ²
Flash fire	people	½ LEL	LEL
explosions	people	2 kPa	7 kPa
	equipment	-	20 kPa

Table 10: "Harm" and "no harm" criteria relevant for fire and explosions proposed for calculations of safety distances in IGC DOC 75/70/E

The relevant event frequencies and harm criteria according to IGC Doc 75/07/E are show in Table 11.

Event frequency	Safety distance
Event frequency > 3.5*10 ⁻³ /yr (=100 x Ft)	Distance “no harm”
3.5*10 ⁻⁵ /yr (= Ft) < Event frequency < 3.5*10 ⁻³ /yr	Distance “harm”
Event frequency < 3.5*10 ⁻⁵ /yr (=Ft)	No safety distance required

Table 11: Relevant event frequencies and safety distance criteria according to IGC Doc 75/07/E

8.2.4 Application to hydrogen refuelling station

In this chapter the proposed method for the calculation of safety distances, as described above (essentially the method described in IGC Doc 75/07/E), will be applied to an HRS. As outlined earlier, and will become clear throughout this paragraph, the results cannot be applied to any HRS. Installation-specific and site-specific assessments will be required on a case-by-case basis until standardisation has been achieved. Data from the QRA on a reference HRS (hereafter shortly referred to as “the QRA”) and data from the CFD calculations hereafter referred to as “the CFD calculations”) have been used as input in this paragraph. Hence all assumptions and (limiting) conditions mentioned in the QRA and CFD calculations are applicable here as well. Both the QRA and CFD results, but particularly the CFD calculations, are strongly affected by the chosen geometry and layout of the HRS.

8.2.4.1 Identification of events

Identified hazards for an HRS are:

- H2 – causing (vapour cloud) explosions (flash fires) pool fires (from liquid H2) and jet fires
- Other combustible material (shop, cars) causing fires
- External impact (cars)

From figure 8.1 and 8.2 in the QRA the relevant elements (of the reference HRS) for the safety distance can be extracted. These are shown in Table 12. Indicated is also whether such an element can be a hazard source (S), or a target (T). As can be seen

most elements can be both source and target. This will depend on the deviating event. For those elements that can be a source, the relevant deviations are shown and types of hazards they may create (fires – f, flash fire – ff, or explosion - ex) are shown. For the target elements the “harm” and “no harm” criteria are shown, with a distinction between equipment (E) and people (P), derived from Table 10. Explosions and flash fires will only occur after a built-up of an ignitable gas cloud of H₂ (i.e. leakage in confined spaces) and delayed ignition. Direct ignition will cause a jet fire. Other fires may be caused by combustible material as present in the service building (shop), customer cars, tanker trucks, in the vent stack, and by pools of liquid H₂ in case of (very) large leaks.

Element	Source or Target	If S: deviation	If S: Type of hazard ⁽ⁱ⁾	If T: Harm criterion	If T: No harm criterion
H ₂ – production (Electrolyser or reformer)	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Compressor	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Buffer storage for CGH ₂	S,T	leak	f	E: 37.5 kW/m ² , 20kPa	E:-
CGH ₂ dispenser	S,T	leak, ext. impact	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Evaporator	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Storage of LH ₂	S,T	leak	f	E: 37.5 kW/m ² , 20kPa	E:-
Vent stack	S,T	fire	f	E: 37.5 kW/m ² , 20kPa	E:-
Piping (gas)	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Piping (liquid)	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
Pump (liquid)	S,T	leak	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
LH ₂ dispenser	S,T	leak, ext. impact	f, ff, ex	E: 37.5 kW/m ² , 20kPa	E:-
LH ₂ Unloading area / LH ₂ tanker	S,T	leak	f	E: 37.5 kW/m ² , 20kPa	E:-
HRS service building / shop	S,T	Shop fire	f	E: 37.5 kW/m ² , 20kPa P: 9.5 kW/m ²	E:- P: 1.6 kW/m ²
Fence	T			E: 37.5 kW/m ² 20kPa P: 9.5 kW/m ² , LEL, 7 kPa	E: - P: 1.6 kW/m ² , ½ LEL, 2 kPa
Customer cars	S,T	Fire, ext. impact	f, ext. impact	E: 37.5 kW/m ² , 20kPa, undefined	E:-, undefined
People on site	T			P: 9.5 kW/m ² , LEL, 7 kPa	P: 1.6 kW/m ² , ½ LEL, 2 kPa

(i) f = fire, ff = flash fire, ex = explosion

Table 12: Overview of elements, deviations and consequences to consider during calculation of safety distance

From Table 12 all possible events (or accident scenarios) should be evaluated. For example, for the compressed gas dispenser the following scenarios should be evaluated (derived from event tree 1, appendix E of the QRA):

1. Leak – immediate ignition – shutdown failure – jet fire
2. Leak – immediate ignition – shutdown – short lived jet fire

3. Leak – no immediate ignition - shutdown failure (H2 accumulation) – delayed ignition - flash fire and explosion
4. Leak –no immediate ignition - shutdown failure (H2 accumulation) – no delayed ignition – no effect
5. Leak –no immediate ignition - shutdown (minor H2 accumulation) – delayed ignition - flash fire and explosion
6. Leak –no immediate ignition - shutdown (minor H2 accumulation) – no delayed ignition – no effect

In the QRA the following leaks were distinguished:

- Small leaks (0.1-5 mm)
- Large leaks (5-12 mm)
- Full bore ruptures

On the basis of the criterion that the event frequency should be larger than $3.5 \cdot 10^{-5}$ /yr, full bore ruptures can be dismissed on forehand (see table 10-1 of the QRA). This, for example, assumes implementation of a crash barrier, sufficiently effective to reduce the event frequency to a value below $3.5 \cdot 10^{-5}$ /yr. Of course this effectiveness should be assessed.

Therefore, for the evaluation of safety distances, two sets of scenarios were analysed: one for a small leak and its possible outcomes (S-1 thru S-6) and one for a larger leak (L-1 thru L-6).

Using the data presented in figure 1 and table 1 of appendix E plus table 10-1 of the main report of the QRA (Appendix IV of the handbook) the event frequencies for the 12 scenarios (i.e. small and large leaks) can be calculated. These are summarised in Table 13.

Scenario nr	Leak type / freq (1/yr)	Immediate ignition		Shutdown failure		Delayed ignition		Event freq.	criterion
S-1	Small leak / 3.30E-02	0.3	Y	0.15	Y	-	-	1.49E-03	harm
S-2				0.85	N	-	-	8.42E-03	no harm
S-3		0.7	N	0.15	Y	0.2	Y	6.93E-04	harm
S-4						0.8	N	2.77E-03	no effect
S-5				0.85	N	0.1	Y	1.96E-03	harm
S-6						0.9	N	1.77E-02	no effect
L-1	Large leak / 4.07E-03	0.4	Y	3.9E-03	Y	-	-	6.35E-06	no saf. dist. required
L-2				0.9961	N	-	-	1.62E-03	harm
L-3		0.6	N	3.9E-03	Y	0.25	Y	2.38E-06	no saf. dist. required
L-4						0.75	N	7.14E-06	no effect
L-5				0.9961	N	0.2	Y	4.86E-04	harm
L-6						0.8	N	no effect	no effect

Table 13: Event frequencies for leak scenarios for CGH2 dispenser, based on data from QRA for model station

In case of a jet fire (scenarios S-1, S-2, L-1 and L-2) the event frequencies should be attenuated by the probability of the jet hitting the target. This however can only be

done after calculation of the shape and size of the jet; hence after effect / consequence calculations are done.

For 8 of the 12 scenarios above, safety distances need to be calculated. As outlined earlier specialised calculation techniques, also used for QRA's, can be used for this purpose, as well as CFD methods.

From the QRA (Appendix IV of this Handbook) and CFD calculations (Appendix V of this Handbook) only a very limited number of pressure data, jet and cloud dimensions (i.e. distances to LEL) are reported⁵. No heat loads are reported, required for fires. For short-lived jet fires (immediate ignition but successful shutdown), however, criteria for flash fires rather than (prolonged) fires will be more appropriate, provided shutdown takes place only a few seconds after release.

On this basis, for the relevant criteria (i.e. “harm” and “no harm”) the (limited number of) distances that could be extracted from the QRA and CFD calculations are summarised in Table 14. A distinction is made between 35 and 70 MPa (350 and 700 bar) HRS's.

Scenario nr	Event freq.	effect	criterion	Relevant values	Distance for 35 MPa (350 bar) HRS	Distance for 70 MPa (700 bar) HRS
S-1	1.49E-03	Jet fire	harm	P: 9.5 kW/m ²	Not reported	Not reported
				E: 37.5 kW/m ²	Not reported	Not reported
				P: LEL	Not reported	4 m
				P: 7 kPa	Not reported	Not reported
				E: 20 kPa	Not reported	Not reported
S-2	8.42E-03	Short lived jet fire	no harm	P: 1.6 kW/m ²	Not reported	Not reported
				P: ½ LEL	Not reported	6 m
				P: 2 kPa	Not reported	Not reported
S-3	6.93E-04	Flash fire / explosion	harm	P: LEL	Not reported	Not reported
				P: 7 kPa	Not reported	Not reported
				E: 20 kPa	Not reported	Not reported
S-5	1.96E-03	Flash fire, explosion	harm	P: LEL	Not reported	Not reported
				P: 7 kPa	Not reported	Not reported
				E: 20 kPa	Not reported	Not reported
L-2	1.62E-03	Short lived jet	harm	P: LEL	Not reported	21 (19 m at 1.5 m height)
				P: 7 kPa	Not reported	Not reported
				E: 20 kPa	Not reported	Not reported
L-5	4.86E-04	Flash fire, explosion	harm	P: LEL	7 m	Not reported
				P: 7 kPa	Ca. 7 m	> 7 m
				E: 20 kPa	5.5 m	7 m

Table 14: Calculated safety distances for various events. Data from QRA (S-1, S-2 and L-2) and CFD calculations (L-5)

From the list of safety distances the longest distance should be selected as the safety distance belonging to this element of the HRS, thereby making a distinction between

⁵ The purpose of the QRA were to calculate the fatality risk for humans on site and off site. Hence, e.g. radiation levels are not reported as fires (as a simplification) are considered fatal to all people hit by flames or inside buildings, cars etc hit by flames, but otherwise not. Harm criteria for safety distances are more strict, and more detailed calculations are required for the events selected.

people and equipment as a target. Of course Table 14 should be completed before such a choice can be made. If the target is within this safety distance measures need to be taken or source and target should be further separated. Measures that can be taken may be mitigation measures (those limiting the effects, e.g. a fire wall) or preventive measures (those limiting the event frequency, e.g. reducing the probability of ignition).

In this example case, for instance, the safety distances will be unacceptable. For instance a distance of 19 m between a person and the dispenser (in case of a jet fire) will be unacceptable, as customers and their cars will be much closer to the dispenser. The best way to reduce the safety distance for the dispenser is by taking (more or better) preventive measures that reduce the event frequency to negligible values (i.e. a value below $3.5 \cdot 10^{-5}$ /yr), by reducing the leak frequency (e.g. better coupling design, leak test prior to each fill, trained users) and/or the probability of ignition.

Finally it should be stated that many of the data (like failure frequencies, ignition probability) and calculation models are derived from other applications than those involving hydrogen. It is therefore important to collect data and to validate models for hydrogen applications.

8.3 Hazardous areas

The hazardous area is the area around an installation where a flammable / explosive atmosphere may be present that is inherent to the properties and activities of that installation. Thus, in these areas activities are restricted or subject to special precautions (e.g. no bare flame, work permit)

The figures below provide examples of hazardous area classification around dispenser and process equipment. For comparison the concept of safety distance is shown also. Safety distances shown are just examples as their value depends on local conditions, as outlined in paragraph 8.2.

REFUELLING STATION PLANT
WITH BUILDING OR ENCLOSURES
PLAN VIEW

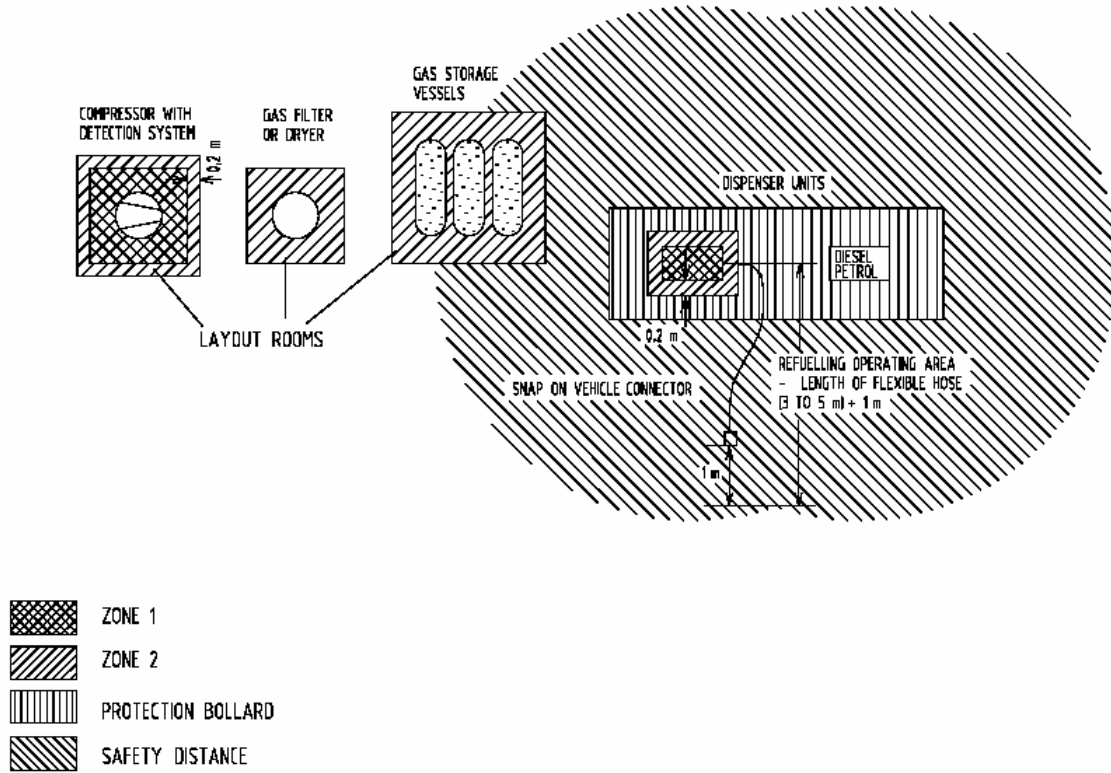


Figure 24: Safety distances and hazardous zones – example 1

REFUELLING STATION IN OPEN AIR

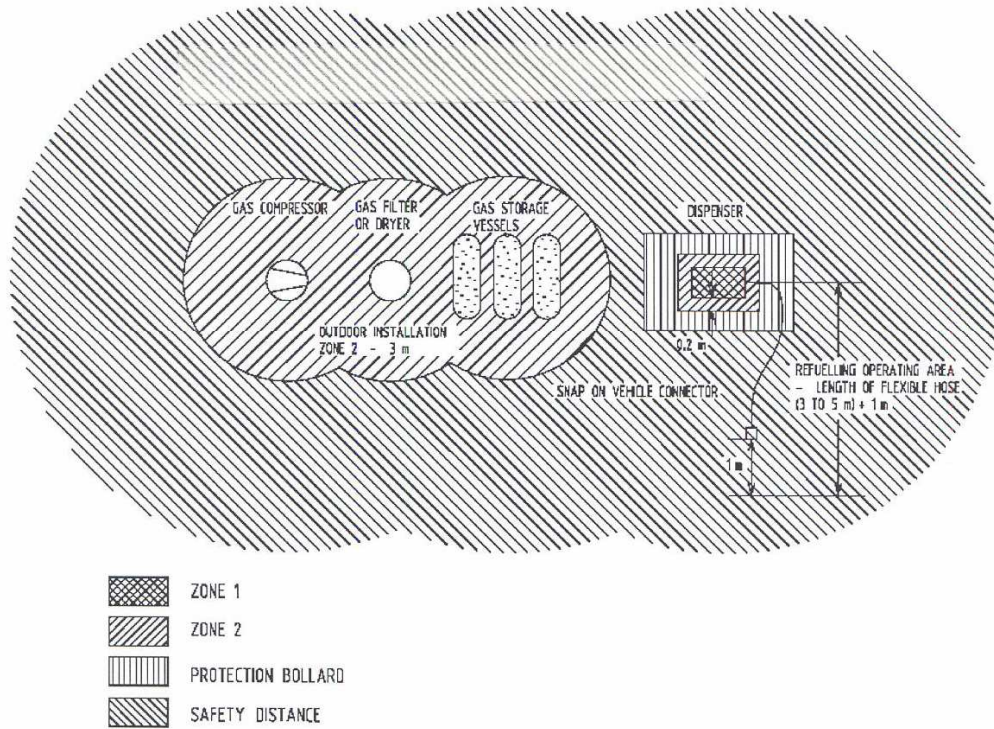


Figure 25: Safety distance and Hazardous areas – example 2

REFUELLING STATION PLANT WITHIN
EQUIPMENT OR ENCLOSURES/BUILDINGS.
FRONT VIEW

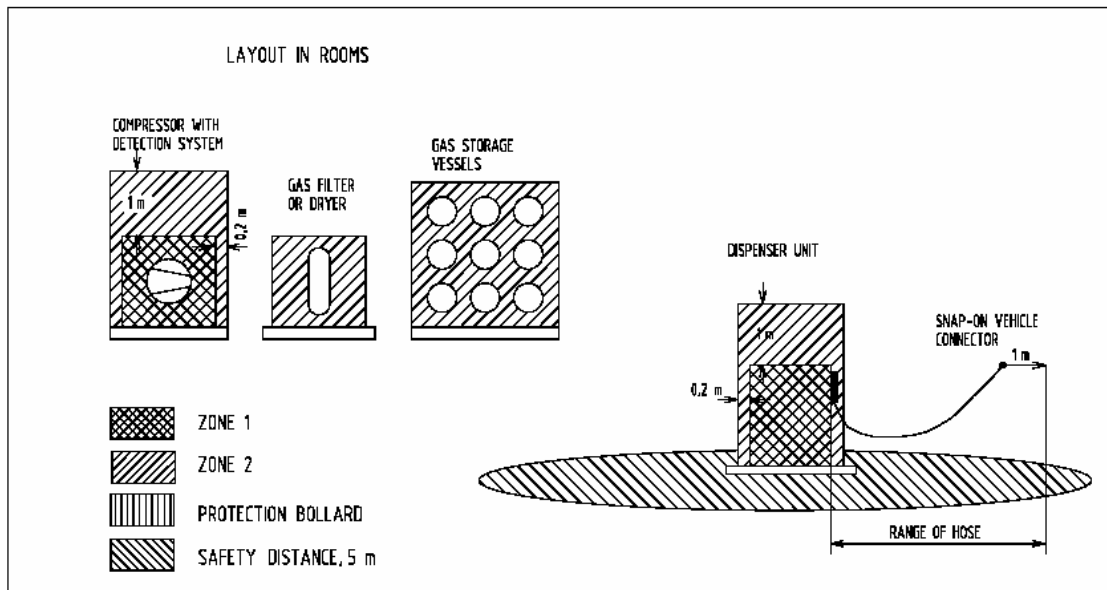


Figure 26: Safety distance and Hazardous areas – front view

Determination of the hazardous area – usually in a three-dimensional shape – is done on the basis of the foreseeable quantity that can escape and the likelihood of occurrence. It gives the zone where specific care should be taken in order to avoid the presence of ignition sources and to provide explosion-proof equipment and smoking prohibition.

This concept is covered by the ATEX regulations (ATEX Directive 94/9/EC), the IEC standard and European Norm IEC/EN60079-10 “Electrical apparatus for explosive gas atmospheres. Part 10 Classification of hazardous areas” and for the USA in NFPA 70 “National Electrical Code, Article 500”. These are widely acknowledged international standards/norms. Harmonisation and application is considered sufficiently implemented by these standards.

8.4 HRS plant level recommendations

8.4.1 Site selection and HRS lay out

8.4.1.1 Site selection

It is possible for the dispenser posts of Hydrogen to be located within the operating area of a public petrol station or a refuelling station. Their operating areas may overlap.

All hydrogen filling station installations shall be situated in open air. Indoor refuelling is not permitted. For any underground installations additional requirements shall be considered.

The installation shall not be located beneath or near electric power cables, piping containing all classes of flammable and combustible liquids, piping containing other flammable gases, or piping containing oxidizing materials. Care shall be exercised with regard to location relative to sources of fuel, such as pipelines or bulk storage containing other flammable gases or liquids or other potential hazardous substances that could jeopardize the integrity of the installation.

All hydrogen refuelling stations shall be located so that it is readily accessible for product supply and distribution vehicles, fire fighting services and easy escape routes in case of an emergency. In cases where personnel could be trapped inside the station, there shall not be less than two separate outward opening exits, remote from each other, strategically placed in relation to the degree of hazard considered.

Barriers or bollards, to eliminate vehicular impact, shall suitably protect the installation. Precautions, such as the erection of safety barriers or fences, shall be taken to protect against damage during the manoeuvring of any hydrogen supply unit and by unauthorized tampering. HRS that is permitted to be unattended shall be designed to secure all equipment from tampering.

Fencing is required for parts of the refuelling station, which are not open for the public to prevent access of unauthorized persons where other means are not provided. Where fencing is provided, the minimum clearance between the fence and any installation shall be 0.8m to allow free access to and escape from the enclosure. The height of the fencing should be at least 2m. Timber or other readily combustible materials shall not be used for fencing.

All gates shall be outward opening and wide enough to provide for easy access and exit of personnel.

Any firebreak walls or partitions shall be made of brick, concrete or any other suitable non-combustible material of 90 minutes rating.

Consideration shall be given to the proximity of other activities or buildings containing process equipment, where there is a potential fire or explosion hazard.

All HRS or refuelling facilities shall have permanent lighting at points of transfer and operation. The lighting shall be designed to provide illumination of all parts of the station. Emergency lighting shall be provided.

Site preparation shall include provisions for retention of spilled LH2 and other materials within the limits of plant property and for surface water drainage. Enclosed drainage channels for LH2 shall be prohibited if applicable.

Roadways and yard surfaces at the station shall be constructed of non-combustible materials, especially the surfaces located below liquefied hydrogen piping as well as areas located under the fill connections and delivery vehicles. Uninsulated hydrogen piping from which liquid air is able to drip, shall be constructed of non-combustible materials. Asphalt and bituminous paving shall be assumed to be combustible.

8.4.1.2 System arrangement

A hydrogen station with on-site production of hydrogen consists typically of:

- Feed Pre-treatment
- Hydrogen production unit (electrolyser or natural gas steam reformer)
- Gas purification
- Hydrogen compression
- High-pressure storage
- Dispenser
- Utilities (cooling water, inert gas, power supply, etc.)

System arrangements for on-site production of hydrogen by water electrolysis and by natural gas reforming are discussed below.

Hydrogen generation by water electrolysis

Typical sketch of a hydrogen refuelling station with on-site production of hydrogen by water electrolysis is shown in the next figure:

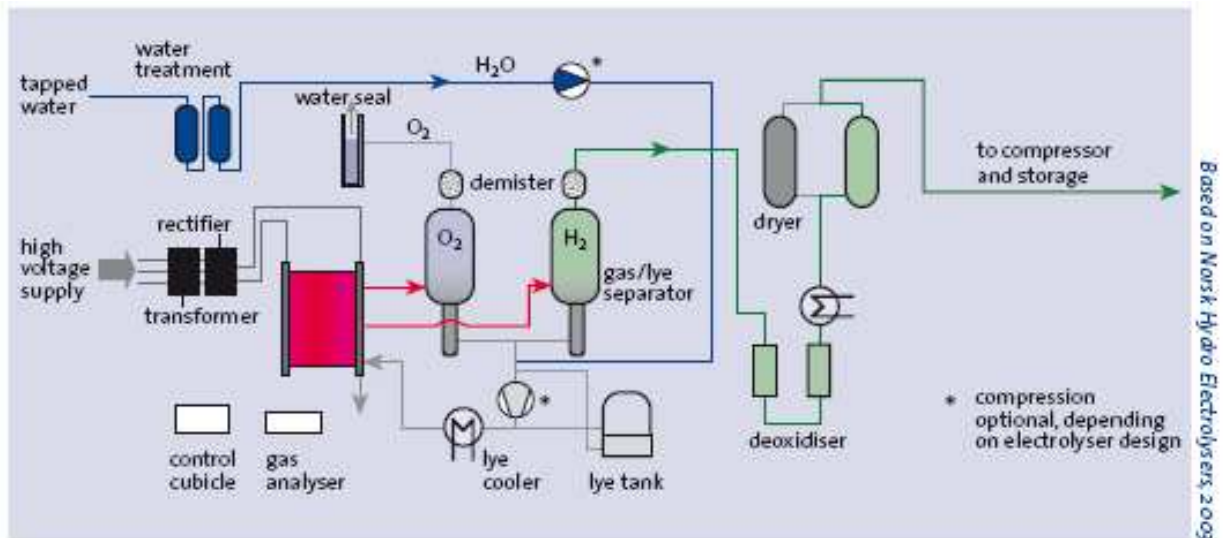


Figure 27: Ref CUTE

Feed pre-treatment

The feed pre-treatment consist of a water purification unit and lye preparation. The feed-pre-treatment units should be located close to the electrolyser.

Hydrogen production unit - electrolyser

The hydrogen production process consists of an electrolyser, which is supplied with feed water, to which a DC current is applied. The incoming AC main supply is stepped down to a lower voltage and rectified to DC and supplied to the electrolyser. The process generates hydrogen and oxygen in the ratio of 2:1. The produced oxygen is normally released to the atmosphere after a pressure control valve.

The oxygen route, pipelines, equipment and outlet shall be subject to special consideration taking into account the reactive properties of oxygen.

The electrolyser and the power supply, transformer and rectifier shall be designed according to current regulations and acknowledged standards and codes.

Electrolysers shall comply with ISO 22734-1

Gas purification

Downstream the hydrogen production, gas purification equipment is included for removal of oxygen and moisture. Oxygen is removed by deoxidizing; water moisture is removed by water vapor absorption. Normally a twin tower dryer is used.

The purified hydrogen gas is fed into a compressor to compress the gas to the specified pressure.

An inert gas supply system, e.g. nitrogen or argon, shall be available for purging purposes.

The hydrogen production unit, including the transformer, rectifier, and gas purification should be located inside an enclosure. The enclosure should be divided into different compartments separated by a steel wall: one compartment for the process units and one compartment for DC power supply and control system.

The process unit compartment should contain the electrolyte system, the cooling water system, the feed water system, the electrolyser, the dryer system and the inert gas valve panel. The control room compartment may contain the transformer, the rectifier, control panels with PLC (programmable logic controllers), MCC (Motor Control Center), fire and gas control functions. A local operation panel should be located inside the control room compartment. Communication with remote control units should be established.

Hydrogen compression

The produced hydrogen is compressed to 350 – 700 bar prior to refuelling of the vehicle tanks.

The compressor should be supplied by an approved supplier and delivered as a complete skid mounted package including a complete instrument package to ensure safe and reliable operation. The compressor skid should be located as a separate unit.

The type of compressor may vary. All types of compressors are acceptable provided that they have been designed with particular reference to hydrogen service. Any vibrations from the compressor shall not be transferred to the pipe work.

Safety controls shall be installed to ensure that temperature and pressure levels do not exceed or fall below set operating levels.

Important compressor requirements are related to the specified gas pressures and the fact that the hydrogen gas shall maintain oil-free. Oil free diaphragm compressors or hydraulic compressors are alternatives.

To take care of regulation of the production capacity a suction buffer tank should be included upstream of the compressor, located outside the compressor enclosure.

Hydrogen high-pressure storage

The compressed hydrogen should be transported in a pipeline to high-pressure storage vessels.

The vessels are divided into several vessel banks, a high-pressure bank, a medium-pressure bank and a low-pressure bank. This arrangement will allow a three stage "cascade filling" of vehicles. A two-stage cascade filling system combined with a booster compressor, or a multiple stage cascade filling system with more than three pressure banks are other options. Each vessel bank should be equipped with its own pressure relief devices and pressure monitoring instruments.

The storage pressure is typically 35 – 80 MPa (350 – 800 bar).

A gas distribution valve panel for distribution of gas from the compression unit to the storage tanks and from the storage tanks to the dispenser should be located inside an enclosure, e.g. inside the compressor enclosure.

The pipeline transferring the hydrogen from the gas distribution panel to the dispenser enclosure may be located in a duct, below ground, or above ground on a pipe rack. If located in a culvert, the “roof” of the culvert should be a grating to achieve good ventilation in case of releases inside the culvert.

Inert gas system

Prior to start-up and at process deviations that lead to shutdown with depressurization, the electrolyser shall initiate automatic purging of the pipes and equipment with inert gas, e.g. nitrogen or argon.

Purging may also be carried out manually, by coupling nitrogen to specified connection points.

The inert gas for purging is normally taken from gas bottles. The inert gas bottles should be located close to the production facility.

Hydrogen generation by gas reforming of hydrocarbons e.g. natural gas

Reforming is the process of transforming hydrocarbons into hydrogen. The process takes place in three main stages (see next sketch) (i) reforming, (ii) water-gas shift, and (iii) purification.

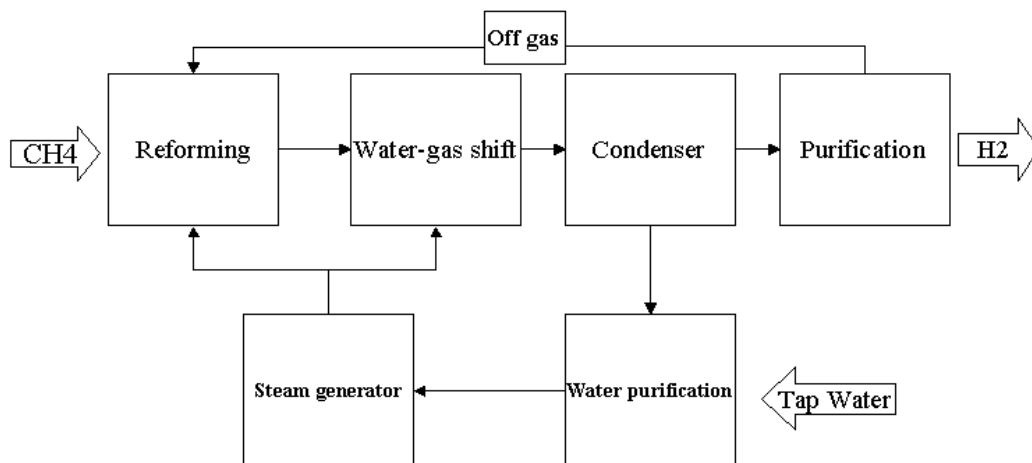
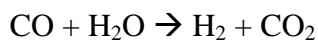


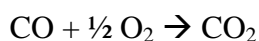
Figure 28: Schematic of natural gas reforming process for hydrogen production

In the first stage (reforming), and depending on the type of reactor, natural gas feedstock reacts with steam (in a steam reforming reactor, SMR) or oxygen (in a partial oxidation reactor, POX) to produce a synthesis gas (synthesis gas) that is composed mostly of H₂ and CO. In the second stage (water gas shift), the synthesis gas reacts with steam and produces more hydrogen according to the reaction:



The produced gas is 50-60% hydrogen rich, the rest is composed of CO₂, CH₄, H₂O and a fraction of CO (0.5-1%). Surplus water from the gas exiting the shift reactor is condensed and recycled. Very often, removal of organic compounds and dissolved CO₂ is necessary prior to sending water back to the steam generator unit.

In the last step (purification), dry reformat is either sent to a purification unit or to a preferential-oxidation reactor, depending on the intended use for hydrogen. For industrial hydrogen, that requires a purity of 99.999%, Pressure-Swing Absorption (PSA) is the technology of choice for hydrogen production capacities of 50-1,000 Nm³/hour. Palladium membrane is another alternative but has been considered uneconomic for production capacities above 10 Nm³/h. For fuel cell applications, a preferential-oxidation process is normally applied to reduce the CO content to a few ppm.



The reforming process is flexible with respect to feedstock. Fossil fuels like LPG and naphtha have been used commercially as feed for steam reformers. POX reformers have been operated with heavy fraction of fossil fuels like diesel and heating oils as feed. Reforming processes have been developed for partial oxidised compounds like dimethylether and methanol. These compounds are easier to reform than hydrocarbons and less heat transfer is involved. These simplify the process design and these technologies are in some locations competitive despite high feed costs.

Catalytic reformer processes are sensitive to impurities in the feeds. Purification of the feed is important for the performance of the reformer and downstream units. Water need to be treated to avoid fouling of steam generator facilities as well as catalysts. Catalytic ATR and Pox units will in some locations require purification of incoming to avoid poisoning of the catalytic systems.

Many concepts have been proposed for CO₂ capture from large scale reformers. The same principles can be applied for small scale reformers. However, little attention has been paid on cost effective scale down of these processes. New reformer concepts have been launched to reduce the CO₂ avoidance cost like thermo catalytic cracking, sorbent enhanced reforming and cyclic auto thermal reforming.

In the following a detailed review of the technologies for reforming of hydrocarbon is given. Focus has been on commercial and semi-commercial process developed for the hydrogen filling station market.

The following technologies are used in current plants for reforming hydrocarbons to hydrogen:

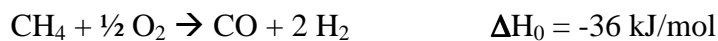
Steam reforming

The steam reforming (SMR) is the most widely applied reforming technology. The reaction is endothermic and requires external heat supply:



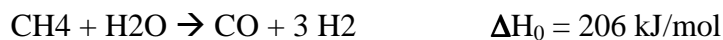
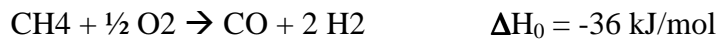
Partial Oxidation

In Partial Oxidation (POX), methane is oxidized to produce carbon monoxide and hydrogen according to the following reaction:



Auto thermal reforming

Auto thermal reforming (ATR) combines partial oxidation and steam reforming reactions in a single reactor where natural gas is mixed with both steam and oxygen (or air):



8.4.2 Identification of and access to Hazard Zones

The extent of the hazard zones shall be indicated by permanent notices, particularly at access points, or by distinctive lines painted on the ground. Notices shall indicate the nature of the hazard, e.g.

HYDROGEN - FLAMMABLE GAS
NO SMOKING - NO NAKED FLAMES

Only authorised personnel shall be allowed to enter these zones. These personnel shall be aware of the hazards likely to be encountered and the relevant emergency procedures. Any work other than that directly connected with operating the station shall be covered by a Safety Work Permit system.

8.4.3 Building

Buildings in which hydrogen systems are installed shall be of single story construction, designed for the purpose of use and be well ventilated with outlets at the high points. The degree of enclosure should be at a minimum level consistent with providing a reasonable working environment in relation to local weather conditions.

Adequate measures shall be taken to ensure that hydrogen cannot penetrate into service ducts, electrical wiring, electrical conduits, staircases and passages that connect to locations that are designated as safe areas, i.e. outside the hazard zone.

Buildings used for hydrogen operation shall be of a fire resistant construction as determined by applicable codes or regulations. A safety plot plan shall be worked out, including escape routes.

Doors that do not have direct access to the outside shall be of a fire resistant construction and shall be self-closing.

Explosion relief shall be provided only in the exterior walls or roof and should be designed in such a way that if an explosion occurs, the resulting pressure will be relieved without the explosion relief system emitting dangerous projectiles.

The total relieving area should not be less than either the area of the roof or the area of one of the longest sides. This area may consist of any one or a combination of the following;

- An area open to the outside,
- Outward swing doors in exterior walls,
- Lightly fastened hatch covers,
- Light roof design.

Lighting shall be provided that is of an adequate intensity for all enclosures and operating areas so that, at all times operations can be carried out safely. The lighting equipment shall be suitable for use in hydrogen areas.

Where heating is required, it should preferably be by hot water or warm air. Where re-circulation systems are used, consideration shall be given to the possibility of hydrogen contamination and adequate precautions shall be taken. The heat sources shall be located remote from the buildings.

The building or enclosure shall have good low and high-level natural ventilation to the open air. Outlet openings shall be located at the highest point of the room in the exterior walls or roof.

In areas where natural ventilation is not possible, consideration should be given for the installation of permanent hydrogen detection. This detection equipment shall be at suitably located point(s), considering the design of the natural and/or forced ventilation system.

8.4.4 Hydrogen gas detection and hydrogen fire detection

The principles and considerations for the detection of hydrogen gas and hydrogen fire are mainly extracted from the ANSI/AIAA Guide to Safety of Hydrogen and Hydrogen System (G-095-2004) (former NASA document NSS (1740.16, 1997)).

8.4.4.1 Hydrogen gas detection

Hydrogen is colourless, odourless, and therefore the gas is not detectable by human senses. Well-placed, reliable hydrogen detectors are imperative for a safe installation. A leak or spill of hydrogen shall be recognised by the use of hydrogen detection systems in enclosures where hazardous accumulations may occur. Examples of enclosures are the cabin of a hydrogen production unit and the compressor unit, the dispenser unit and the canopy of the hydrogen fuelling station. In open-air situations, measuring of hydrogen gas is not sensible. Hydrogen gas detection shall be followed

by alarm signals, automatic procedures to shut-off and isolate (parts of) the hydrogen system and pre-determined actions to be taken by the responsible employee.

The measuring of hydrogen with commercially available hydrogen sensors is based on various principles for instance: catalytic combustion sensors, electro chemical sensors, semi conducting oxide sensors and thermal conductivity detectors. Characteristics such as minimum detection limits, response time, power requirements and applicability in a defined gas environment are presented in ANSI/AIAA Guide to Safety of Hydrogen and Hydrogen System (G-095-2004).

8.4.4.2 General considerations for hydrogen detection systems

1. Requirements regarding hydrogen sensors to be specified are:
 - The minimum gas concentration detection requirements,
 - Full scale range of the detector system,
 - Level of concentration for which alarm detection is required,
 - Response time,
 - The accuracy,
 - The operating temperature,
 - The selectivity and the sensitivity for interference gases such as hydrocarbons,
 - Reliability and recalibration frequency and
 - The interface to facility safety and shutdown systems.
2. The time for detection, transmission and display of a hydrogen concentration shall be as short as possible. The USA National Renewable Energy Laboratory (NREL)⁶ proposes a response time for hydrogen safety sensors < 1s. Compatibility with the responding safety system shall be ensured.
3. The measurement range of hydrogen sensors is related to the hydrogen concentration level at which succeeding steps (such as alarm and shut-off actions) shall be taken. Visual and audible alarms shall be provided when the worst allowable condition is exceeded. The allowable condition must still be in the safe range: the warning indicates a problem. An example: alarm signal at 10% of the Lower Flammability Level (0,4% H₂ in air) and shut-off at 25% of the Lower Flammability Level (1% H₂ in air). The NREL proposes a measuring range for hydrogen safety sensors of 0.1 -10 % H₂ in air.
4. Detection units shall not be ignition sources.
5. The number and distribution of detection points is related to possible leak rates, ventilation conditions and the volume of the enclosed location. In enclosed area's, generally, the inlet of air shall be on the lowest possible level, the outlet of air on the highest possible level on the opposite side. By this configuration, the flow of air is routed through the enclosed area. The

⁶ Source : Proceedings of the 2002 U.S. DOE Hydrogen Program Review NREL/CP-610-32405: Interfacial stability of thin film fiber-optic hydrogen sensors. NREL.

hydrogen sensors shall be positioned near the ceiling or at the highest level, where accumulation of hydrogen can be expected.

6. Detectors shall be maintained and periodically recalibrated to ensure acceptable performance.
7. The appropriate hydrogen detections system shall be used when explosion suppression techniques using inert gas purges are installed.
8. A 1% by volume hydrogen concentration in an exhaust purge should generate an alarm. A higher hydrogen concentration at a purge exhaust indicates a major leak or fire hazard after the purge is exhausted in air.

8.4.4.3 Hydrogen fire detection

Hydrogen flames are not visible during daylight conditions. For remote operations the continuous monitoring of locations where hydrogen fires may occur (for instance vents, safety release valves) shall be considered. For continuous monitoring thermal fire detectors and optical sensors for detecting hydrogen fires are applicable. These detectors can be equipped with an alarm function.

For locating small hydrogen fires a broom may be used. The dry straws of the broom ignite as it passes through a flame.

8.4.4.4 General considerations for hydrogen fire detection systems

1. The radiation from the sun can overpower the hydrogen flame emission, resulting in an invisible flame during the day, in the visible spectrum. Therefore, the fire detection should not be susceptible to false alarms from the sun, lightning, welding and lighting sources (applies especially for optical sensors).
2. Hydrogen fires emit radiation over a broad spectral range, which means that no extreme peaks for hydrogen appear. Also radiation of the hot water molecule is measured by the sensor. This should be kept in mind when optical sensors for detecting hydrogen fires are used.
3. The minimum distance to the flame and length of the flame to be detected by the fire detection system shall be specified.
4. The fire detection system response time is to be specified based upon the prevention of loss of function, equipment and protection of people.

8.4.5 Fire prevention and fire fighting

8.4.5.1 General

The essentials of fire prevention are to:

- Minimise all potential sources of leaks,
- Eliminate, as far as possible, all sources of ignition, and
- Make provision for isolation of hydrogen, means of escape and methods of controlling any fire.

Smoking, fires and open flames of any kind are prohibited within the areas defined in § 8.2. Warning notices shall be clearly posted in accordance with § 8.4.2.

Adequate means of giving alarm in the event of a fire shall be provided. These should be clearly marked and suitably located.

Full emergency procedures shall be established for each particular installation in consultation with the local fire authorities and periodic drills should be carried out.

Adequate means of escape in the case of emergency shall be provided. In cases where personnel could be trapped inside compounds or buildings there shall be not less than two separate outward opening exits, remote from each other, strategically placed in relation to the degree of hazard considered.

Emergency exits shall be kept clear at all times.

The area within 3 metres⁷ of any hydrogen installation shall be kept free of dry vegetation and combustible matter. If weed killers are used, chemicals such as sodium chlorate, which are a potential source of fire danger, should not be selected for this purpose.

Water shall be available in adequate volume and pressure for fire protection as determined in consultation with the relevant authorities.

Maintenance or repair work shall only be carried out after the relevant parts of the plant, or area, have been checked and a Safety Work Permit has been issued by a competent person. This is particularly important where such maintenance work introduces an ignition hazard, e.g. welding.

For liquid hydrogen storage it is important that when water is used to keep equipment cool and that careful control is exercised. Water should not be sprayed near relief valve vents or vent stack outlets due to the potential danger of plugging vents with ice.

8.4.5.2 Fire fighting equipment

The location and quantity of fire fighting equipment shall be determined, depending on the size of the hydrogen station and in consultation with the local fire authorities.

The equipment shall be periodically inspected. The inspection date and the result should be recorded.

Personnel shall be trained in the operation of the equipment provided.

Means to cool down hydrogen storage vessels that could be exposed to fire shall be available.

Extinguishing of a hydrogen leak fire shall be attempted only if subsequent re-ignition is not a hazard. In this case Monex powder extinguishers are effective. CO₂ extinguishers shall not be used, as CO₂ ice particles may become a source of ignition due to static electricity build-up. Many fire extinguishers are not effective on a hydrogen fire.

⁷ EIGA IGC Doc 15/06/E mentions 3 m. The NFPA 55: 5 m (also applicable for high pressure (70 MPa - 700bar) applications?) NFPA 50-B: 7.6 m for LH₂.

8.4.5.3 Action in event of fire

Most hydrogen fires from high-pressure systems originate at the point of discharge and the flame will have the characteristic of a torch or jet. Such fires are extremely difficult to extinguish.

The most effective way to fight a hydrogen fire is to shut off the source of hydrogen supply, provided this can be done safely.

Where hydrogen cannot be isolated, hydrogen fires should not be extinguished whilst the flow of leaking hydrogen is continuing, because of the danger of creating an explosion hazard more serious than the fire itself. Surrounding equipment, when necessary, shall be cooled with water jets or sprays during the fire.

Hydrogen flames are almost invisible and the approach must be made with caution, a flammable material such as paper or cloth affixed to a fire retardant rod can be used if necessary to detect a flame boundary.

The following are guidelines, which should be used for formulating emergency procedures:

- Raise the alarm;
- Summon help and fire fighting services;
- Wherever possible, and it is safe to do so, turn off valves to cut off the source of hydrogen supply;
- Wherever possible, and it is safe to do so, move gas cylinder away from fire area; beware of potential burst of gas cylinders exposed to fire;
- Evacuate all persons from the danger area, except those necessary to deal with the emergency;
- Always approach any fire from the windward direction;
- Cool adjacent objects, from a distance and preferably unmanned;
- Avoid transmittance of the fire to buildings nearby;

For further details see 9.2.

8.4.6 HRS emergency shut down

An important preventive measure is emergency shut-down. It is important that the shut down philosophy is made clear thereby making a distinction between;

- Emergency shut down (complete shut down with local depressurisation - triggered by fault such as loss of ventilation, gas detection, manual action, ...);
- Ultimate emergency shut down (complete shut down with depressurizing of all equipment including buffer storage - ultimate shut down triggered by fire on buffer storage or by manual stop).

Shut down is initiated in case a threshold level (temperatures, gas concentrations, gas flows, pressure levels, fire detection) is exceeded, which is continuously measured by detectors and sensors. In this case IEC 61508 is recommended (Functional safety of

electrical/electronic/programmable electronic safety-related systems by the International Electro technical Commission).

8.4.7 Security

Gaseous hydrogen

Precautions, such as the erection of safety barriers or fences, shall be taken to protect against damage during the manoeuvring of any hydrogen supply unit and by unauthorised tampering.

Where the storage installation area is not under the direct control of authorised persons, it shall be contained within a secure, locked enclosure and the key held by an authorised person.

Liquid Hydrogen

Fencing is required to prevent access of unauthorised persons, where other means are not provided. On controlled sites with sufficient supervision, fencing is optional.

Where fencing is provided the minimum clearance between the fence and the installation shall be 0.8m to allow free access to and escape from the enclosure.

Timber or other readily combustible materials shall not be used for fencing. The height of the fencing should be at least 2m.

Gates shall be locked during normal operation.

8.5 Specific recommendations

8.5.1 On-site production

Refer to applicable standards in chapter 7.3.1.1.

8.5.2 Pipeline interface

A hydrogen refuelling station may be directly connected to a hydrogen production plant via a pipeline. The pipeline internal diameter is typically 150 mm. Depending on the operator and the status of the installation the pipeline pressure varies typically from 2 to 10 MPa (20 to 100 bar). GH₂ has therefore to be compressed to the desired pressure at HRS level.

In general gaseous hydrogen supplied by pipeline is for industrial (e.g. chemistry) application. Gas purity may not be compatible with an application in vehicles. Gas analysis and potential purification has to be carried out at HRS level.

The pipeline interface shall be earthed and bonded to give protection against the hazards of stray electrical currents and static electricity.

General requirements concerning piping are provided in chapter 8.1.1.

Regulations, codes and standards applicable to pipeline are listed in § 7.3.1.2.

8.5.3 Hydrogen dispensing

The dispenser has to be located outdoor, at point of use. If the dispenser is covered by some kind of roof, the roof shall be designed to prevent H₂ accumulation under the roof. Natural ventilation will limit the risk of build up of large ignitable gas clouds.

8.5.3.1 Gaseous Hydrogen buffers

Gaseous dispensers usually include high-pressure buffer storages for fast dispensing. These vessels can be grouped into single storage banks at different pressure levels and different size. The single storage banks do not need to be separated from each other by a safety distance. Each group of storage banks is equipped with its own set of safety devices, independent from the other group. The storage vessels shall be permanently fixed according to the specifications of the manufacturer. Means shall be provided to protect them against physical damage.

8.5.3.2 Safety valves

Safety valves are used to prevent an over pressurization of the vehicle tank system. The overall maximum filling pressure for the vehicle tank system shall be limited to 1,25 x 1,1 x NWP (Nominal Working Pressure). Presence of safety valves shall be documented, together with their cracking pressure.

8.5.3.3 Enclosure

The enclosure shall be weather protected with no sharp edges. The handling of dispenser hoses and couplings shall be easily possible. The dispenser hoses shall not touch the ground when the nozzle is stored in the dispenser unit. All displays shall be easily readable.

8.5.3.4 Filter

There shall be a 5 µm filter installed to protect the vehicle from particles in the hydrogen flow bigger than 10 µm.

8.5.3.5 Breakaway coupling

The hose of the HRS shall be protected by a breakaway coupling from severe hydrogen leakages in case of unintended vehicle drive away. The breakaway coupling shall release within a force band of 200-400 N in axial direction.

8.5.3.6 Dispenser grounding

A grounding connection of the fuelling station to ground has to be installed. The hydrogen source and the fuelling station need to have a common grounding.

8.5.3.7 Vehicle grounding

Vehicle grounding can be performed by one of the following solutions:

- 1) Grounding through vehicle tires

(Preferred method if refuelling area ground surface conductivity is adequate). Resistance between pad and ground shall be less than 1 MOhm.

- 2) Connection of a dedicated grounding strap prior to nozzle connection

8.5.3.8 Operating instructions

The dispenser operating instructions shall be posted at the dispensing device.

8.5.3.9 Pre-fill leak tightness test

The connection between nozzle and vehicle should be tightness tested before each fuelling.

8.5.3.10 Hydrogen detection

A system for automatic detection of H₂ gas inside the dispenser housing, which contain most of the valves and measuring devices for the dispenser, is recommended. Shut down should be initiated automatically upon gas detection.

8.5.3.11 Dispensing process interruption

In case of interruption of the dispensing process, due to a power or system failure, the user shall not be exposed to any hazard. Moreover the user shall be informed of the interruption and shall receive proper instructions.

8.5.3.12 Hydrogen supply isolation valve

Hydrogen supply to the dispenser shall include a fail-safe isolation valve downstream the process equipment (e.g. compressor and buffer storages, liquid hydrogen pump).

8.5.3.13 Emergency dispenser shut down

At minimum one manual ESD button near the dispenser shall be available. A second manual ESD button in a larger distance from the dispenser (safe area) is recommended.

Activation of one emergency button only shall immediately terminate all on-going fuelling. The hose and connections shall be depressurised automatically.

Emergency shut down will be released in the following situations:

- Manual emergency shut down at the dispenser
- Leakage of hydrogen at the Nozzle by pressure tightness test
- Temperature drop of the temperature control at the Nozzle (in case of hydrogen pre-cooling)
- Loss of electricity or drop down of Nitrogen and Hydrogen or Helium supply pressures
- Detection of hydrogen via gas sensor inside the dispenser enclosure

8.5.3.14 Detection of severe leakages

The fuelling station needs to provide measures to detect severe leakages. In addition, a test for vehicle-HSS (Hydrogen Storage System) leakage shall be performed by a low-pressure pulse test prior to fuelling.

The following points need to be documented:

- Initial pressure pulse to detect vehicle-HSS leakages
- Additional measures to detect severe leakages (at least one necessary)
- Hydrogen sensor on fuelling area to detect vehicle leakages
- Plausibility check of HRS pressure to detect pressure drop during fuelling

8.5.3.15 Pressure inlet sensor failure

The HRS needs to be pressurized with hydrogen all the time to prevent air entrance. The inlet pressure shall be permanently supervised and a failure of the inlet pressure sensors shall be detected automatically. If the inlet pressure is less than the required minimum inlet pressure, the station shall stop automatically. A restart is allowed only after purging the Fuelling Station.

The minimum inlet pressure shall be documented. The following elements shall be available as well:

- Inlet Pressure detection
- Automatic Stop of HRS if inlet pressure is too low
- Restart possible only after purging

8.5.3.16 Liquid Hydrogen dispensing

The refuelling hose, as a movable and manipulated part of the dispenser, shall be monitored for the loss of vacuum insulation. The dispenser should be automatically shut down in the case of a loss of vacuum.

Dispensing shall stop in case of sudden or heavy tension at the fuelling hoses and Nozzle (break away system used for gaseous dispensing is not applicable).

8.5.3.17 Lighting

Hydrogen fuelling facilities transferring product during the night shall have permanent lighting at points of transfer and operation. The lighting shall be designed to provide illumination of the dispensing apparatus and dispensing area, such that all controls including emergency shutdown devices are visible to the operator.

8.5.4 Gaseous hydrogen storage system

Steel cylinders and storage tubes are commonly used in industry to store pressurised hydrogen, varying from a single cylinder to multi-cylinder packs and stacked tubes. Cylinders may also be made of composite materials.

Flammable materials should be kept at a distance from the tank.

Connections between vessels and pipe work and on pipe work should be carefully considered both for durability, contamination and permeation.

Underground piping connections should be butt-welded and consideration should be made for the effect that welding will have on pressure ratings.

8.5.5 *Liquid hydrogen storage system*

A cryogenic storage tank consists typically of an inner and outer vessel, separated by a vacuum to minimise heat ingress by conduction. Inside the vessel the product will exist in both liquid and gaseous phases.

Cylindrical vessels can be built either vertically or horizontally. Design should ensure minimum heat leak into the vessel and minimise boil off. Heat transfer could occur as radiation, convection or conduction depending on the installation chosen.

- Boil off – the vaporisation of liquid hydrogen to gaseous phase - will always occur. The installation should therefore be equipped with an overpressure regulation circuit to remove the gas and keep tank pressure at equilibrium. The removed gas should be safely utilised, vented or otherwise disposed of.
- Pressure relief circuits should be backed up by relief devices.
- Always keep vessel above atmospheric pressure.
- Cryogenics will cause pipe work to shrink when cooled and expand when warmed up again. This should be designed for.
- When considering the ventilation for boil off hydrogen, remember that much colder gasses will be less buoyant in air than ambient hydrogen. Cloud formation can cause asphyxiation and also cause explosion risk.

Flammable materials should be kept at a distance from the tank.

The ground surface and plinth above which the tank, vaporiser and refilling area stands should be made of a non-flammable material non-permeable to cryogenics. Consider the collection of liquefied oxygen-enriched air beneath cold lines and whether it could penetrate the ground or run into drains before boiling off.

The ground surface should not be made of a flammable material such as asphalt or other bitumen based materials.

Where heating is required to vaporise liquid hydrogen, it should, ideally, be supplied from hot water or steam supplies, to eliminate both the need for electrical equipment in the vicinity and the potential for contamination of re-circulated streams.

8.5.6 *Specific storage configurations*

8.5.6.1 Under-ground storage systems

Hydrogen can be stored safely underground providing necessary precautions are undertaken. Underground storage reduces the impact of engulfing fires above ground. Further benefits include reduced space, aesthetics and reduced impact exposure both from accidental and malicious attack.

Further to the considerations made for above-ground storage, the following points give examples of the risks inherent and avoided by burying the vessel and some

suggested means of mediating these risks. Clearly the overriding message is that leaks must be avoided in all circumstances and proper detection, containment and removal should be made to minimise the dangerous impact of the leak.

- Storage of gases or liquids that vaporise at ambient conditions is always safer in open, well-ventilated areas. Vaporised cryogenics are colder and often remain denser than air for some time. The space surrounding the vessel can be described as ‘confined’ when three or more walls of a square enclose it. Confined spaces create substantial risk to personnel that are required to install, maintain, remove or in anyway work near the vessel. There is a hazard of asphyxiation due to leaked product that cannot be vented fast enough. There is also an increased risk of ignition due to the oxygen-enriched atmosphere that can result from liquefaction of air in contact with non-insulated liquid hydrogen lines. In case of ignition it is also an increased risk of strong explosion due to the high level of confinement around the tank.
- Precautionary measures must be taken to avoid leaked hydrogen or other gas concentrations entering underground conduits (such as water and gas mains) and foundations of buildings.

Buried storage system

The following issues are to be considered for buried vessels:

- Corrosion Protection (Cathodic Protection, coatings, materials of construction, proper burial per existing standards)
- Structural Design Issues (soil forces, water table, ground Freezing)
- Pressure Vessel Integrity (Double wall construction, comparison to pipelines and other pressurised underground vessels)

Liquid hydrogen storage in vault

Underground storage of liquid hydrogen typically consists of a horizontal cryogenic Stainless Steel tank, either sealed or contained within a vault.

- The subterranean vessel may be contained within a vault to reduce corrosion. Consideration must be given to the medium between the vault and vessel walls. Where air is present, liquefaction may occur on poorly-insulated vessel walls and pipe work. As the temperature decreases within the vault, Oxygen will liquefy more readily than other air gasses and remain liquid for longer, creating a rich concentration of oxygen around the point of liquid collection and a significant fire hazard. Though sealing the vault with a suitable inert purge gas should remove this risk, it would then add to asphyxiation risk.
- Where liquefaction of surrounding air or purge gasses may occur within a vault, consideration must be given to the damaging effects this may cause to vault walls and other equipment.
- Drainage should be considered. Condensed water vapour and potential water leaks into a vault must be removed to avoid corrosion. Cryogenics and gasses must not enter into such drainage systems.

- Where the outer wall of a vacuum-insulated tank fails, oxygen concentrations vaporising as they gather on the floor could be drawn into the vacuum chamber, thus significantly increasing the risk of fire and explosion.
- Though maintenance of the vessel itself maybe infrequent, consideration should also be given to the subsequent installation of machinery such as pumps at the vessel level. Such machinery is likely to need more frequent routine and unexpected maintenance and therefore carries a higher asphyxiation risk.
- Before installing storage vessels underground, consideration should be given to local seismic activity and, where necessary, earthquake damage mediation must be designed into the housing.

8.5.6.2 Canopy mounted gaseous storage systems

Similar to surface storage systems, gas storage vessels can be raised above the canopy of the fuelling station. As for underground storage, this can reduce spatial issues.

Note: Technically a canopy mounted liquid storage system is feasible. However, this configuration was never used so far.

It can also be argued that faster venting of gas is possible, for example in case of fire, with much lower risk to people or equipment on the ground. Leaks from raised equipment are likely to disperse more quickly.

Gaseous storage is preferred in this instance both in terms of safety and practicality.

- Collision damage should still be considered. Drivers of high vehicles may misjudge the height of a low canopy.
- Maintenance planning must consider ladder use and work at height.
- Safety distances surrounding the canopy storage must still be considered, despite vertical separations from ground-level equipment satisfying the codes. Horizontal high-pressure leaks may travel some distance before rising, particularly with a strong tailwind. Such leaks could enter neighbouring facilities, or high-sided vehicle (e.g. double-decked bus) windows before rising. The storage area can be surrounded by deflection walls to ensure such leaks are directed upwards.

9 Operation and maintenance of an HRS

9.1 Operating requirements

Training shall be arranged to cover all the aspects and potential hazards that the particular operator is likely to encounter.

It shall cover, but not necessarily be confined to, the following subjects for all personnel:

- The potential hazards of hydrogen
- Site safety regulations
- Emergency procedures
- The use of fire fighting equipment
- The use of protective clothing/apparatus including breathing sets where appropriate
- Safe work permits for maintenance activities

In addition individuals shall receive specific training in the activities for which they are employed.

It is recommended that the training be carried out under a formalised system and that records be kept of the training given and, where possible, some indication of the results obtained, in order to show where further training is required.

The training program should make provision for refresher courses on a periodic basis.

Activities other than those directly related to the hydrogen operation should be kept remote from hydrogen equipment.

Detailed operating instructions containing all necessary technical information in clear form shall be prepared for each system. These instructions shall be used in the training program and shall be available to the relevant operating personnel.

Operating personnel shall wear suitable clothing and where necessary protective equipment.

Where single manned operation is used on any part of the plant, adequate means of summoning assistance in the event of an emergency shall be provided. This should be backed up by a system of checks.

The installation and operation of electrical systems in hydrogen stations must be in accordance with the Regulations, Standards and Codes of Practice of each country.

9.2 Emergency safety plan

Preparation measures	Description	According to/ specification
Fire fighting	Plan of Attack for different scenario's whereby danger, tactics and means are nominated. Sufficient fire extinguishing material should be present. Availability of fire extinguishing material guaranteed. Unobstructed access required.	Remarks: Hydrogen flames are not visible. Hydrogen fires should <u>not be</u> extinguished before the supply of hydrogen has been stopped. Cooling of adjacent devices that contain hydrogen may be a tactic for which sprinklers may be used.
Emergency response plan	Shall be prepared to cover potential emergencies and shall be coordinated with the local emergency services	Contains the availability and duties of individual facility personnel and the availability of external response personnel during the identified emergencies

An example of detailed Emergency Response Plan (ERP) has been prepared by WP4 and is provided as Appendix III.

9.3 Maintenance requirements

9.3.1 General principle

Preventive maintenance is mandatory to ensure trouble free operation of an HRS.

The refuelling site shall have a written maintenance program or process safety analysis program in place. The operator shall maintain a written record of the required maintenance.

Maintenance shall be performed based on the OEM component manufacturer's recommendations and not less than every 6 months. Maintenance records shall be made available upon demand. Records of required maintenance shall be provided to the authority having jurisdiction upon request.

Fuelling facilities shall be free from rubbish, debris, weeds, and other material that present a fire hazard.

Grass areas on the hydrogen fuelling facility grounds shall be maintained in a manner that does not present a fire hazard. Grass should be kept fresh and green, and cut grass should be removed immediately as rotting grass may self ignite.

A preventive maintenance program shall be in place and shall include a schedule of written procedures for test and inspection of facility systems and equipment.

Each component in service, including its support system, shall be maintained in a condition that is compatible with its operation or safety purpose by repair, replacement, or other means.

If a safety device is taken out of service for maintenance, the component being served by the device shall be taken out of service unless the same safety function is provided by an alternative means.

If the inadvertent operation of a component taken out of service could cause a hazardous condition, the system shall be shut down until the component is replaced.

Safety, gas detection, and fire protection equipment shall be tested or inspected at intervals not to exceed 6 months.

Maintenance activities on fire control equipment shall be scheduled so that a minimum of equipment is taken out of service at any one time and fire prevention safety is not compromised.

Access routes for movement of fire control equipment to a hydrogen fuelling facility shall be maintained at all times.

Maintenance/repairs procedures should follow normal engineering practice, with additional precautions relating to hazard zones. Special attention shall be paid to ensuring that systems are adequately depressurised and purged, before any work is undertaken and a Safe Work Permit is issued.

Detailed maintenance programmes should be prepared for each system, making individual reference to items of equipment in the system. The following guidelines may be used.

A documentation system should be set up to include the following information:

- Flow sheets
- Vessel dossiers
- Pressure test certificates
- Operating instructions
- Equipment manufacturers maintenance instructions
- Equipment drawings
- Piping drawings (including any modifications)
- Material schedules
- Modification details and approvals
- List of recommended spare parts

A suitable system for recording the frequency and extent of all maintenance and periodic tests shall be provided. This should include a means of recording defective or suspect equipment to ensure that prompt and correct action is taken.

Where modifications are made to any part of the system, or to individual items of equipment, these shall be subject to technical approval and conformance, at least, to the original standards and be adequately tested.

Any changes made shall be fully documented.

Schedules shall be established detailing maintenance tasks and their frequency. The following shall be included as key items:

- Periodic inspection/pressure test of vessels and piping systems should be done on annual basis
- System checks of leakage
- Safety shut-down system functional check
- Pressure relief device testing
- Control and monitoring equipment testing
- Filter checks
- Electrical system/grounding integrity checks
- Compressor maintenance
- Flexible hoses
- In addition, the following should also be scheduled:
 - Painting
 - Notices
 - Pipeline identification

Flexible refuelling hoses can be considered to be vulnerable and a source of potential hazard, special attention is required regarding their use.

Hoses shall be inspected regularly. Attention shall be paid to the integrity of the electrical continuity, end fittings and evidence of physical damage. They shall be tested or replaced at fixed intervals. Recommended test and inspection intervals can be obtained by a risk based approach.

The operator's attention is drawn to the importance of avoiding corrosion that can otherwise limit the working life of the cylinders and affect the fatigue characteristics in serious cases. The implementation of good periodic preventative maintenance in anti-corrosion procedures is strongly recommended.

A manually operated shut-off valve to isolate each dispensing unit shall be provided for maintenance purposes.

Maintenance or repair work shall only be carried out after the relevant parts of the plant, or area, have been checked and a competent person has issued a Safe Work Permit. This is particularly important where such maintenance work introduces an ignition hazard, e.g. welding.

All personnel engaged in the operation and/or maintenance of hydrogen stations/systems shall have received training suitable for the work on which they are engaged.

A systematic approach to the maintenance of hydrogen systems is necessary to ensure safe and correct operation.

9.3.2 Typical maintenance program for a gaseous HRS

This paragraph presents a typical maintenance program for a gaseous HRS:

COMPONENTS	OPERATIONS	FREQUENCY
Break away (X410)	Replacement of O-Ring on the GH2 outlet pipe	Every two years
Compressor	A-type Visit (see Table 16)	Every year
	B-type Visit (see Table 16)	Every two years
	C-type Visit (see Table 16)	Every two years
Main station	Leak test at Maximum Service Pressure with leak spray on screwed sub-assemblies	Every 6 months
	H2 venting control	Every 6 months
Filing hose	Replacement of the filing hose	Every two years
Compressor feeding hose	Replacement of the feeding hose on the compressor skid	Every year
Filter F110	Visual control of the filter element and replacement of the gasket. Cleaning with compressed air if necessary	Every 6 months
Safety Devices	Replacement of the Pressure Safety valves on the bundle, test of the PSV (NB: it is the responsibility of the customer to make sure the local regulation for pressurised equipment is applied)	Every 3 months
- Pressure safety valves		
- Gas detection system	H2 detector calibration test onsite	Every 6 months
- Emergency stop	Emergency stop verification	Every year
Pressure transmitters	Verification of sensors value	Every year
Temperature transmitters	Verification of resistivity	Every year
Hand valves for High Pressure isolation	Replacement of the needle o-ring, gasket ring	Every two years
Hand valves for High Pressure isolation	Replacement of the needle o-ring, gasket ring	Every two years
Automatic valves for High Pressure isolation	Verification OPEN/CLOSE and stroke of the piston, closing of the valve when no air supply available, tighten the mechanical parts, and H2 leak test with leak spray according to the manufacturer recommendation	Every year
Filling couplings	Leak test Maximum Service Pressure with Nitrogen	Every 3 months
Electric valve	Open/Close test, mechanical tightness, leak test	Every 3 months
Flow meter	GH2 leak test on connectors	Every 3 months
H2 bundles	GH2 leak test on all the installation	Every 3 months
Electrical cabinet	Ground pad testing	Every year
	Air venting filter, electrical connection tightness, overheating components, ...	Every 3 months

Table 15: Typical maintenance requirements for gaseous dispensing HRS

For the Compressor, typical types of visits are given in the following table:

Running time/maximum frequency	OPERATIONS
VISIT TYPE A Max. 2000 h	-Valve internal tightness control -Flow pressure limiting control setting control -Process parameters control (pressure, temperatures, power, flow rate) -Mechanical parts control (drive belts of the compressor...)
VISIT TYPE B Max. 4000 h	-Mechanical parts control (drive belts of the compressor...) -Process parameters control (pressure, temperatures, power, flow rate) -Valves inner ports control and/or replacement -Oil drain -Frame and metal filter cleaning -Oil Filter replacement -Motor greasing -Suction gas filter cleaning -Replacement of diaphragm
VISIT TYPE C Max. 8000 h	-Mechanical parts control (driving belts of the compressor...) -Process parameters control (pressure, temperatures, power, flow rate) -Valves inner ports control and/or replacement -Oil drain -Frame and metal filter cleaning -oil Filter replacement -Motor greasing -Suction gas filter cleaning -Replacement of diaphragm -Safety elements control: Gas, oil, water, etc) -Replacement of the oil non return valve -Replacement of internal parts of the compensator -Replacement of internal parts of the pressure limiting control -Replacement of O-ring on oil circuit

Table 16: Typical inspection plan for the compressor of a gaseous dispensing HRS

10 Vehicle interface requirements

This section discusses both gaseous and liquid hydrogen interfaces. Further information on the vehicle description and requirements are provided in Appendix VI.

10.1 General requirements

10.1.1 Compressed Hydrogen refuelling

The OEM's have developed a common refuelling process. This document describes the targeted refuelling process based on vehicle requirements and also defines a series of detailed requirements (performance, hardware, etc...) for the vehicle interface at fuelling stations.

Due to the differing thermal behaviour of different vessel types, all HRS's should use this refuelling specification. The following documents provide specification and requirements for the fuelling process:

- SAE TIR 2601 (in progress)
- SAE TIR 2799
- Vehicle manufacturers commonly agreed specification available at: http://nextenergy.org/industryservices/70MPa_Specification_Docs.asp

A communication interface between vehicle and HRS will be introduced, with the purpose of optimising the refuelling process. Both the optimised communication and more conventional non-communication re-fuelling systems are described in this document.

10.1.2 Liquid refuelling

The amount of hydrogen is measured in mass (kg). The measurement tolerance is in accordance with the standards for conventional fuels.

The HRS must prevent the nozzle dropping on the ground, or nozzle shall be designed not to fail in this situation.

The Hydrogen quality provided should be in accordance with SAE J2719 with a particular requirement for 95% content of "Para-H2".

Inclination of the fuel stations ground shall not be above 1.5%.

The HRS shall be able to refuel a vehicle tank with a MAWP between 0.2 MPa and 1 MPa (2-10 bars).

Concluding the refuelling process could be possible at any time during the refuelling process (except during warm refuelling as mentioned in the safety requirements).

The station needs to be designed for any back flow from the vehicle tank during the refuelling process.

10.2 Grounding

The requirements for the electrical installation for hydrogen vehicles are included in many codes and standards. The validation of the electrical installation including all requirements for discharge of any currents or charges is done on behalf of the vehicle homologation.

Grounding to HRS during refuelling needs to be provided such that the vehicle ground plane is at the same potential as the refuelling station prior to fill nozzle making connection with the vehicle. A conductive path should exist between the vehicle chassis, via the conductive pad, and a common ground wire (earth). The total resistance through the pad and the tires should not exceed 125 Mohms, and the fuel receptacle should be bonded to the chassis. This value is based on SAE 1645, relating to the complete electrical resistance between earth ground and the conductive chassis of the vehicle. See SAE J1645 for recommended practices for minimizing electrostatic charges and their effects.

Measurement shows that stations that are built according to ISO TS 20012 have enough conductivity at the ground to discharge static accumulation.

10.3 Communication with the vehicle

A communication link between the HRS and the vehicle may be implemented according to SAE TIR J2601.

Both the HRS and vehicle must be enabled in order to start the refuelling process.

On the vehicle side, the data interface consists of contacts that are directly connected to a normal open relay. The relay is part of the vehicle safety loop.

When the refuelling process is initiated, the control system of the vehicle will be activated. All safety related aspects of the vehicle are checked by the vehicle control system. If all sensors and actuators are working within the expected range, the vehicle refuelling relay will be energized. The refuelling process is then enabled.

The signal from the HRS is routed through the vehicle relay and the refuelling process commences.

The LH2-Dispenser is equipped with control devices, which control the communication with the vehicle and the internal control system for the automatic nozzle. The control system is also responsible for controlling (opening, closing) the filling valve and gas return valve of the LH2-Dispenser.

If a failure or emergency occurs at the LH2-Dispenser site, the control system will give a signal for the refuelling to stop or initiate an emergency shut down (see § 8.5.3).

Data exchange:

The HRS will drive a binary self safe signal consisting of a 10V and 10mA DC, to the vehicle. If the vehicle potential free contact in the vehicle is closed by the vehicle, the refuelling process will start.

All parameters relating to the HRS and vehicle safety must to be considered, assessed and addressed as required.

10.3.1 Gaseous hydrogen tank system

The infrared-based hardware of the refuelling data/communication interface is currently being developed, collaboratively, by Daimler Chrysler and General Motors. HRS providers and other OEMs are invited to participate in the development of a common refuelling process and related interface hardware. The communication interface together with the refuelling process specification ensures a complete fill under all circumstances. The SAE technical information report TRI 2799 specifies a guideline for the hardware requirements for fuelling a hydrogen vehicle with compressed hydrogen storage rated at a nominal working pressure of 70 MPa @ +15°C. It contains a description of the casing geometry and optional communication hardware, along with the communications protocol relating to the refuelling of an hydrogen vehicle. The aim of this document is to enable the harmonized development and implementation of the hydrogen fuelling interfaces.

The overall hydrogen fuelling system consists of a dispenser and an hydrogen vehicle. The connector couples the hydrogen fuelling system (dispenser) and the Vehicle, and that hydrogen fuelling coupling is specified as the fuelling connector interface. There are three portions of the hydrogen fuelling coupling: a mechanical; a process; and, a data portion. The SAE document J2601 describes the data portions of the fuelling interface. See Figure 29.

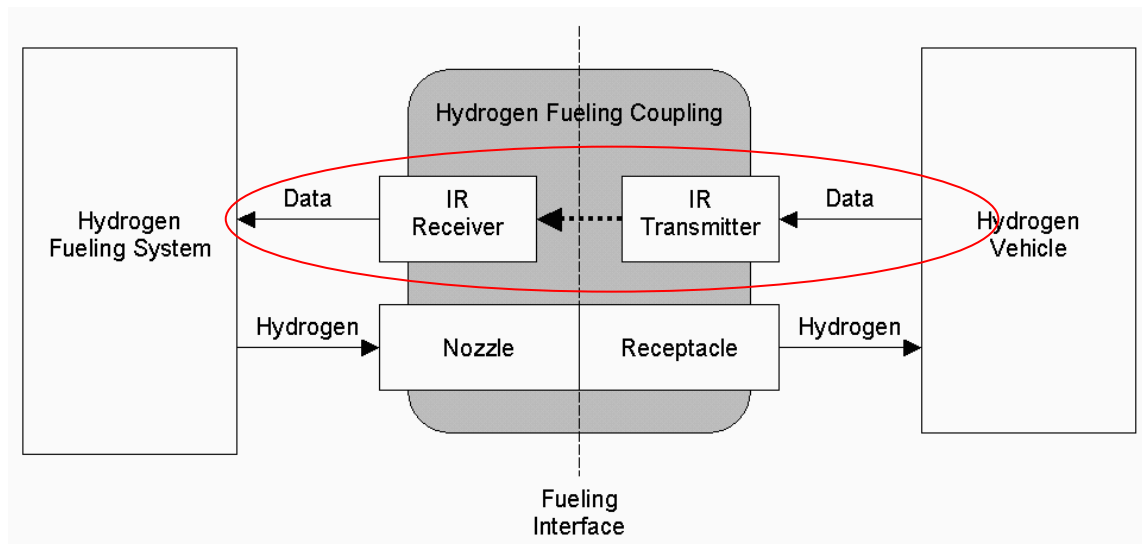


Figure 29: Overall fuelling system

10.3.2 Liquid hydrogen tank system

The data interface for LH2 refuelling differs from the CGH2 data interface. The communication for LH2 vehicles does not require a data exchange. No data protocol will be transmitted.

Nevertheless the HRS and the vehicle must be linked together during the refuelling process.

The communication between vehicle and HRS consists of a self safe binary signal DC voltage, 10V and 10mA, sent from the HRS. At the vehicle a potential free contact receives the signal.

The vehicle, with onboard liquid hydrogen storage, has a different connection type, which includes a data interface and refuelling procedure as required by a vehicle with CGH2 storage system.

The receptacle and coupling have to handle cryogenic liquid hydrogen flow and cryogenic gaseous hydrogen back flow from the Vehicle Tank system.

Both the HRS and vehicle must be enabled in order to start the refuelling process.

On the vehicle side the data interface consists of contacts, which are directly connected to a normal open relay. The relay is located within a safety loop.

By initiating the refuelling process, the control system of the vehicle will be engaged. All safety related areas of the vehicle are interrogated by the vehicle control system. If all the sensors and actuators are working within the expected range, the vehicle refuelling relay will be energized. The refuelling process is fully enabled.

The signal from the HRS will be routed through the vehicle relay and the refuelling process commence.

According to SAE 2578 the following are requested by the vehicle control system:

- Ignition off
- Pressure difference not less than 1 MPa between HRS and vehicle storage system
- Tank level < 85%
- Park brake engaged
- H2-Sensors in the vehicle showed up no H2-concentration within all compartments in the vehicle

Breakdown of the communication signal either in the vehicle or on the HRS instigates the Emergency stop. Therefore the filling process will be interrupted.

10.4 Refuelling interface (nozzles and breakaway)

Nozzles shall be one of three types as described hereunder.

TYPE A: A nozzle for use with dispensing hoses that may remain fully pressurized when the dispenser shuts down. The nozzle shall not allow gas to flow until a positive connection has been achieved. The nozzle shall be equipped with an integral valve or valves, incorporating an operating mechanism, which first stops the supply of gas,

then safely vents the trapped gas before allowing the disconnection of the nozzle from the receptacle. The operating mechanism shall ensure the vent connection is open before the release mechanism can be operated and the gas located between the nozzle shut-off valve and the receptacle check valve is safely vented prior to disconnecting the nozzle.

TYPE B: A nozzle for use with dispensing hoses that may remain fully pressurized at dispenser shutdown. A separate three-way valve connected directly, or indirectly, to the inlet of the nozzle is required to safely vent trapped gas prior to disconnecting the nozzle. The nozzle shall not allow gas to flow until a positive connection has been achieved. Venting is required prior to disconnection of the nozzle. External three-way valves shall be constructed and marked, indicating clearly the open, shut and vent positions.

TYPE C: A nozzle for use with dispensing hoses which are depressurised (0.5 MPa and below) at dispenser shutdown. The nozzle shall not allow gas to flow until a positive connection has been achieved. The function of preventing flow can be controlled by the dispenser as long as it is receiving a positive connection signal from the nozzle.

In addition, nozzles shall be designed for a life of 100 000 cycles with manufacturer specified maintenance. The three-way valve used for actuating Type B nozzles shall meet the same number of cycles as the nozzle (i.e., 100 000 cycles).

To distinguish the pressure level of the storage system of a hydrogen vehicle, the receptacles and nozzles must be hardware coded by different length of the receptacle.

It is not possible to connect a 70 MPa (700 bar) nozzle to a 35 MPa (350 bar) receptacle, because of the different design of the receptacle.

A 35 MPa (350 bar) nozzle can be connected to a 70 MPa (700 bar) receptacle, because a 70 MPa (700 bar) vehicle could also be refuelled by a 35 MPa (350 bar) dispenser.

10.4.1 35 MPa (350 bar) gaseous hydrogen interface

SAE J2600 is the standard for 35 MPa (350 bar) refuelling interfaces.

SAE J2600 applies to design, safety and operation verification of Compressed Hydrogen Vehicle interfaces referred in the documents for the nozzle and receptacle.

All vehicle OEM's follow the SAE J2600 for the vehicle receptacle. The nozzle mounted to the hydrogen filling station dispenser shall be manufactured in accordance with SAE J2600.

Receptacles shall comply with all sections of the aforementioned SAE document.

The receptacle on the vehicle shall be designed for a life of 15 000 cycles and 15 years with manufacturer specified maintenance.

The receptacle shall be equipped with an internal check valve to prevent the escape of gas. The check valve shall be of the non-contact type, opening by differential pressure only.

Receptacles are designed with protection against dirt contamination when connected or disconnected. For example, this requirement is met if the receptacle has a filter upstream of adequate size to protect the functionality of the check valve. A receptacle

shall have a means to prevent the ingress of fluids and foreign matter when disconnected. For example, the above SAE document includes a test to verify the resistance to contamination.

A number of reproducible, different tests shall be performed for the receptacle and nozzle. These tests are described in the aforementioned SAE document, e.g. handling, dropping, leak tests for different temperatures, vibration resistance, abnormal loads, rocking/twisting, thermal stress, durability and maintainability, hydrostatic, corrosion, deformation, thermal cycling and materials test.

The receptacle shall be designed to operate from – 40 °C to 85 °C.

For 35 MPa (350 bar) applications a TYPE A nozzle should be used.

BREAK AWAY:

Similar to gasoline refuelling stations, a break away device between the refuelling hose and HRS is required to avoid major damage to the station (and vehicle). Break away force should be between 220 N and 660 N, ISO TC197. The similar requirement for CNG-Vehicles is a load of 670 N at the receptacle at any direction.

A standard for the break away coupling is not available yet. Only a working draft is available: ANSI HG 4.4 / Standard for Breakaway devices for hoses used in compressed hydrogen vehicle fuelling stations.

10.4.2 70 MPa (700 bar) gaseous hydrogen interface

Best practice and experience of 70 MPa (700 bar) systems is available. Based on the design criteria of the SAE 2600 and the field experience, the consensus for the preferred type of receptacle design to be used for 70 MPa (700 bar) applications for North America and Europe has been reached. However due to the different designs required for Japan no decision for a world wide standard has yet to be agreed.

A technical information report from SAE is available. This SAE-TIR-2799 will be superseded by J2600 in two years. SAE J2600 will be also be the standard for 70 MPa (700 bar) refuelling interfaces.

SAE J2600 applies to design, safety and operation verification of Compressed Hydrogen Vehicle interfaces referred into the document as nozzle and receptacle.

All vehicle OEM's follows the SAE J2600 with the vehicle receptacle. The nozzle mounted to the hydrogen filling station dispenser shall be manufactured according the SAE J2600.

The receptacles shall comply with all sections of the mentioned SAE document.

The receptacle on the vehicle shall be designed for a life of 15 000 cycles and 15 years with manufacturer specified maintenance.

The receptacle shall be equipped with an internal check valve to prevent the escape of gas. The check valve shall be of the non-contact type, opening by differential pressure only.

Receptacles are to be designed with protection against dirt contamination when connected or disconnected. For example, the requirement is met if the receptacle has a filter upstream of adequate size to protect the functionality of the check valve. A

receptacle shall have a means to prevent the ingress of fluids and foreign matter when disconnected. For example the SAE document includes a test to verify the resistance to contamination.

A number of different, reproducible tests, shall be performed for the receptacle and nozzle. Those entire tests are described in the mentioned SAE document, e.g. handling, dropping, leak tests for different temperatures, vibration resistance, abnormal loads, rocking/twisting, thermal stress, durability and maintainability, hydrostatic, corrosion, deformation, thermal cycling and materials test.

The receptacle shall be designed to operate from – 40 °C to 85 °C.

For 70 MPa (700 bar) applications a TYPE C nozzle should be used.

BREAK AWAY:

Similar to gasoline refuelling stations a break away device between refuelling hose and refuelling station is required to avoid major damage of station (and vehicle). According to ISO TC197, the break away force is between 220 N and 660 N.

A standard for the break away coupling is not available yet. But a working draft is available: ANSI HG 4.4 / Standard for Breakaway devices for hoses used in compressed hydrogen vehicle fuelling stations.

10.4.3 Liquid hydrogen interface

For liquid hydrogen systems a SAE document, as a technical information report, is available. The SAE-TIR 2783 is not a standard, but until 2009 all dispensers for LH2 shall follow this technical information report.

The SAE J2783 applies to design, safety and operation verification of Liquid Hydrogen Vehicle Interfaces. Refuelling connection device shall consist of the following components, as applicable:

A: receptacle

B: nozzle

C: dispenser

The general requirements for the LH2 interface are:

- a) Refuelling of tanks with a MAWP between 0.2 and 1 MPa (2 and 10 bar) shall be possible
- b) Bi-directional refuelling (refuelling line and back gas line) shall be implemented
- c) The nozzle shall be designed for 100.000 refuelling cycles without maintenance
- d) Nozzles shall have a means to prevent the ingress of solid matter from upstream sources. For example, this requirement is met if the nozzle has a filter upstream of adequate size to protect its functionality
- e) The nozzle shall be protected against solid and liquid contamination when in parking position

- f) Refuelling shall be possible under any relevant environmental conditions (ice, snow, rain, - 40°C to 85°C)
- g) The nozzle shall be designed for a flow rate through the filling pipe of up to 120g/s of liquid hydrogen
- h) The dispenser system shall have the means to prevent dropping of the nozzle to the ground. Otherwise the nozzle shall be able to withstand the impact force. This must be proved by a drop test

In addition to the general requirements the following basic safety requirements shall be fulfilled.

- a) It shall not be possible to deliver hydrogen unless the nozzle and receptacle are connected properly and positively locked.
 - I. Leakage test prior to the opening of the shut off valves of the receptacle and the stop refuelling process. Nozzle. If leakage is detected.
 - II. Nozzle shut off valve shall not open in an uncoupled state.
- b) Disconnection of the nozzle shall only be possible if the refuelling of cryogenic H₂ has stopped and the nozzle and receptacle valves are closed.
- c) The act of venting, or de-pressurizing, of the connection space between nozzle types and receptacles to ambient pressure is required prior to disconnection.
- d) No uncontrolled release of critical amounts (tbd) of hydrogen during the refuelling process through the fuel station dispenser system including the nozzle.
 - III. Leakage through the dispenser system shall be detected and limited to a non critical amount.
- e) It shall not be possible to remove a nozzle when the contained pressure is greater than ambient pressure.

10.5 Driver instructions

The level of knowledge, experience and comfort will impact the training necessary for an early fuel cell vehicle driver. In some cases, we might imagine a case where a customer already has familiarity with fuelling with compressed gas. In other cases, a customer may have no previous knowledge and will need more extensive review. Therefore, an instruction program should be both flexible and easily acquired, so all who have an interest in driving a fuel cell vehicle are given the opportunity.

A driver instruction program must meet the needs of three parties: (1) the driver, (2) the station operator, and (3) the vehicle manufacturer (OEM). It should make sure a driver is safe, capable and comfortable with the use of hydrogen and the refuelling procedures. A training program should be regarded as a comprehensive strategy to educate and reinforce the proper and safe fuelling procedures and simply not a one-time orientation session. The responsibility of executing this strategy is that of the driver, the station operator, and the OEM.

10.5.1 Driver

The main interface between vehicle and fuelling station is the driver. A driver must clearly understand and adhere to OEM instructions for properly and safely fuelling the vehicle. In addition, a driver shall follow all instructions and safe operating procedures posted by the station operator.

Driver shall follow the OEM instructions to prepare the vehicle for filling, including:

- Properly positioning the vehicle for fuelling;
- Following the instructions in the vehicle manual, (and any additional training approved by the OEM);
- Using the correct nozzle and/or dispenser (and at the approved pressure for compressed hydrogen).

Divers shall be aware of and able to locate the safety devices and procedures at the HRS:

- Emergency shut down (E-STOP), locations, how to activate;
- Hydrogen or fire detection system and/or fire suppression systems;
- In the event of an alarm, a leak (hissing sound), or fire, push the E-STOP (if possible) and leave the area.

It is also recommended that drivers obtain a short introduction into hydrogen properties to properly navigate the differences between hydrogen and existing transportation fuels, such as gasoline and natural gas. This provides an opportunity to avoid potential misconceptions by early adopters. Both station operators and OEMs should actively work with drivers to offer background knowledge on hydrogen.

10.5.2 Station operator

HRS's are, and will be, operated by a variety of organizations, from local governments to traditional retail gasoline stations. Station operators shall ensure the following information is clearly displayed in a conspicuous manner:

- Clearly identified stations and dispensers (signs);
- Access procedures (private, public, or other);
- Fuelling procedure (clear steps via diagram and/or dispenser interface);
- Emergency stops (sign / posting);
- No smoking / open fire / electronic devices near dispenser (sign / posting);
- Do not leave fuel pump unattended when fuelling the vehicle (sign / posting);
- Do not let children operate the dispenser; children should be kept away from the dispenser area (sign / posting).

10.5.3 Vehicle manufacturer (OEM)

OEMs are uniquely positioned to educate, respond, and offer guidance to drivers during the vehicle initial orientation. An OEM shall deliver clear fuelling instructions in such a manner the OEM is comfortable with driver's ability to safely operate and refuel the vehicle, including guidance on general safety measures taken by station operators.

Each OEM is also positioned to identify distinct fuelling procedures related to its own vehicle. These procedures shall be reviewed during driver training and may include:

- A vehicle fuelling mode;
- Fuelling with communication between vehicle and station;
- Pressure of hydrogen storage, e.g. 70 MPa (700 bar) versus 35 MPa (350 bar);
- Vehicle shut down procedure, e.g. vehicle fuel filler door open;
- How to react in the event of an emergency.

10.6 Acceptance of HRS based on OEM perspective

This acceptance documentation shall not substitute for any legally required local acceptance procedures.

Before any functional test is performed, all safety related tests and checks need to be passed and documented.

Compliance of the HRS against requirements listed in § 8.5 shall be checked.

HRS to vehicle interface is described in the standard SAE J2601. This standard is currently in progress. SAE TIR 2799 temporarily provides specification for the 70 MPa (700 bar) interface.

10.6.1 Codes and approval authorities

For all public stations, the certification for its operation from the authorities must be checked. All legally required tests and approvals must be performed and documented. The fuelling station operating company and manufacturer are responsible for assuring full legal compliance.

Applied codes and approval authorities shall be listed in the HRS documentation.

10.6.2 Passive safety compliance

All safety related tests have to be performed and passed prior to performing any performance testing.

10.6.2.1 Grounding and set-up

A grounding connection of the fuelling station to ground has to be installed. The hydrogen source and the fuelling station need to have a common grounding.

For proper vehicle grounding, station procedures can include:

- 1) No external strap and grounding through vehicle tires

(Preferred method if refuelling area ground surface conductivity is adequate)

- 2) Dedicated grounding strap
- 3) Grounding through CaFCP ground pin

Measurements to be performed without hose and nozzle attached to vehicle receptacle:

This measurement shall be made with grounding connections in place per the station operation procedure.

Resistance pad to ground: (Requirement: < 1 MOhm)

Resistance Nozzle to ground: (Requirement: < 10 Ohm)

Visual inspection of the wiring:

All connections tight fit to the ground connectors	OK / NOK
Routing of wiring without obstructions for HRS and operators	OK / NOK
Power supply to the HRS reasonably installed	OK / NOK
Safety distances to possible ignition sources	OK / NOK

The refuelling area ground surface material shall be identified (concrete or asphalt or other) and recorded.

10.6.2.2 Leak and pressure test

All necessary leak and pressure tests have to be performed by the station manufacturer. The station needs to be fully certified and approved to perform hydrogen fuelling.

10.6.3 Functional safety

10.6.3.1 Fuelling Station with no data communication to vehicle or with non-communication refuelling mode

The fuelling station manufacturer shall document the station operation procedure and ensure that the station performs as specified.

Hot Soak Test

Non-Com-fill, vehicle HSS (Hydrogen Storage System) Start pressure 5 MPa (50 bar), start temperature preconditioned 25° degree above ambient, continue refuelling to 100% SOC in non-communication mode.

The temperature inside the Vehicle HSS shall not exceed 85°C and no overflow to hydrogen densities higher than 40.3 g/l is allowed.

Cold Soak Test 1

Vehicle HSS 100% SOC, start temperature preconditioned to 15° degree below ambient. Vehicle HSS defuelled to 75% SOC and immediately refuelled to final pressure, calculated by the HRS.

The temperature inside the HSS shall not exceed 85°C and no overfill to hydrogen densities higher than 40.3 g/l is allowed.

10.6.3.2 Fuelling Station with data connection to vehicle according CaFCP Fuelling Interface Specification

For fuelling the Vehicle-HSS at fuelling stations with communications according the California Fuel Cell Partnership Fuelling Interface Specification it shall be assured through testing that the fuelling station terminates fill if vehicle temperature signal exceeds 85°C or if a termination request is sent to the HRS via the confirmation signal. If the vehicle pressure signal is used by the station, then the fuelling shall be terminated if the pressure signal exceeds 87.5 MPa (875 bar). In addition, overfilling of the vehicle-HSS shall be prevented by an appropriate fuelling algorithm and procedure.

The Fuelling Station shall continuously supervise the confirmation signal and terminate refuelling anytime if confirmation signal is lost.

The Fuelling Station shall terminate fuelling during comm.-fill if the transmitted vehicle temperature signal exceeds 85°C.

If the fuelling station uses the vehicle pressure signal, the HRS shall terminate fuelling if the vehicle pressure signal exceeds 87.5 MPa (875 bar).

Cold Soak Test

The refuelling station shall not overfill the vehicle-HSS to hydrogen densities higher than 40.3 g/l, even under cold soak conditions. For the calculation of the filling procedure, vehicle temperature and pressure data provided via the CaFCP connection can be used.

Cold Soak Test 1

Empty the tank of a filled vehicle by driving as far as possible. Fill the vehicle immediately after arriving at the Filling Station. The HRS shall terminate fuelling if the hydrogen density in the vehicle HSS (Hydrogen Storage System) exceeds 40.3 g/l. The hydrogen density in the vehicle, as well as the temperature and pressure, shall be monitored and supervised on the vehicle PC104 Display.

The temperature inside the Vehicle-HSS shall not exceed 85°C and no overfill to hydrogen densities higher than 40.3 g/l is allowed.

Cold Soak Test 2

Empty the tank of a filled vehicle by driving to a fill of approximately 50 % SOC. Fill the vehicle immediately after arrival at the Filling Station. The HRS shall terminate

fuelling if the hydrogen density in the Vehicle-HSS exceeds 40.3 g/l. The hydrogen density in the vehicle, as well as the temperature and pressure, shall be monitored and supervised on the vehicle PC104 Display.

The temperature inside the HSS shall not exceed 85°C and no overfill to hydrogen densities higher than 40.22 g/l is allowed.

10.6.4 Performance tests

10.6.4.1 Back to back fill

If possible, two consecutive fills with two vehicles shall be performed to evaluate the HRS performance to perform back-to back fills.

10.6.4.2 Signal quality test

The temperature signal provided to the HRS connector and the temperature signal displayed on the HRS display should not differ by more than 3%.

If the vehicle pressure signal is used for the filling algorithm, the pressure signal provided to the HRS connector and the pressure signal displayed on the HRS display should not differ by more than 3%.

Accurate communication is desirable in order to realize the benefits of communication refuelling. However, data quality is not a safety issue, because the vehicle can ultimately terminate the fill through the enable on/off signal.

11 Review of technical and safety measures

11.1 Stages (hierarchy) of safety assurance

The following three stages (hierarchy) of safety assurance can be identified:

1. Prevention of accidents by application of state of the art technology and following technical standards.
2. Mitigation, e.g. creation of distance between hazard source and vulnerable target (e.g. safety distances, hazard zones).
3. Well-prepared emergency response.

This section covers the first point only. See § 8.2 and § 8.3 for the safety distances as well as hazard zones, and § 9.2 for the emergency response plan.

11.2 Review of currently applied measures

Prevention of accidents starts by avoiding an accidental hydrogen release. Such a release may result from hardware failures, software failures, operational errors or external impact. Underlying these failures may be factors like e.g. incorrect system or equipment design, incorrect system specifications, inadequate maintenance, inadequate operating procedures, insufficient training of personnel etc...

The preventive measures below cover the following issues:

- The technical system (the hardware),
- Maintenance,
- Operations,
- Good housekeeping, and
- Fire prevention.

Such measures are recommended to ensure safety.

Table 17 reflects measures applicable in particular to equipment located in non-public areas.

Table 18 reflects measures applicable to the dispenser.

Preventive measures	Description	According to/ specification Background of requirement
Fail safe approach	The production is shut-off in the event of a power or equipment failure	Specify shut down philosophy – See § 8.4.6
Fire detection	Detection at multiple locations. See § 8.1.8 and § 8.4.4.3 and § 8.4.4.4	Specify shut down philosophy – See § 8.4.6
Hydrogen gas detection	Detection at multiple locations See § 8.4.4.1 and § 8.4.4.2	Specify succeeding steps such as alarm and shut-off actions.
Manually operated emergency shut down (ESD)	In case of emergencies local responsible persons must be able to shut down the installation completely	

Safety devices	Safety valve, rupture disks Accumulation of hydrogen in closed areas (roofs, eaves of buildings) should be avoided. Vents shall discharge in open air at high level and ignition sources shall be avoided. Avoid collection of moisture in the vents of safety devices	Pressure equipment directive (PED 97/23/EC) Safety devices shall be installed on tanks, lines and component systems to prevent damage by overpressure.
Sealing of pressure release valves	The adjustment of pressure release valves shall be provided with a means for sealing the adjustment to prevent tampering. If the seal is broken, the valve should be removed from service until being reset and sealed by competent personnel.	NFPA 52-06
Safety devices of the hydrogen compressing system	Consists of: - Inlet pressure indicator/switch, - Oxygen analysis, - Temperature indicator/alarm, - Discharge pressure indicator/switch, - Water pressure/flow alarm in the cooling water system, - Low pressure/flow alarm in purge gas system of electrical equipment, - Low pressure/flow alarm in compressor crank case	EIGA IGC Doc 15/06 The switches shall cause the compressor to shut down or may be arranged to shut down the compressor at a predetermined level.
Pipelines	- Shall be clearly marked by means of colour coding and/or labels - Shall make use of welded or brazed joints wherever possible.	EIGA IGC Doc 15/06
Isolation valves	Shall be provided so that the hydrogen source can be shut off safely	EIGA IGC Doc 15/06
Instruments	- Shall make use of safety glass and blow-out backs on pressure gauges - Sampling lines shall minimise quantities (i.e. flow and pressure) of hydrogen delivered to analysis instruments	EIGA IGC Doc 15/06
Filling of storage facility	Shall be provided with - Non-return valve - Main isolation valve - Remote operated shut-off valve - Vent/purge outlet valve - Each branch: isolation valve - Pressure indicator/alarm high	
Testing	After installation all piping, tubing and fittings shall be tested and proved hydrogen gas-tight at maximum operating temperature	NFPA 52-06 EIGA IGC Doc 15/06 Pressure tests shall be witnessed by responsible persons and suitable test certificates.
Barriers and fences	Protection of storage containers, piping, valves, regulating equipment against vehicular impact and damage by unauthorised persons	The minimum distance between the fence and the installation should be 0.8 m to allow free access to and escape from the enclosure. All gates shall be outward opening and wide enough to provide for an easy access and exit of personnel. There shall be at least two separate opening exits, remote from each other. Access to storage, compression and gas processing equipment by member of public

		should be restricted by a secured enclosure.
Physical protection measures	Adequate means of escape	In case where personnel could be trapped inside compounds or buildings there shall be not less than two separate outward opening exits, remote from each other – EIGA IGC DOC 15/06
Fire fighting equipment	Fire fighting equipment shall be periodically inspected and the inspection date recorded	EIGA IGD Doc 15/06
Earthing	All metallic structures must be earthed to avoid static charging. Resistance should be less than 10 Ω .	Protection against static electricity, electrical charge (sparks), lightning EIGA IGC Doc 15/06
Explosion venting	In housing of CGH2-compressor on top of container roof	
Maintenance requirements	Description	According to / specification
Maintenance	A preventive maintenance program consistent with the manufacturer's recommendations shall be in place and shall include a written regular schedule of procedures for tests and inspection of facility systems and equipment. The maintenance shall be carried out by a qualified representative of the equipment owner.	NFPA 52-06
Preventive operational safety requirements	Description	According to / specification
Training of personnel	The installation manager and his substitute(s) have to be trained by the designer/constructor of the plant in order to understand the system, its safety features and the tasks of the owner of the installation.	Option: the installation may function without operators and then will in principle be controlled from a distance.
Training of personnel	The installation manager should take care of the instruction of gas station operator(s) regarding their role in daily operations and in the event of emergencies.	EIGA IGD Doc 15/06 Subjects of the training may be: - potential hazards of H ₂ - Site safety regulations - Dangers of using unauthorised electrical equipment - Emergency procedures - The use of the fire fighting equipment provided - The use of protective clothing/apparatus
Operating personnel Personal Protective Equipment (PPE)	Precautions against accumulation of static charges: operators, working in a hazardous area, shall wear conductive footwear and working clothes of non-flammable and non-static materials	
Remote surveillance of production and storage facility	The use of telemetering techniques may be considered	Automatic reporting of hydrogen detection signals to operator (24 hours presence)
An installation manager shall be designated to direct technical efforts.	Supervision of the technical system, approve maintenance activities and primary point of contact for all activities regarding the installation.	
Good housekeeping	Description	According to / specification

Clearance of combustibles	The area within minimal 8 m of any hydrogen container shall be kept free of dry vegetation and combustible material.	NFPA 55: 5 m NFPA 50-B: 7.6 m for LH2. EIGA IGC Doc 15/06: 3 m On the basis of the QRA in Appendix IV a minimal clearance distance of 8 m has been chosen.
Operating instructions	For installations that require any operation by the user, instructions shall be maintained at operating locations	EIGA IGC Doc 15/06
Labelling requirements	Stationary compressed gas containers, cylinders and tanks shall be marked. Markings shall be visible from any direction of approach.	NFPA 55-05
Fire prevention	Description	According to/ specification Background of requirement
Fire prevention	Work permit for activities	Any work other than that directly connected with operating the station shall be covered by a Safety Work Permit System. EIGA IGC Doc 15/06
Fire prevention	<ul style="list-style-type: none"> - Minimize all potential sources of leaks - Eliminate all sources of ignition (Ban of open fire in danger zones) - Make provision for isolation of hydrogen 	Any electric equipment should be suitable and approved for use in the zoned area.
Warning signs at access points to hazard zones	Signs with the words “Hydrogen – Flammable gas – No smoking –No naked flames” in plainly legible, bright red letters not less than 25 mm high on a white background	Only authorised personnel shall be allowed to enter these zones. EIGA IGC DOC 15/06

Table 17: Overview of preventive measures for non-public area

Preventive measures	Description	According to / specification
Break away coupling	The filling of the vehicle will be stopped if the vehicle drives away before it is disconnected from the filling station. Automatic shut off valves may also be required for higher pressure HRS designs.	To be examined according manufacturer's requirements, at least monthly.
Dispensing device has to be made of flame resistant materials		
Barrier	Protection of dispensing device against vehicular impact	
Hose	Protection from damage. Shall be tested for leaks per manufacturer's requirements and any unsafe leakage or surface cracks shall be reason for rejection and replacement	EIGA IGC Doc 15/06 /NFPA52-06 See § Erreur ! Source du renvoi introuvable. , § Erreur ! Source du renvoi introuvable. and § Erreur ! Source du renvoi introuvable.
Testing	After installation all piping, tubing and fittings shall be tested and proved hydrogen gas-tight at maximum operating temperature	NFPA 52-06
Hydrogen sensors inside dispenser and pump cabinet	Detection of hydrogen will cause an emergency shut down and the complete system will run into safe operation automatically (all valves will be closed, release of hydrogen to atmosphere will be minimized)	
Manually operated emergency shut down button (ESD)	To be located near dispenser and in service station shop	
Fast fill station	At fast fill installations all equipment specifications should be respected	
Maintenance	Description	According to / specification
Maintenance	A preventive maintenance program consistent with the manufacturer's recommendations shall be in place and shall include a written regular schedule of procedures for tests and inspection of the dispensing equipment. The maintenance shall be carried out by a qualified representative of the equipment owner.	NFPA 52-06
Preventive operational safety requirements	Description	According to / specification
Communication	Any alarm signal has to be reported visually and audibly to the station operator.	
Training of personnel	The installation manager should ensure instruction of gas station attendants when the installation is constructed and ready for use regarding their role in monitoring/correcting the use of the station by visitors	
Training of personnel	The installation manager should ensure instruction of gas station attendants regarding their role in the event of emergencies.	EIGA IGD Doc 15/06 Subjects of the training may be: - potential hazards of H2 - site safety regulations - emergency procedures - the use of the fire fighting equipment provided - the use of protective clothing/apparatus
Indoor refuelling is not permitted	Only outdoor refuelling is applied. Roof or canopy can be used as weather shelter.	
Good housekeeping		
Clearance of combustibles	The area within 8 m of any hydrogen container shall be kept free of dry vegetation and combustible material.	NFPA 55: 5 m NFPA 50-B: 7.6 m for LH2. EIGA IGC Doc 15/06: 3 m On the basis of the QRA in §

		Erreur ! Source du renvoi introuvable. a minimal clearance distance of 8 m has been chosen.
Permanent lighting is required during operation hours	The employee in the service station shop should be able to overlook the whole HRS and its activities.	
Emergency exits shall be kept clear at all times		EIGA IGC Doc 15/06/E
Fire prevention	Description	According to/ specification
Fire prevention	Work permit for activities	Any work other than that directly connected with operating the station shall be covered by a Safety Work Permit System. EIGA IGC Doc 15/06
Fire prevention	<ul style="list-style-type: none"> - Minimize all potential sources of leaks - Eliminate all sources of ignition (Ban of open fire in danger zones) - Make provision for isolation of hydrogen 	Any electric equipment should be suitable and approved for use in the zoned area.
Warning signs	Signs with the words "STOP MOTOR, NO SMOKING, NO CELL PHONES, FLAMMABLE GAS"	NFPA 52: in plainly legible, bright red letters not less than 25 mm high on a white background at the dispensing station.

Table 18: Overview of preventive measures relative to dispenser

12 Risk assessment methodologies for HRS approval

12.1 Introduction

Hydrogen has been and is being broadly used in chemical and metallurgical applications, the food industry and the space program. Thus, with proper handling and engineering controls, hydrogen use can be as safe as other fuels in common use [1].

A “lower risk fuel” does not always mean a safer application of the fuel. Safety is connected to the level of risk .How could you measure how much risk you face? This chapter aim to show how to measure this intangible concept by measuring the potential effects of different accidents, as these effects are truly measurable. There exist several methodologies to assess the risks faced and to evaluate safety compared to desired levels. Once you can measure the risk, you can evaluate possible alternatives to use to reduce the risk of an HRS and achieve the desired risk level. This could be even smaller than the risk of a common petrol station.

This chapter aims to explain the risk assessment process, as a key part of safety management, to be followed in the process of reaching approval of an HRS, showing different methodologies and main hazards to be assessed.

12.2 Concepts involved in risk assessment

- Tolerable risk: Every risk below the maximum risk the society is willing to face in a current, given context.
- ALARP principle: As Low As Reasonable Practicable principle pretends to show that, whenever the risk faced is tolerable, risk reducing measures should be implemented if the ratio cost - beneficial effect is worth.
- Consequence: Severity of the harms caused to people, equipment or effects in the common operation of the process due to an accident.
- Exposure: Number of times a worker faces an event in a determined period of time.
- Harm: Physical injury or damage to the health of people, or damage to property or the environment.
- Hazard: Potential source of harm
- Probability: Likelihood of occurrence of a determined event. Commonly, it is expressed as expected period of time needed to the event to occur in common operation. It can also be expressed as a number between 0 and 1, where 1 is certainty of the event to occur and 0 the certainty of the event not to occur.
- Risk: Combination of the probability of occurrence of harm and the severity of that harm.
- Risk analysis: Systematic use of available information to identify hazards and to estimate risk.
- Risk assessment: A risk analysis followed by a risk evaluation.
- Risk control: Controlling the risk exposure of the system/process by reducing risk actions.

- Risk evaluation: Procedure based on the comparison of risk achieved with tolerable risk.
- Risk magnitude: Measure that makes possible to evaluate the risk in a quantitative way. It depends on probability, exposure and consequence.

12.3 Risk assessment process

12.3.1 Risk management

The risk management is a systematic approach that involves two different areas, as shown in Figure 30. Firstly, there is the risk analysis method, which identifies all possible hazards that can appear in the HRS and estimates how much each hazard contributes to the safety of the HRS. There could be hazards that are very remote but very dangerous, as an explosion of the hydrogen storage vessels, and others less dangerous but more frequent, as the release of hydrogen from a pipeline. Which one makes a determined HRS less safe? It cannot be answered *a priori*, as we need to evaluate all the consequences caused from the hazard and the probability of the failure to occur. This is the topic involved in risk analysis, in which the end is an estimation of all the risks involved in the HRS.

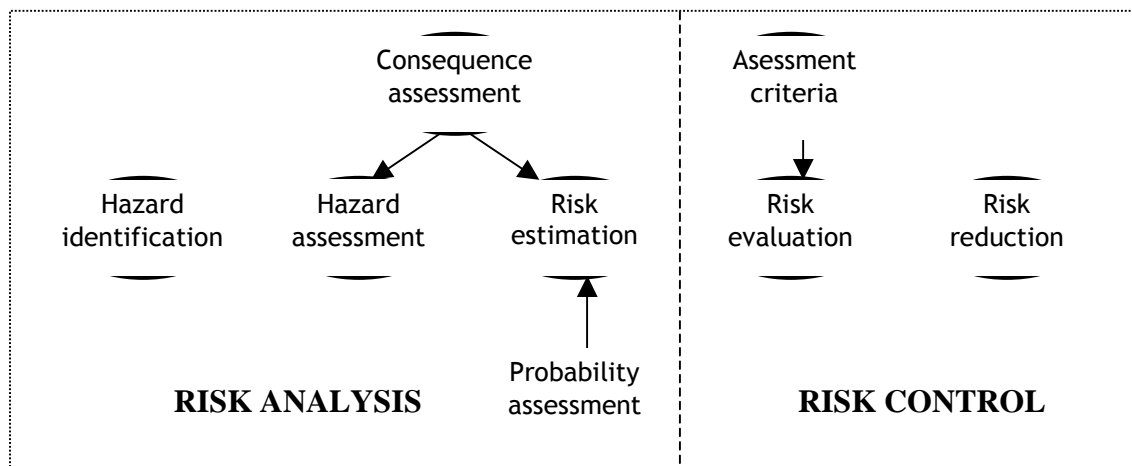


Figure 30: Risk management scheme [2]

Secondly, there is the risk control method, which evaluates if the risks pass all the criteria imposed. There are two types of acceptance criteria. One consists of assessing each risk individually, e.g. some guidelines or codes can specifically express that the distance of the nearest urban area to the HRS need to be above a certain level. Thus, you need to assess each risk individually to fulfil all the restrictions imposed by codes or standards. The other type of acceptance criteria involves evaluating the risk in groups, depending on the risk consequence, e.g. if we want to assess the risk of any client's damage, we need to evaluate how each hazard contributes to this risk and if it is below the adopted criteria. The aspect in common for both types of acceptance criteria in the risk control method is the reduction of risk, which needs to be practiced whenever the risk faced is above the tolerable risk level or the ALARP principle is not matched.

It is important to differentiate between the ALARP principle and the risk acceptance criteria. The risk acceptance criteria states that every risk that cannot be categorized as a tolerable risk must be reduced up to the point in which it can be categorized as a tolerable risk. On the other hand, the ALARP principle (As Low as Reasonable Practicable) involves a cost-benefit analysis, i.e. one should start reducing those risks that have a smaller marginal cost of reduction and should do so while its cost is relatively small. The term relatively is a subjective term that involves the use of common sense and is more directed towards agencies and code makers. Figure 31 illustrates clearly the concept of the ALARP principle.

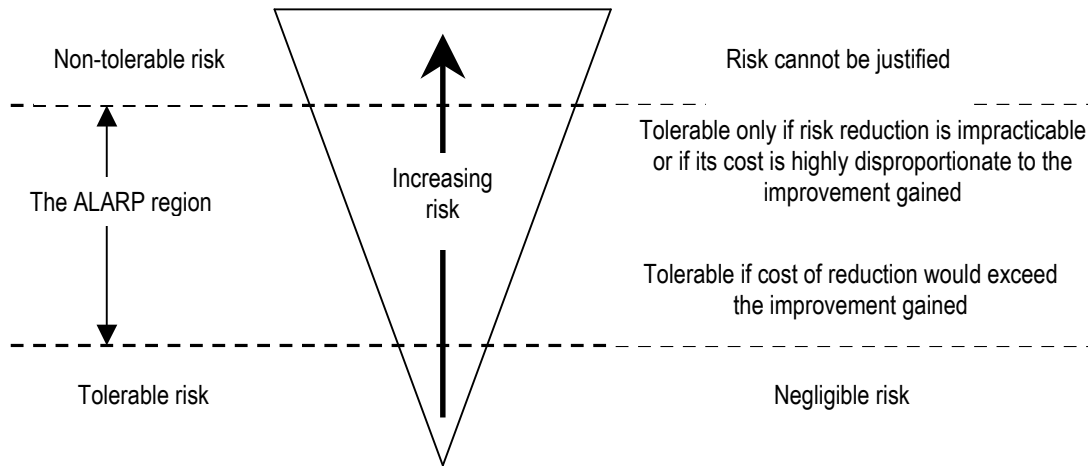


Figure 31: The ALARP principle [2]

The ALARP region, tolerable risk and non-tolerable risk are not the same for every person or culture. Thus, local standards and codes must be studied in depth depending on the mandatory code in each country. Despite of this, the context can be considered pretty much the same for every country. In case of non-existence of a developed country mandatory code in this topic, other's country can be used as a guideline.

12.3.2 Risk acceptance criteria

In case of non-existence of a code or standard stating or advising risk acceptance criteria to follow, several alternative strategies can be carried out. The three strategies discussed by the European Integrated Hydrogen Project phase 2 (EIHP 2) are [3]:

1. Comparing with statistics from existing petrol stations, giving an historical average risk level.
2. Comparing with estimated risk levels from risk analyses.
3. Comparing with general risk in society.

Examples of this last third alternative concerning to maximum death rate tolerable for clients of an HRS are:

- Dutch authorities suggest a base death rate (i.e. probability for a death to occur) of $1 \cdot 10^{-4}$ per year for the age group 10 to 14 years in any process in the society.
- UK authorities suggest a base death rate of $2.8 \cdot 10^{-4}$ per year for the age group 5 to 14 years in any process in the society. Thus, UK society is less risk averse to death than Dutch society.

In the EIHP2 project it was decided to compare with general risks in the society, mainly due to lack of relevant statistics and risk analyses of existing petrol stations. This choice also satisfies the general criteria of assuring that the risk level associated with hydrogen applications should be similar to or smaller than the risks associated with comparable non hydrogen systems. For further details of the risk acceptance criteria developed in the EIHP2 project, ref [3] can be consulted.

For risk evaluations of a hydrogen refuelling station, it can be practical to use a coarse methodology with a risk matrix. One such methodology is Rapid risk Ranking Methodology (chapter 12.4.6). These approached have been applied by others, one example is given in ref [4]. In case of being able to evaluate the risk, the risk acceptance criteria established by the European Integrated Hydrogen Project (EIHP) is shown in Table 19, in its form of risk matrix, and the meaning of each concept is shown in Table 20 and Table 21. It follows the RRR (Rapid Risk Rating) methodology explained in the paragraph 12.4.6.

		PROBABILITY (per year)				
		A (<0.001)	B (0.01-0.001)	C (0.1-0.01)	D (1-0.1)	E (10-1)
SEVERITY	1 (Catastrophic)	H	H	H	H	H
	2 (Severe loss)	M	H	H	H	H
	3 (Major damage)	M	M	H	H	H
	4 (Damage)	L	L	M	M	H
	5 (Minor damage)	L	L	L	L	M

Table 19: The Rapid Risk Ranking Risk matrix developed in the EIHP2 project [9]

Level name	Description
High (H)	High risk, not acceptable. Further analysis should be performed to give a better estimate of the risk. If this analysis still shows unacceptable or medium risk redesign or other changes should be introduced to reduce the criticality.
Medium (M)	The risk may be acceptable but redesign or other changes should be considered if reasonably practical. Further analysis should be performed to give a better estimate of the risk. When assessing the need of remedial actions, the number of events of this risk level should be taken into consideration.
Low (L)	The risk is low and further risk reducing measures are not necessary

Table 20: Risk levels in the risk matrix for acceptance criteria proposed by EIHP [9]

Level	Description	Definition	Frequency
A	IMPROBABLE	Possible, but may not be heard of, or maybe experienced world wide.	About 1 per 1000 years or less
B	REMOTE	Unlikely to occur during lifetime/operation of one filling station	About 1 per 100 years
C	OCCASIONAL	Likely to occur during lifetime/operation of one filling station	About 1 per 10 years
D	PROBABLY	May occur several times at the filling station	About 1 per year
E	FREQUENT	Will occur frequently at the filling station	About 10 per year or more.

Table 21: The probability levels in the risk matrix for acceptance criteria proposed by EIHP [9]

Level	Description	Definition		
		People	Environment	Material
1	CATASTROPHIC	Several fatalities	Time for restitution of ecological resource such as recreation areas, ground water >5 years	Total loss of station and major structural damages outside station area
2	SEVERE LOSS	One fatality	Time for restitution of ecological resource 2 - 5 years	Loss of main part of station. Production interrupted for months.
3	MAJOR DAMAGE	Permanent disability Prolonged hospital treatment	Time for restitution of ecological resource < 2 years	Considerable structural damage Production interrupted for weeks
4	DAMAGE	Medical treatment Lost time injury	Local environmental damage of short duration < 1 month??	Minor structural damage Minor production influence
5	MINOR DAMAGE	Minor injury Annoyance Disturbance	Minor environmental damage	Minor

Table 22: Description of consequence severity levels as proposed in the EIHP2 [9]

CONSEQUENCE LEVEL	ASSET DAMAGE	HUMAN DAMAGE
Extremely severe damage	Collapse of nearby dwelling houses	One or more fatalities of pedestrians or dwellers
Severe damage	Major damage of nearby dwelling houses	One or more fatalities of customers or station workers
Damage	Minor damage of nearby dwelling houses	Injury and hospitalization
Small damage	Windows broken	Injury and medical treatment
Minor damage	No damage to nearby dwelling houses	Minor injury

Table 23: Types of consequence levels in the risk matrix for acceptance criteria developed based on the EIHP2 project by [4]

This risk acceptance criterion is a guide that is proposed by the EHIP. The idea is that we will have no hazard categorized as H, and the least possible hazards categorized as M. There are other, more developed, risk acceptance criteria, but this is the simplest one, which does not mean it is not good. It is easily applicable and a very good option when there is no high experience in the field treated, as in the case of HRS's.

12.3.3 Risk assessment procedure

The risk assessment procedure consists of an iterative process that does something similar to the risk management shown in figure 1, but in a looping way. Thus, the procedure to follow is the accommodation of the risk management to a mechanical process to be done until the final risk can be considered tolerable. This procedure is shown in the Figure 32.

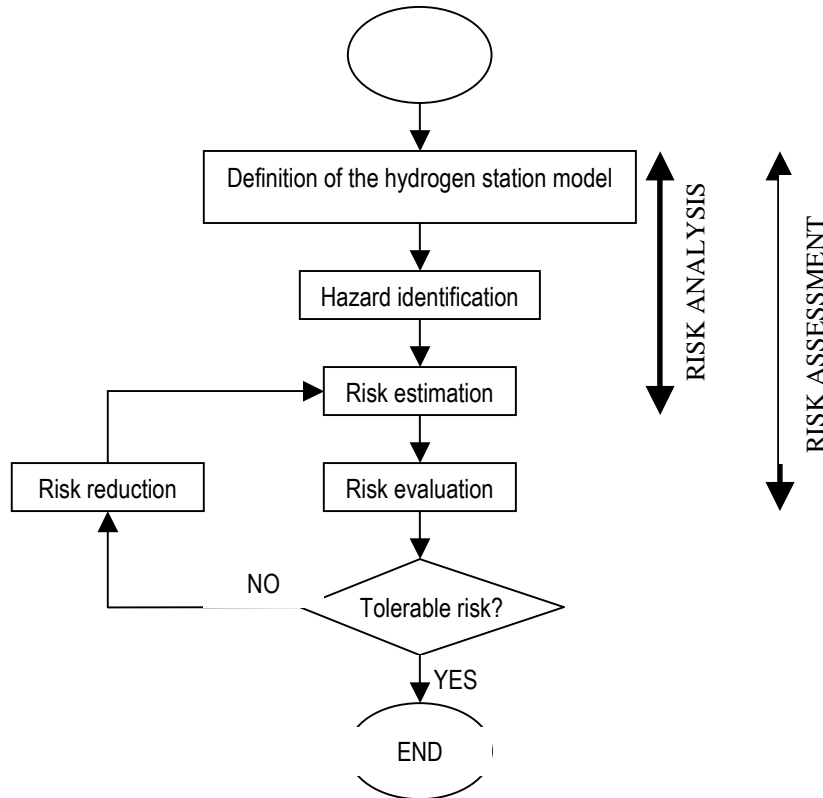


Figure 32: Flowchart of risk based approach [4]

12.3.4 Hydrogen accident databases

It has already been stated that the process of risk assessment involves two important features: estimation of probability of an event to occur and the consequences of this event. CFD simulations and simplified tools can be very useful in the assessment of the potential risks in an HRS.

One of the most challenging questions when assessing risks associated with an HRS is to evaluate how often a failure might occur. The preferable way to find out would be to utilise experience data from real HRSs. Due to the limited experience with HRSs in the world, there is a real need for a worldwide database, which can be used to establish the failure rates expected for the hazards identified. Such information will also assist in learning from past experiences.

Currently two databases are under development, one in Europe and another one by the US DOE. The European database work is undertaken in the EU’s 6th Framework Programme, project “HySafe – Safety of Hydrogen as an Energy Carrier”, in the work package named WP5 – HySafe Information System (HySafe IS). The development of

the Hydrogen Incident and Accident Database (HIAD)⁸ is an important part of the HySafe IS. The American database is being developed by the US Department of Energy and is fully and freely available at <http://h2incidents.org/> and can be completed from personal experiences. It is a simplified version of the above cited HIAD [3].

12.4 Risk assessment methods

The main difference between the risk-assessment methods presented in this chapter is in how the hazards are identified and the degree to which the risk is quantified. For some purposes it is sufficient to identify which hazards are likely to occur, yet in other cases, e.g. when comparing the risk of different systems or site layouts, it is important to quantify how frequent a hazard occurs and the expected impact the hazard will lead to at and around the particular site.

The table below summarises and gives recommendations with respect to areas of use for the risk assessment methods described in this chapter:

Method	Qualitative /quantitative	When to be used	Benefit
HAZID	Qualitative	Early in the design process when little detail about design is available. As first step of a QRA or a RRR	Identify at an early stage concerns and issues with respect to risk associated with the concept or activity. Requires little time.
HAZOP	Qualitative	During detailed design (P&IDs must be available). Detailed design review to verify a safe and reliable process design.	Focus on safe process safety and operability.
SWIFT	Qualitative	Design review of a process with focus on safe design. Less detailed than a HAZOP.	Less time consuming than a HAZOP.
FMECA	Semi-quantitative	Detailed design review with focus on safe design. An effort to rank the risk contributors is included. Less detailed than a QRA.	Less time consuming than a full QRA. Coarse method for identification of main risk contributors.
RRR	Semi-quantitative	Early in the design process when little details about design is available. Less detailed than a QRA.	Identify at an early stage concerns and issues with respect to risk associated with the concept or activity. Gives a framework for identification of main risk contributors and prioritisation of risk reducing measures.
QRA	Quantitative	A QRA may be performed during the feasibility studies, as a coarse risk assessment during the concept phase, as well as a detailed risk assessment when the facility design is frozen, when the facility is under construction, or even during the operational phase.	A detailed tool for identification of main risk contributors for an HRS design, a method for assessment of the acceptability of the design compared to defined acceptance criteria and a systematic method for identification and prioritisation of risk reducing measures. A very efficient risk management tool, particularly if used during the design of an

			<p>HRS to evaluate different design solutions and optimise design with respect to both risk and economical aspects. Can for example assess the effect of physical changes to the HRS layout.</p>
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Table 24: Summary of risk assessment methods (source: DNV)

12.4.1 HAZID – HAZard IDentification

A HAZID is a simple qualitative risk assessment method. The method is often used in conceptual design work, and the intent is to use some form of structured session to identify concerns and issues associated with the concept or activity being reviewed. Most HAZID session use drawings (PFD’s-Process Flow Drawings and layout drawings) and guidewords as basis for a structural brainstorming. A basic HAZID session does not include any quantification of a hazards probability or severity, but merely identifying the hazard. A HAZID is normally included as one of the first steps of other risk assessment methods, such as QRA and RRR which are described later in this chapter.

12.4.2 HAZOP – HAZard and OPerability study

HAZOP studies are usually undertaken to determine whether any implications of a process design have been overlooked. In particular it seeks to identify problems with the operability of the system, and any associated hazard. A HAZOP is a formal, systematic and detailed process design examination tool.

A HAZOP team should include design and operations personnel with technical experience and expert knowledge of the particulate design, as well as someone who is independent and can take an objective view of the design. A HAZOP is structured around a set of guidewords, which ensure complete coverage of all possible problems while allowing sufficient flexibility for an imaginative approach. The guidewords are used to generate questions to investigate potential deviations from the intention of the design. When possible deviations are identified the cause of each deviation, its consequences, possible safeguards, as well as recommendations and actions, are to be included in a HAZOP report.

The typical scope of a HAZOP is to consider all operations represented by a series of piping and instrumentation diagrams, P&ID’s. HAZOP approaches have also been developed for review of written procedures, control logic, electrical one-line diagrams and other systems.

The HAZOP involves systematic consideration of different parts of the process, termed nodes. The HAZOP follows a process, node by node, which also considers the interaction with the rest of the plant. The study assesses the hazard potential of operations outside the design intention or malfunction of individual items of equipment, and their consequential effects on the facility as a whole. The probabilities of hazards occurring are not assessed in the HAZOP study, thus the study is qualitative only.

The main purpose of a HAZOP is to identify how a complex system can fail and to determine qualitatively whether the process design is robust and whether the existing safeguards are adequate.

The study can contribute to process design improvements affecting the operability and the safety at the plant. A HAZOP may be required by regulatory or company specific requirements.

Being a study focusing on process design and operability the HAZOP obviously has limitations when it comes to external non-process hazards (airplane crash, earthquake, etc.). It is also not suitable for evaluation of layout specific issues such as; need for fire protection, optimising design to limit risk of explosions, use of fire walls to reduce risk to people etc. Neither is HAZOP's suitable for detailed review of complex computer control systems of which P&ID's are a poor source of document. Due to the very detailed and time-consuming examination of operability hazards, and involving a fairly large group of people, the HAZOP is a resource intensive risk assessment technique.

12.4.3 SWIFT – Structured What-IF checklist

The SWIFT technique has been developed as an efficient alternative to HAZOP for providing highly effective hazard identification when it can be demonstrated that circumstances do not warrant the rigor of a HAZOP. SWIFT can also be used in conjunction with or complementary to a HAZOP.

While a HAZOP study examines the plant line by line and vessel by vessel, SWIFT is a systems oriented technique examining complete systems or subsystems. Instead of studying each component on a P&ID, as with a HAZOP, the SWIFT study is looking at a part of the process e.g. a complete P&ID. To ensure comprehensive identification of hazards SWIFT relies on a structured brainstorming effort by a team of experienced process and control systems experts. The “what if” questions are structured according to various categories, and supplemented by questions from a checklist. Typical “what if” questions may also start with “how could”, “is it possible”, or something similar.

Before starting the group discussions the team leader should ask for input on known hazards occurred in similar facilities, previous incidents with catastrophic potential, and facility layout. The following step is to present categories for further questions and discussions. Typical categories include material problems, external effects or influences, operating errors, emergency operations, etc. For each of the categories the group members are urged to do an individual “brainstorm” to come up with appropriate questions. When all questions for a given category are asked and discussed the team goes through a checklist, corresponding to that category, ensuring that the category has been thoroughly assessed, before proceeding to the next category.

The study requires the input of knowledgeable team members to evaluate the consequences of hazards that might result from various potential failures or errors they have identified. The team is assessing the likelihood of an incident, the potential consequences, and the adequacy of safeguards to prevent or mitigate a deviation from normal intended operation through the discussion around the “what if” questions.

The advantage of the SWIFT technique compared to a HAZOP is that it is less time consuming, because it avoids lengthy discussions of areas where hazards are well

understood or where prior analysis has shown no hazards are known to exist. Its effectiveness in identifying hazards comes from asking questions in a variety of important areas, according to a structured plan, to help ensure complete coverage. However, the SWIFT method does not have the same emphasis on identification of operability related aspects as does the HAZOP.

12.4.4 FMECA – Failure Mode, Effect and Criticality Analysis

FMECA is a technique developed for detailed design review down to component level. The methodology involves a detailed evaluation of failure modes, effects, and criticality for each component, equipment and system studied.

The difference between FMEA (Failure Mode and Effect Analysis) and FMECA is the criticality analysis. While FMEA is a plain qualitative technique assessing the reliability of a system by analysing failure modes and identifying the effects of each failure, the criticality analysis quantifies the probability of each failure. Linking the probability to the effect, or consequence, the FMECA method is able to draw a semi-quantitative risk picture.

The first basic steps to prepare for the FMECA review are to 1) establish a list of functional blocks consisting of subsystems and items, 2) clarify the purpose of each item, 3) analyse and list each items failure modes, and 4) establish criterion for highlighting or acceptance; either qualitative or quantitative.

The essence of the FMECA is to apply a general questionnaire to each identified failure mode including the following questions:

- Cause of failure mode; e.g. external hazards, malfunction, failure derived from sub-item.
- Effect of failure; either a local effect affecting the item only or a global effect affecting the main system operation.
- Detection; how is the failure detected?
- Response and repair; what are the corrective actions taken to eliminate the failure mode, minimize the effect, or to repair failed items?
- Consequences; what is the severity of the failure mode with regards to personnel, environmental, and economic loss?
- Probability; what is the probability of the failure modes appearance?
- Actions and remarks; what actions are to be taken if the effect of a failure mode exceed the acceptance criterion? Are there any recommendations for design or operation improvements?

For practical purposes an overview of the risk may be presented in a probability-severity matrix designed to highlight the acceptability of the risk.

12.4.5 QRA – Quantitative Risk Assessment

QRA is a methodology to quantify the risks of a plant or facility. To be able to quantify the risk, the frequency of the relevant hazards and the potential consequences of the hazards must be quantifiable as well. Much of the effort in a QRA thus has to be on the frequency analysis and consequence assessment.

The hazard identification normally takes the form of a HAZID, as described in § 12.4.1. However, if a HAZOP, a SWIFT or a FMECA study has been performed for the system ahead of the QRA, results from these studies can also be used as input to the QRA. The qualitative outcome of this hazard identification process should form the basis for the scenario selection.

All incidents and failures leading to a given scenario should be analysed in order to quantify the frequency of such a scenario. The frequencies are calculated based on available statistical data and/or detailed cause analysis. Likewise the potential consequences of all selected scenarios should be quantitatively assessed. In general when consequences are calculated for fire and explosion events, one will consider the potential release (release calculations), the potential for gas build-up and dispersion (dispersion calculations), as well as dimensions and duration of any resulting fire (fire and explosion calculations). Fire and explosion hazards may affect people in a variety of ways, primarily relating to impact of heat / radiation and explosion overpressures (hazardous effects). Based on the effect calculations the impact on people or equipment exposed to the hazardous effects is assessed.

By multiplying the frequencies with the probability of a given impact and the impact in terms of i.e. number of fatalities, the risk of such an impact is quantified, typically utilising an event tree. The risk is then compiled to a format so that it can be compared with the risk acceptance criteria applicable for the specific HRS. Risk Acceptance Criteria for a hydrogen refuelling station can be set by the authorities in the relevant country or by the station owners, depending on the regulations in the country. If the estimated risk level is too high compared to the acceptance criteria, risk reduction measures must be identified and implemented. Through the risk assessment it is quantified which are the main risk contributors on the HRS. The main risk contributor should have a special focus in the risk reduction process and with respect to safety management of the facility.

Based on the findings from the QRA, risk reduction measures are suggested and the risk reducing effect of the measures can be quantitatively evaluated. By evaluating the effect on risk and the cost of different suggested risk reducing measures, the most optimal measures with both respect to risk reduction and economy can be selected for implementation.

QRA's can be a very efficient risk management tool, particularly if used during the design of a HRS to evaluate different design solutions and optimise design with respect to both risk and economical aspects. For example to:

- Optimise relative location of equipment, to prevent escalation and/or exposure of people to potential accidents
- Optimise shutdown segment sizes
- Assess the need for fire protection of equipment or support structure
- Assess the need for designing buildings against explosion overpressures

A QRA may be performed during the feasibility studies, as a coarse risk assessment during the concept phase, as well as a detailed risk assessment when the facility design is frozen, when the facility is under construction, or even during the operational phase. The level of detail and scope of work will vary at the different stages of facility development. Since the QRA may include one or more of the

previously presented assessment methods it must obviously be considered more time and resource consuming.

Compared to qualitative studies, like HAZID, HAZOP, FMEA, and SWIFT, the quantitative frequency analysis and consequence calculations make the QRA a more accurate risk assessment tool. The risk result is depending on data directly linked to components or systems failure frequency, and calculations based on the facility layout. Component and system changes or changes in facility layout may therefore be directly reflected in the calculated risk.

A QRA, conducted on a reference HRS, is presented as an illustration in Appendix IV. In this particular QRA study on a reference Hydrogen Refueling Station, the use of Leak offshore data has been used because of the lack of data and information on Hydrogen leaks, which makes it difficult to calculate leak frequencies. However, the results give an indication of the leak frequency that can be expected. Thus, the results should not be used to conclude whether the safety risk at Hydrogen Stations is acceptable or not. They can, however, be used as input to where risk reducing measures, if necessary, would give the largest benefit.

12.4.6 RRR – Rapid Risk Ranking

RRR [9] is a simpler approach than a QRA, and suitable to be used when the information available is not sufficient for a full QRA. The methodology was developed (and applied) in the EIHP2 project⁹ to undertake assessments of HRS alternatives at an early development phase where detailed information is generally lacking. The method is based on risk ranking, of identified hazards and their probability and consequence. The hazard identification and risk estimation will normally be undertaken in a group session. When specific data is not available, the assessments will be based on judgements made by the group of experts and project owners participating. As RRR depend on expert judgement the knowledge, competence, and experience requirements to the members of the assessment team is high. The risk result may be characterised as semi-quantitative.

For a large facility, such as an HRS, it may be recommended to split the system into subsystems, e.g. production unit, compression unit, storage facility, and dispenser unit. The steps of a RRR are similar to the steps of a QRA except that the detailed frequency calculations and consequence assessments are replaced by estimates and evaluations.

Typical steps when performing a RRR are:

- Concept presentation, where the layout drawings of the facility and process conditions are presented together with a description of detection, control, and emergency systems
- Hazard identification session
- Frequency, consequence and impact estimation
- Risk evaluation and ranking
- Assessing the risk and comparing it with the acceptance criteria defined
- Identification of remedial actions where needed

⁹ <http://www.eihp.org/>

12.4.7 Hazard consequence models used in QRA

To quantify the risks posed by particular hazard scenarios both the frequency of occurrence and the severity of the consequences must also be quantifiable. The consequences are usually quantified using mathematical models; these may be either so-called Engineering models or Computational Fluid Dynamics (CFD) models. The purpose of this section is to describe briefly both types of model and their merits in the context of the approval process for a HRS. In support of this handbook a thorough assessment of the hazards associated with a HRS was performed. From an extensive list, a number of interesting and representative scenarios were analysed using state-of-the-art CFD models; the results are summarised in Appendix V.

Engineering models are based on a simplified representation of the physics and on experimental data. This means that the models will have a limited range of applicability and caution must be exercised so as to not extrapolate the results of the model too far. The engineering models are not generally able to take into account a complex geometry. The models are generally conservative, and sometimes overly conservative, but are relatively easy to use and provide a near-instant answer.

CFD modelling involves solving a set of partial differential equations governing: conservation of mass, momentum, energy, species mass fractions and turbulence quantities, which are strongly coupled and highly non-linear in nature. In principle, it is possible to model very complex scenarios, though in reality one will typically have to exclude some details in order to make the simulation tractable. The computational domain is divided into a number of small elements, often referred to as computational cells. The cells can take many different shapes, e.g. tetrahedrons or hexahedrons, where the former cells are typical of an unstructured mesh and the latter of a structured mesh. The set of partial differential equations are then solved for each of the computational cells; typically up to a million cells are used. It is also necessary to define suitable boundary conditions and initial conditions.

The accuracy of the CFD simulation is dependent on a number of factors such as time step size, if the problem is transient, the resolution of the mesh, where a finer mesh leads to a more accurate solution, the choice of physical sub-models, i.e. turbulence and combustion models, and the initial and boundary conditions, which are not always known. The output from CFD models can be quite beguiling, and the extent to which particular models have been validated for specific applications should always be ascertained.

Figure 33 shows an example of how elements of an HRS might be represented in a CFD model with a typical mesh, finest in the areas where the greatest detail is needed. The elements: a vehicle (green), dispenser units (magenta), and a wall (grey), are somewhat simplified.

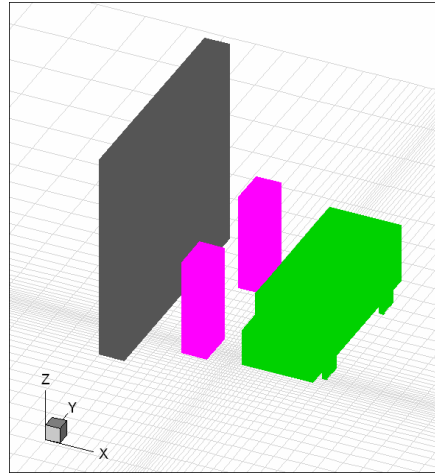


Figure 33: CFD model representation of a vehicle and dispensers units on a HRS

Figure 34 shows typical outputs from a CFD simulation: the extent of the hydrogen-air cloud above the lower flammability limit (a), and a colour contour plot of the hydrogen concentration (b), from a hydrogen leak at one of the dispensers.

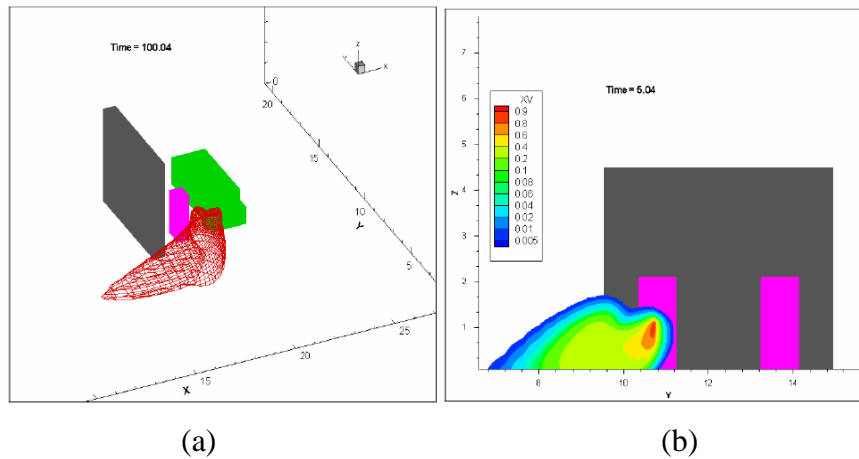


Figure 34: Typical output from a CFD simulation

As illustrated above, the visual aspect of CFD output can be particularly valuable in showing the extent of hazard consequences.

CFD simulations tend to be time-consuming to set up and the computer run times can be of the order of weeks for the most complex scenarios. This would make the use of CFD intractable if a large number of different scenarios need to be modelled. A number of different approaches based on probabilistic reasoning have been developed, which can reduce the number of CFD simulations required.

In summary, engineering models are widely used in assessing hazard consequences, they are quick and easy to use but they are not well suited to complex geometries. Increasingly, the more sophisticated CFD models are being used, as both the models themselves, and the computers on which they run, are rapidly improving. CFD models

require expert users, but they do provide very detailed output that cannot be matched by simple engineering models.

12.4.8 Combination of risk assessment methods

Different risk assessment methods have different benefits and, also, different drawbacks. They also have different levels of depth in the global risk analysis. Figure 35 shows the guideline proposed in the project CUTE. It is a good example of the order in which to use some of the risk assessment methodologies explained. The idea is to start with a simple, straightforward and robust methodology (RRR) in order to refine, step by step, the conclusions obtained by using other methodologies that improve the results obtained, up to the QRA analysis, a very efficient and detailed risk management tool.

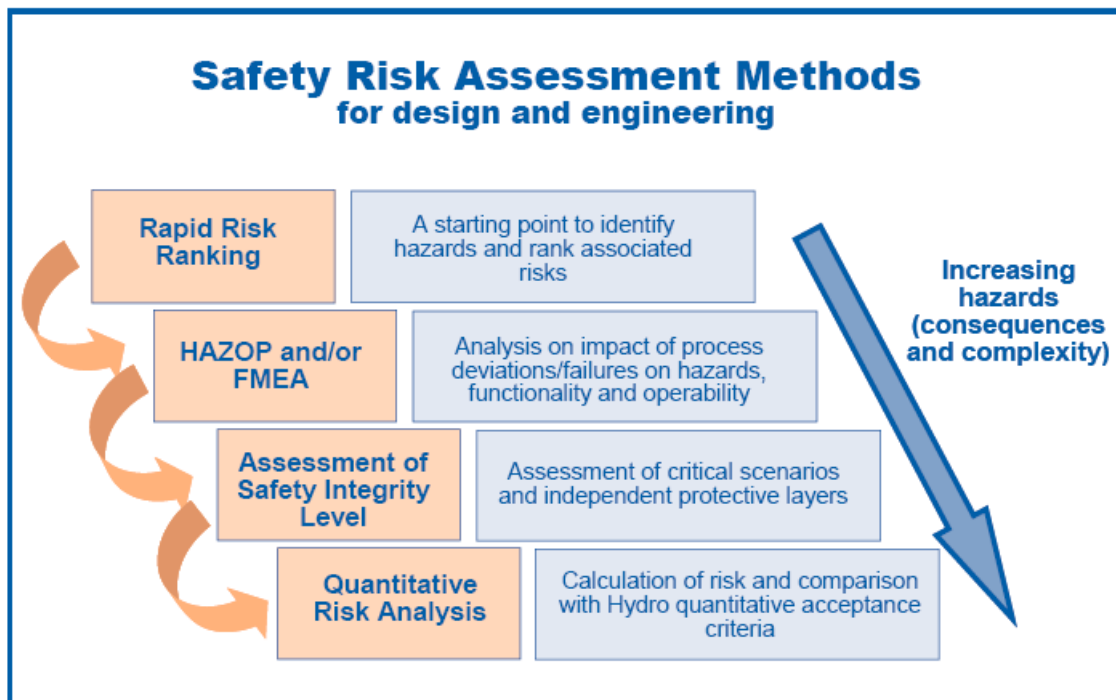


Figure 35: Safety risk assessment methods [2]

Project CUTE (Clean Urban Transport for Europe) was an ambitious project in the field trial of fuel cell buses and their hydrogen infrastructure [8]. The project follows a comprehensive approach in which safety is an important task, and its recommendation in risk assessment methodology is shown in this paragraph as several HRS's have been set up in the framework of this project, being this experience very valuable.

12.5 Most common hazards in HRS's

The main layout of an HRS is shown in Figure 36. There are several processes of production of hydrogen that can be carried out on-site or in an external place, so the purification and compression do. The storage can be made at different levels of pressure or, even, liquid. Something similar happens to the dispensing of hydrogen, which can be liquid or gaseous at different levels of pressure.

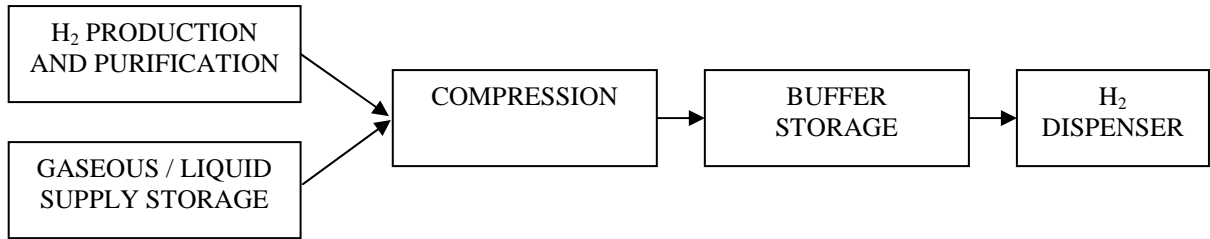


Figure 36: Flowchart of an HRS

Despite of all the possible alternatives in an HRS, there exist some common hazards that must be taken into account in a first preview of a risk assessment process. They are shown more precisely in [5] for an HRS with on-site production with an electrolyser, but, mainly, the hazards are:

1. Hydrogen gas leak inside the production unit.
2. Hydrogen gas leak from compressor unit.
3. Hydrogen gas leak from the storage unit.
4. Catastrophic rupture of a hydrogen cylinder caused by material failure, internal explosion or escalated jet fire.
5. Hydrogen gas leak from piping/valves/connections between storage and dispenser.
6. Hydrogen gas leak in the dispenser area.
7. Hydrogen gas release from car refuelling at HRS.
8. Hydrogen liquid release from car refuelling at HRS.
9. Hydrogen release from loading system during unloading of tanker.
10. Hydrogen leak from connection or valve at the H₂ tank.
11. Catastrophic rupture of H₂ tank caused by material failure or escalated jet fire.
12. Hydrogen leak from H₂ distribution system or pump.
13. Hydrogen leak in the H₂ dispenser area.

It is not strange to notice that all of the hazards with the hydrogen in an HRS are related to leaks. It is like this due to the properties of hydrogen and its propensity to ignition, deflagration and detonation. Another important source of hazard that can lead to a leak is the hydrogen embrittlement: the result of hydrogen entering into the structure of the metal, causing the metal to lose some of its strength.

Another very important source of hazard concerns human errors. An error is defined as the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim. A table of proposed nominal human unreliability that could be used in a risk assessment is shown in Table 25.

GENERIC TASK	UNRELIABILITY (%)
Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55
Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26
Complex task requiring high level of comprehension and skill	0.16
Fairly simple task performed rapidly or given scant attention	0.09
Routine, highly-practised, rapid task involving relatively low level of skill	0.02
Restore or shift a system to original or new state following procedures, with some checking	0.003
Completely familiar, well designed, highly-practised, routine task occurring several times per hour, performed to highest possible standards by highly-motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids.	0.0004
Respond correctly to system command even when there is an augmented or automated system providing accurate interpretation of system stage.	0.00002

Table 25: Generic classification of proposed nominal human unreliability [7]

12.6 Bibliography

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Part II: Permitting process

13 Description of the recommended approval process for HRS

The process of obtaining an approved Hydrogen Refuelling Station (the Process) is outlined in Figure 37. The Process involves three parties: The Owner, the Project and the Authorities. The roles and responsibilities of the three parties are indicated in the figure and further described in the Process description below.

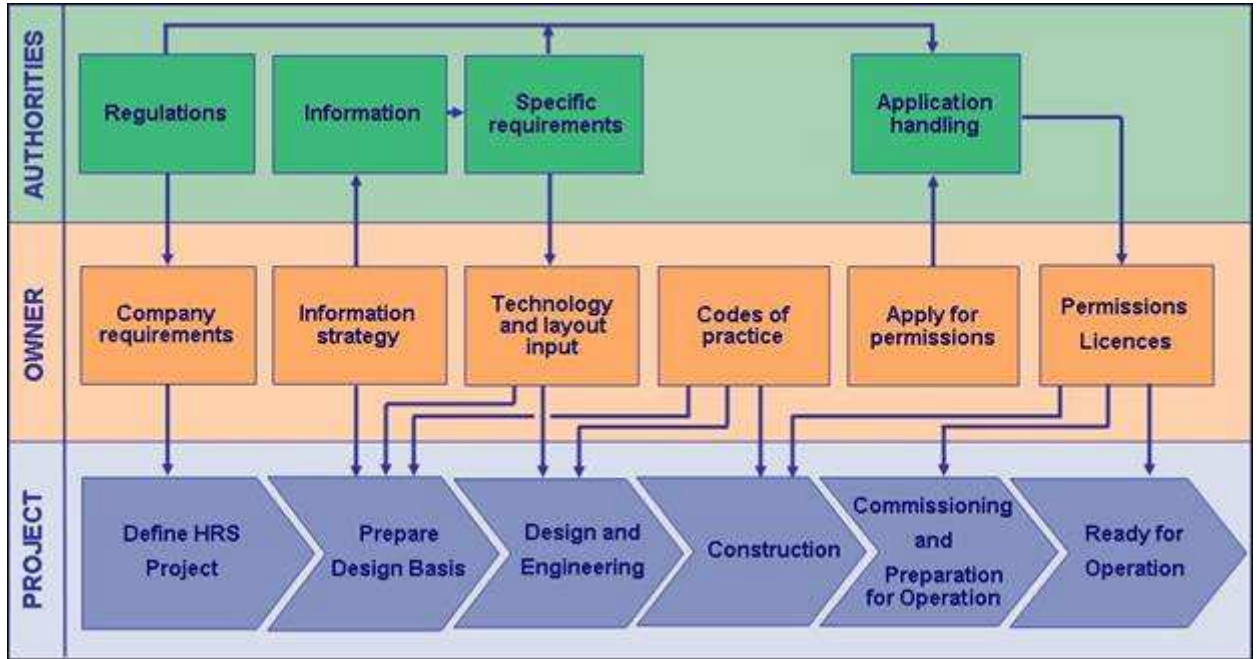


Figure 37: The Process of obtaining an approved HRS

13.1 The Roles

The Owner:

The Owner is the party that owns the HRS and that decides the location, the capacity, the technology basis and that supplies the overall framework for establishing the HRS.

The Project:

The Project is the Owner’s organisation that accomplishes the establishment of the HRS. The Project may involve external consultants and specialists whenever beneficial for the establishment of the station.

The Authorities:

The Authorities are the bodies that set the requirements for the HRS, and ensure compliance of those requirements. The authorities approve the station, and issue the required permissions and licences.

The Authorities comprises regional, national and local authorities. The Authorities may delegate certain parts of the control and approval tasks to a Notified Body.

13.2 The Process

Step 1: Define HRS Project Scope

The overall concept of the HRS Project is defined by the Owner. This definition should include the overall concept of hydrogen supply and processing, the location, the capacity, and the operating philosophy. Mandatory requirements, i.e. regulations set by the Authorities (appendix) and requirements set by the Owner (Company requirements) should also be included in this definition.

Step 2: Information to the Authorities and Stakeholders

As soon as establishment of an HRS is foreseen, the Owner should inform the Authorities and other Stakeholders, e.g. neighbours and other local bodies, about the HRS Project. Although information to the Authorities at this stage is regarded to be informal, the Owner should inform the Authorities that a formal application according to specified regulations will be issued at later stage. The Authorities may outline specific requirements for the HRS, e.g. due to location, population, lay out, etc. These requirements should be included in the Owner's input to the Project.

Step 3: Prepare the HRS Design Basis

Having defined the scope of the HRS Project a detailed Design Basis for all parts of the HRS should be prepared. The specifications and the concepts described in the Project definition should act as basis for preparation of the Design Basis. In addition, the Owner's information strategy, the hydrogen supply and technology basis and a basic HRS layout should be included.

The Design Basis should also include a list of recognized standards and codes of practice that should be used as guidelines in the design and construction of the HRS. This list of standards and codes of practice typically comprise both national and international standards as well as the Owner's Company Best Practice. A list of reference documents are given in § 7.

All requirements set by the Authorities or by the Owner should be included in the Design Basis.

Requirements and targets related to Health, Safety, and Environment (HSE) should be specified in the Design Basis. A typical framework for ensuring that the HSE requirements are complied with is by implementing the following principles in the order as indicated:

1. Principles of inherent safety
2. Barriers preventing development/limiting consequences of incidents/ accidents
3. Operational instructions

Step 4: Design and Engineering

The HRS should be designed according to the Design Basis. The standards and codes of practice listed in the Design Basis should be used actively as guidelines in order to create a practical, cost efficient and safe HRS in compliance with all mandatory requirements.

The engineering activities should include preparation of all documentation needed for construction as well as documentation relevant to demonstrate that all requirements set by the Authorities and by the Owner are met. Normally, safety studies are prepared in this step.

Documents to be included in the Owner’s formal application to the Authorities should be prepared.

The process of obtaining an approved HRS focused on the approval process

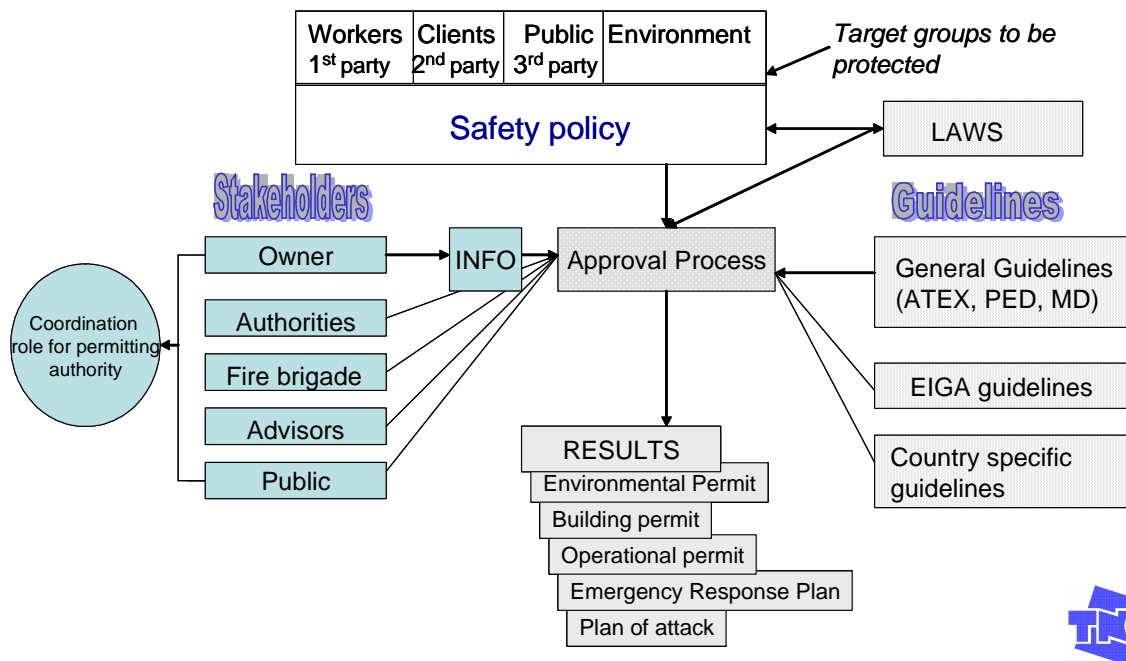


Figure 38: Process of obtaining an approved HRS focussed on the approval process

The approval process from the authorities’ point of view starts when the owner of the future HRS applies for the respective permits, such as there are: a building permit, an environmental permit and an operating permit. In the first stage of the building and approval process of an HRS, steps 5, 6 and 7 address the actual approval process used by the authorities. These steps are outlined below.

Step 5: Apply for permissions

As soon as the HRS is designed and all documents needed for formal application to the Authorities are prepared, the Owner should send a formal application to the Authorities. Depending on local and regional regulations, separate applications for

construction and operation may be needed. The Owner and the Project should be well aware of the Authorities' application handling procedures in order to implement the application handling in the timeline of the HRS establishment project.

When a future owner of a HRS applies for the permit, the first task of the permitting authority should be to bring all stakeholders together to inform each other about the information needed, to clarify the roles in the process and to agree on a realistic time schedule for the activities to be executed. The information about the documents to be submitted to the authorities is presented in chapter 14.4.3.

Step 6: Application handling

The Authorities should handle the applications according to procedures set forward in the regional or local regulations including any specific requirements given to the HRS project.

The Owner and the Project should be understand the application handling procedures and may be asked to present the HRS station project formally to the Authorities as part of the formal application process.

During the formal handling process the Authorities control that all requirements are fulfilled and duly documented. Any clarification or additional information needed should be communicated by the Authorities to the Owner at an early stage of the Application handling.

The Application handling process may include a public hearing.

The authorities will issue a permit for activities involving hazardous substances based on the existing laws. The intention of these laws is to protect the various target groups such as the workers (1st party), clients of the HRS (2nd party) and the public (outside the gate: 3rd party).

Generally these laws include:

1. Prevention of accidents.
2. Creation of a safety zone or safety distance.
3. Optimal preparation of emergency services (contingency planning).

For specific country legal requirements see chapter 14.4.1.

Step 7: The Issue of Permissions and Licences

The authorities will judge, depending on their safety policy:

1. Which of the various guidelines for the construction of a HRS are applicable and
2. Whether a hazard identification study an/or qualitative and/or quantitative risk assessment study is required
3. They have a requirement to be informed on the actual implementation of preventive safety measures, zoning measures and preparation measures aiming to protect the various target groups against possible dangers

Before granting the permits, a plan of attack (to be set up by the fire brigade) and an emergency response plan (to be set up by the municipality + emergency services) will be required by the authorities.

When all requirements set forward by the Regulations or by the Authorities as specific requirements are complied with and well documented in the Owner's Application, the Authorities are expected to issue formal permissions for construction and for operation.

Step 8: Construction of the HRS

Having received the permission for construction, the HRS should be constructed as designed and detailed engineered and according to the documentation prepared. Codes of practice specified for construction should be followed.

Construction of the HRS the Project shall comply with the Construction Licence issued by the Authorities. Communication with the local Fire Brigade should be initiated in order to outline an Emergency Plan for the HRS.

Step 9: Commissioning and Preparation for Operation

The construction is completed by checking that the HRS is erected as planned and that all equipment and items included in design are implemented. During commissioning the equipment and systems should be tested and its performance documented.

In parallel to commissioning of the HRS preparation for operation should take place. This involves among others, preparation of operating instructions, preparation of instruction for maintenance and inspection, preparation for emergency plan, planning for emergency drills, training of personnel (operation, maintenance, emergency), etc.

Preparation for Operation also includes planning for implementation of the Licence to Operate issued by the Authorities.

Step 10: HRS ready for operation

Having carried out all the tasks included in the previous steps, the approved HSR is now ready for effective and safe operation with due compliance with the Owner's and the Authorities' requirements and expectations. All documentation should be updated "as built", and readily available to all parties as needed for operation, maintenance, inspection and emergency handling.

14 Country specific issues

14.1 Introduction to country specific issues

The country specific issues focus on the requirements of the authorities with respect to the safety assessment for the approval of an HRS in 5 EU member states, the USA and China. The 5 EU member states are: France, Germany, Italy, Spain and the Netherlands.

Paragraph 14.2 illustrates the identification of stakeholders in the approval process in the above-mentioned 7 countries. The safety requirements for approval of an HRS were identified through interviews.

A compilation of the interviews is given in paragraphs 14.3 thru 14.11.

The analysis of the interviews in the 5 EU member states, the USA and China with respect to the requirements is presented in paragraphs 14.3 thru 14.5.

Depending on the interviewed party, certain topics gained more attention than others.

The interview protocol is shown in Appendix II.

14.2 Identification of stakeholders

Representatives of the following categories of stakeholders were interviewed:

- The owner of the HRS who will generally be the applicant for the permit(s).
- The authority or authorities issuing the permit(s). Depending on the political organisation of the various countries the authority could be an autonomous region, a local regulator, or even an accredited supervisory board. Often separate permits are required for building and operation of an HRS.
- Advisors to the authorities issuing the permit(s). The authority may seek specialised advice for the issues to be considered like environmental impact, public health and safety and workers health and safety. The following was suggested:
 - o Fire brigade. In most countries the fire brigade gives (compulsory) advice on permits on (preventive and mitigating) safety measures and on contingency planning.
 - o Labour inspectorate and /or other inspectors.
- The (governmental and/or advisory) bodies responsible for creation and / or implementation of guidelines and legislation as applied by the authorities issuing the permit(s).
- Members of the public working and/or living in the vicinity of the (future) HRS

In those EU countries where HRS's had been established in the framework of the CUTE (Clean Urban Transport for Europe) project (Germany, Spain, The Netherlands) the authorities involved in the approval process, were approached. In Italy and the USA authorities involved in the approval process of HRS's, built outside the CUTE context, were approached. As no HRS exist in France it was decided to approach the authorities involved in the regulations on dangerous substances (like

SEVESO II) as a starting point. In China the Beijing Fire-brigade Bureau is involved in the approval process of Beijing Hydrogen Park.

14.3 Responsibility and liability of the stakeholder interviewed

In Table 26 an overview of the organisations interviewed and their role in the approval process is presented.

Country	Approval role	Name of organisation interviewed
Germany	Issuer of permit	Behörde für Soziales, Familie, Gesundheit und Verbraucherschutz - Hamburg
	Advisor to issuer	Gewerbeaufsichtsamt bei der Reg. v. Oberbayern - München
	Inspection authority	Regierungspräsidium Darmstadt, Abt. Arbeitsschutz. Frankfurt.
France	Advisor to issuer	DRIRE Inspector (of Rhône Alpes region) Fire brigade (of Fontaine city)
	Responsible for legislation	Ministère de L'écologie et du développement Durable - coordination of inspection services (DRIRE).
	Issuer of permit	Prefect of the "département" : not interviewed
	Inspection authority	DRIRE inspector (Rhône Alpes region)
	None	Coordination of Hydrogen project founding in Direction Générale des Entreprises
	None	Ministère de l'Intérieur, Direction de la Défense et de la Sécurité Civile DDSC - Risk and Crisis Management – in charge of technical and chemical hazards.
Italy	Issuer of permit	Sportello unico per le imprese del comune di Mantova (Single Counter for Business Activities of Mantova City Council)
	Advisor to issuer	Azienda Sanitaria Locale (ASL) della Provincia di Mantova, Servizio Prevenzione Sicurezza Ambienti di Lavoro (Local Health Service of the Province of Mantova, Service for Prevention and Safety in the Working Environment)
	Advisor to SIUC for building permit and operating license, issuer of Fire Prevention Certificate	Comando Provinciale Vigili del Fuoco (Provincial Fire Brigades Headquarters)

Country	Approval role	Name of organisation interviewed
	Hierarchically superior to Provincial Fire Brigade Headquarters	Direzione Regionale dei Vigili del Fuoco della Lombardia (Lombardy Region's Fire Brigades Headquarters)
	Advisor to issuer	Agenzia Regionale Protezione Ambiente (ARPA), Dipartimento di Mantova, Unità Operativa: Territorio e Attività Integrate (Lombardy's Regional Environmental Protection Agency, Department of Mantova, Operative Unit: Territory and Integrated Activities)
	Inspection authority	ISPESL (technical-scientific body in the National Health Service)
Netherlands	Owner	GVB – Municipal Transportation Company Amsterdam
	Issuer of permit	Amsterdam City council
	Advisor to issuer	Environmental & Building Department (DMB-Amsterdam)
		Fire brigade Amsterdam
	Responsible for legislation	VROM inspectorate (Ministry of Housing, Spatial Planning and the Environment)
None	NIFV Netherlands Institute Physical Safety Nibra Arnhem (Task a.o: Training institute for fire brigade)	
Spain (MADRID)	Owner	Empresa Municipal de Transporte (EMT) - Madrid
	Issuer of permit	Comunidad de Madrid. Dpt. De Industria. Madrid
Spain (BARCELONA)	Customer	TMB (Transportes Metropolitanos de Barcelona)
	Issuer of permit	Generalitat de Catalunya. Dpt. De Trabajo e Industria. Secretaría de Industria. Barcelona
USA	Advisor to issuer District of Columbia	DC Office of the Fire Marshal
		DC Department of Health: Environmental Division
		DC Department of Consumer and Regulatory Affairs
	Advisor to issuer State of Michigan	Michigan Department of Environmental Quality/Waste and Hazardous Materials Division/Storage Tank Unit
	Advisor to issuer State of California	Office of the State Fire Marshall
	Issuer of permit State of New York	New York State Dept. Division of Code Enforcement and Administration

Country	Approval role	Name of organisation interviewed
	Issuer of permit State of Nevada	Local government of Las Vegas
	Advisor to issuer State of Florida	Department of Environmental Protection, Tallahassee, Florida
		Division of State Fire Marshal Tallahassee
	Issuer of permit State of North Carolina	Office of the State Fire Marshall in the Authority Having Jurisdiction (AHJ)
China	Issuer of project permit	Beijing Municipal Commission of Development and Reform
	Issuer site permit	Beijing Bureau of Land Resources
	Issuer of fire protection permission	Beijing Fire Brigade Bureau

Table 26: Overview of parties interviewed in various countries

No ‘members of the public’ were interviewed.

The following was emphasised by all parties:

Coordination

The coordination between the stakeholders involved is an important issue, whereby it should be clear which authority has the coordination role. It is advisable that the parties involved seek after agreement on discrepancies in an early stage.

Community relations

To facilitate community acceptance of the HRS it is advisable to determine the requirements for community relations efforts. Neglect of the community concerns and issues may delay the implementation of the project afterwards.

14.4 Required information

14.4.1 Laws/regulations applied

The information that is required for the approval of the building and operation of an HRS will depend on the laws and regulations applicable. As HRS’s are a relatively new type of infrastructure there is not yet a complete view of the risks involved. Neither dedicated regulations nor guidelines exist. Hence other sources of information are used.

In some countries the national implementation of the SEVESO-II guideline is the leading document. As quantities of hydrogen currently stored, or planned to be stored, at an HRS (max. 3.5 tons) are well below the lower limit specified in the SEVESO

guidelines (5 tons) these guidelines are, strictly speaking, not applicable. They were mainly used as an information source for methods, techniques and criteria that could be useful for the safety assessment of an HRS. Once the safety risks associated with an HRS are understood, a more general approach (as for e.g. LPG stations in the Netherlands) may be adopted. Table 27 shows the regulation and guidelines used for the approval of an HRS according to the interviewed parties in the various countries.

Country	Laws/regulations applied regarding HRS
France	<p>Loi n° 76-663 du 19 juillet 1976 relative aux Installations Classées pour la Protection de l'Environnement / French regulation for classified installations for environmental protection (ICPE)</p> <ul style="list-style-type: none"> - Décret n° 77- 1133 du 21 septembre 1977 pris pour l'application de la loi n° 76-663 du 19 juillet 1976 relative aux Installations Classées pour la Protection de l'Environnement / Application decree for above regulation. - Arrêté ministériel du 10 mai 2000 modifié par l'arrêté du 29 septembre 2005 (Loi Bachelot - Arrêté du 29 septembre 2005 relatif à l'évaluation et à la prise en compte de la probabilité d'occurrence, de la cinétique, de l'intensité des effets et de la gravité des conséquences des accidents potentiels dans les études de dangers des installations classées soumises à autorisation) - Loi du 30 juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages - Circulaire du 29 septembre 2005 relative à l'appréciation de la démarche de maîtrise des risques. <p>The above regulation sets two authorisation regimes depending on the hazardous potential of the industrial site:</p> <ul style="list-style-type: none"> - Declaration regime (lowest hazard) - Authorisation regime (highest hazard) <p><u>Under declaration regime:</u></p> <ul style="list-style-type: none"> ▪ Arrêté type – rubrique n° 1416 de ICPE¹⁰ Stockage ou emploi de l'hydrogène (hydrogen storage environmental expectations for stored quantity between 100kg and 1000 kg). <p><u>Under authorisation regime:</u></p> <ul style="list-style-type: none"> ▪ Arrêté type – rubrique n° 1416 de ICPE Stockage ou emploi de l'hydrogène (hydrogen storage environmental expectations for stored quantity above 1000 kg). ▪ Arrêté type – rubrique n° 1415 de ICPE fabrication industrielle d'hydrogène ((hydrogen production environmental expectations for on site hydrogen production whatever the quantity) <p>- Circulaire du 24 mai 1976 relative aux dépôts d'hydrogène liquide / Technical note for liquid hydrogen storage</p> <p>Approval from local authority required on the basis of a specific safety and environmental study (Etude de danger et Etude d'impact).</p>
Germany	<p>HRS's are installations needing a certificate according to §13 BetrSichV (Betriebssicherheitsverordnung) In case of storing up to 10.000 Litres of H₂, the Störfallverordnung is not applicable.</p>
Italy	<p>DM 31 August 2006 Fire Prevention Technical Rule for HRS (SEVESO-II is optional)</p>
Spain	<p>In Barcelona, I.I.A.A. (national implementation for SEVESO-</p>

¹⁰ ICPE: Installation classée pour la protection de l'Environnement

Country	Laws/regulations applied regarding HRS
	II), in Madrid, Reglamento de aparatos a presión
Netherlands	BRZO (implementation of SEVESO-II)
USA	International Fire Code, NFPA 52, NFPA 55, and NFPA 70.
China	Design Code for hydrogen gas stations (GB50177-2005)

Table 27: Guidelines and regulations applied for approval of HRS's in various countries

14.4.2 Permits required

Appendix II shows, under the heading 'Permits required', that the approval process of an HRS may consist of obtaining a number of permits:

- A building permit,
- An environmental permit and
- An operating permit.

Not all permits are required in each country and the order in which permits have to be obtained differs as well. Chapter 13 is focussed on the requirements of the authorities regarding the safety assessment of the approval. For a number of countries the approval process is illustrated in the flowcharts in chapter 14.14.

14.4.3 The required information by the authorities

The owner of the HRS has to apply for the permits.

In most countries the following documents have to be submitted to the authorities:

- Location of the HRS and its surroundings (drawing and lay-out)
- List of plant components e.g. piping, fittings, vessels, materials, heat exchangers etc. and used guidelines/regulations.
- A short description of the process and Process Flow Diagrams (PFD's)
- Impact study on environmental impact in day to day use (gaseous and liquid emissions, noise emissions, waste water, soil contamination)
- Mitigating and preventive safety measures including explosion and fire detection
- Intervention measures in the event of abnormalities

In addition, some countries/states require:

- Hazard identification study, special attention for brittleness (For information on brittleness see EIGA Doc 15 05)
- Qualitative or quantitative Risk Assessment studies (QRA)
- Declaration of installation of pressurised equipment
- Electrical design as well as grounding system and lighting protection system
- Listing of measuring and control systems
- Listing of applicable Regulations, Codes & Standards

- Installation plan and utilities
- Operating instructions

14.5 External and occupational safety policy concerning hydrogen

14.5.1 Target groups for a safety assessment

Three target groups can be distinguished for a safety assessment:

- The public, outside the HRS. This is the target group for external safety. The basic principle of external safety is to guarantee the public a specific level of protection against threats posed by dangerous substances in their immediate environment. The table in Annex II shows that external safety is not always (Germany) or not anymore (Italy) identified as a separate topic. The authority that pursues the policy in this respect may be a health authority (Germany) or/and an environmental authority (The Netherlands, France, Spain).
- Employees of the service station – This is workers safety. This is often the concern of the Labour inspectorate. This aspect was not specifically addressed during the approval process, except in Germany. However, the HRS operating permit itself often contains regulations concerning the skills of attendants and the procedures to be followed by them (e.g. in case of an emergency). Also it is implicitly assumed that compliance with technical standards will largely take care of workers safety. This applies for the Netherlands, Spain and Italy. In France, safety of workers concerns is handled by Labour inspectorate. However, topics such as ATEX zoning (EC/99/92 EC) are dealt with by both labour inspectorate and environmental authority when hazardous industrial activities are concerned.
- Safety of customers at the filling station. For professionals, like the bus drivers of hydrogen fuelled buses, the HRS operating permit may require that persons that execute the refuelling operation should be well instructed. For private customers safety should be more or less guaranteed by proper technical standards or similar rules as for professional drivers may apply.

14.5.2 Safety Policy

Conceptually three stages can be distinguished in a safety policy:

1. Prevention of accidents by application of state of the art technology and following technical standards
2. Creation of a safety zone or safety distance
3. Optimal preparation of emergency services (contingency planning)

In all countries interviewed these three elements were identified.

The prime assurance for the prevention of accidents (and thus taking care of external, worker's and customer's safety) is reached by applying state-of-the-art technology through standards and guidelines. These guidelines are mostly based on experience with compressed natural gas (CNG) but may also be formulated in general terms (like the BetriebsSicherheitsVerordnung Betr.SV – Germany) (see also paragraph 14.6). A

review of best practises on actual experiences with HRS is also presented in WP4 (Deliverable 4.1).

In addition to the prescriptive safety policy, risks may further be reduced by spatial zoning, i.e. the application of safety distances.

France and the Netherlands use a Quantitative Risk Assessment (QRA) to determine the safety distance.

In Italy specific safety distances for HRS included in DM 31/8/2006 are used (based on previous experience with CNG). A QRA, performed on the first HRS in Italy, had shown these to be adequate.

In the US safety distances are determined on the basis of state regulations and applicable codes.

No particular mention of safety distances is made by Spain, although it is mentioned that the normative for CNG is used for the approval of HRS's in Spain. In Spain, both HRS's are inside the bus station perimeters so they do not consider special distance requirements. The HRS's are not considered to be "public" ones.

Germany mentions the use of safety distance, but no method is specified.

In all countries contingency planning is also part of the safety policy. Usually the fire brigade is the leading party in here.

14.6 Technical standards for the construction of an HRS

In Table 28 and Table 30 the technical standards for the construction of an HRS used in all European countries are mentioned as well as those used in the USA and China. For completeness the Codes of Practice of the EIGA are mentioned in Table 29.

Pressure Equipment Directive 97/23/EC
Machinery Directive 98/37/EC
Low voltage Directive 2006/95/EC
Electro Magnetic Compatibility Guideline 89/336/EC
ATEX 137 Directive 99/92/EC Guidelines for determination "non-classified", "zone 0", "zone 1", zone2 in IEC 60079-10. Explosion safe equipment according EX-Zone 1 at locations where H2 is present in apparatus and pipelines

Table 28: Technical standards used in all European countries

EIGA Document IGC 15/06 – Gaseous Hydrogen Stations
EIGA Document IGC 6/02 – Safety in storage, handling & distribution of liquid H ₂
EIGA Document IGC 75/01 – Determination of Safety Distances
EIGA Document IGC 23/00 – Safety training of employees
EIGA Document IGC 40/02 – Work permit systems
EIGA Document IGC 88/02 – Good environmental management practices for the industrial gas industry
EIGA Document IGC 90/03 – Incident/accident investigation & analysis
EIGA Document IGC 100/03 – Hydrogen Cylinders & Transport Vessels
EIGA Document IGC 102/03 – Safety audit guidelines
EIGA Document IGC 122/04 – Environmental impacts of hydrogen plants

Table 29: Technical standards of the European Industrial Gases Association available in Europe but not always mentioned by the interviewed

NFPA 52 (Vehicular Fuel Systems Code)
NFPA 55 (Standard for the Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks)
NFPA 30A (Code for Motor Fuel Dispensing Facilities and Repair Garages)
NFPA 57 (Liquefied Natural Gas Vehicular Fuel Systems Code 1999 Edition) (THIS DOCUMENT HAS BEEN PHASED OUT AND INCORPORATED INTO NFPA 52)
NFPA 70 (National Electric Code)
ASME BPV Code Section VIII, Div.I and Section IX

Table 30: Technical standards used in the USA

In Table 31 Technical standards taken into consideration for approval of HRS's in various European countries are shown.

France	Regulation for NGV stations may be used as a starting point. “Arrêté types 1415 & 1416” mentioned above, for hydrogen storage and hydrogen production, are also likely to be used.
Germany	Technical regulations in BetrSV (leading document)
Italy	DM 31/8/2006 (leading document) Non binding references: NFPA 50A (now NFPA 55) - EIGA 15/96 ISO 15916 ¹
Spain	Regulation of Pressure apparatus Real Decreto 2486/1994 (CNG regulation)
Netherlands	PGS 25 (CNG) NFPA 55 NFPA 57-02 (LNG)
China	In China, BP is the major equipment supplier in Beijing Hydrogen Park. BP applied internationally recognised hydrogen safety codes, principally the NFPA (US National Fire Protection Association codes: NFPA55, NFPA52)
Various countries	Regulations for the storage of hazardous substances

Table 31: Specification of regulations for approval of HRS's

¹ ISO/TR 15916:2004 provides guidelines for the use of hydrogen in its gaseous and liquid forms. It identifies the basic safety concerns and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards

14.7 Methodologies and guidelines for the assessment of external (off-site) effects damage and risks

The methods used to assess external safety, as mentioned in the interviews, are shown in Table 32.

France	The evaluation of the risk is the responsibility of the owner and must be done with both quantitative and qualitative methods with a risk based approach but without commonly accepted methods or software. Latest regulation (Arrêté et circulaire du 29 septembre 2005 relative aux critères d'appréciation de la démarche de maîtrise des risques d'accidents) sets criticality matrix to be used.
Germany	Limited to a hazard evaluation according to BetrSV and

	Explosion protection
Italy	<p>Because of the small amounts of dangerous substances involved, an external safety study is not legally required for an HRS, as for other low-to-medium risk activities by DL n. 334 of 17/8/1999 that implements EU Directive 96/82/EC.</p> <p>DM 31/8/2006 requires a QRA only for the in-situ hydrogen production section of the HRS. However, being the first public HRS of its kind in Italy, a quantitative risk analysis on the whole HRS as prescribed by the “High Risk Activities” Seveso Directive was also considered in the approval procedure for the Zero Regio’s HRS in Mantova.</p>
Spain	No QRA is required. No specific guidelines exist. The existing normative for compressed natural gas is used, taking into account the special characteristics of H ₂ .
Netherlands	In NL a QRA is required for each station. No specific guidelines exist for HRS’s and <i>until specific requirements for H₂ are specified (as with LPG) this will be the case</i> . The Dutch guidelines (as defined for Seveso establishments in CPR-18) will be leading, i.e. scenarios and failure frequencies, will be derived from this to determine safety distances. Relevant distances are also used for land-use planning purposes, e.g. if risk criteria are not met, relocation will be necessary.
USA	In general, states or local governments do not perform quantitative risk assessments nor do they require them of project developers. However, in the United States, it is very common for project developers themselves to perform quantitative and/or qualitative risk assessments and/or FMEA’s.
China	Because the novelty of HRS in China, assessment is checked by experts in an argumentation meeting. In China, BP is the major equipment supplier in Beijing Hydrogen Park. BP applied quantitative risk-engineering techniques which look at potential incidents and their prevention (frequency/probability reduction) or mitigation (consequence reduction). One such technique is Quantified Risk Assessment (QRA).

Table 32: Methodologies and Guidelines for the assessment of external (off-site) effects, damage and risks

From the information in Table 32 it can be seen that for Netherlands, Italy, France, QRA’s, along the lines of the local interpretations of the SEVESO II guidelines, have been or should be performed, resulting in an assessment of off-site effects, damage and risks. In the other countries no specific methods for external safety were mentioned. Nonetheless, for all countries documents are required in which the safety

measures are outlined. In Spain, USA (where external safety was also considered important) and also the Netherlands the choice of the most suitable method is left to the expert judgement of operator, constructor and / or owner of the HRS.

14.8 External safety (off-site safety) and land use planning

Although all countries, apart from Spain, mention the use of safety distances it is not always clear how (or if) they are used in relation to land-use planning. Safety distances (damage radius for a given accident probability / external safety) should not be confused with so called “ATEX zoning” that relates to occupational health and to the choice of appropriate equipment to prevent explosive atmosphere ignition. Only for the countries in which these distances are based on methods derived from the SEVESO directive (Italy, Netherlands France) a link seems to be present (see Table 33).

In the USA, zoning issues and land use requirements, with respect to the siting of HRS’s, come under the cognisance of local governments, rather than the Federal government or requirements in codes and standards.

Of course we are concerned here with safety distances beyond the zoning in the sense of the ATEX guideline, where it concerns avoiding ignition in the event of release of small quantities of hydrogen.

France	Safety distances are set for specific installations like storage of large quantities of liquid hydrogen. For other cases, the safety study shall demonstrate that the hydrogen installation is not likely to cause external effects. Safety distances exist nowadays for conventional and NGV refuelling stations (declaration regime).
Germany	Safety distances inside and outside the HRS are applied.
Italy	<p>The location of the HRS must be compliant with the City Council’s general plan and zoning ordinance for ordinary refuelling stations and, currently, CNG refuelling stations.</p> <p>In case the HRS is located in close proximity to a high-risk activity, local authorities at the higher level than the City Council, i.e., the Province and/or the Region has to compile a risk analysis report of the whole area by putting together the information provided by each single activity in the area. This document must take into consideration also any planned future business or building activity in the area.</p> <p>There are no specific provisions for HRS.</p>
Spain	Both of the HRS’s were considered to be temporary and operating in already restricted areas (bus stations). Outside safety distances are applied according the City Council’s general plan.

Netherlands	A municipality may only designate a piece of land for a high-risk activity in an establishment if the associated risks to the vicinity do not exceed the limit values laid down in the External Safety Establishments Decree. The Decree established environmental quality standards in the form of limit values for location-based risk, e.g. 10 ⁻⁶ per annum for vulnerable objects and for sites in the process of remediation.
USA	Safety distance requirements inside HRS are provided in ICC and NFPA codes, if the local governments chose to adopt them. Safety distances outside HRS's are governed by local zoning and site laws and regulations.
China	Fire separation distance between hydrogen station or hydrogen supply station or hydrogen gas receiver and building or construction shall be no less than that as specified in GB50177-2005.

Table 33: External safety and land-use planning

14.9 The inspection protocol

Only France requires an inspection protocol for any installation including HRS's. Nonetheless some kind of inspection protocol exists for The Netherlands, USA, Italy and Germany. As can be seen in Table 34 these protocols are usually based on maintenance/inspection demands of the equipment used (as prescribed by the owner and / or manufacturer). The fire brigade can be involved in these inspections. In Spain an inspection protocol, based on the risk, is currently being developed.

France	<p>Inspection of ICPE in France is clearly organised and not delegated to private notified bodies (except for pressure vessels). The protocol for inspection is available (in French) at the following address:</p> <p>http://www.drire.gouv.fr/environnement/controle.html</p> <p>This inspection is the responsibility of the DRIRE civil servants or inspectors under the sole authority of the Prefect (local representative of the government).</p> <p>In case of request from the prefect combined inspections by veterinary (in case of refuelling station in a supermarket when food is sold), DRIRE, and fire brigades can be done.</p>
Germany	<p>According to BetrSichV every 5 years by Competent Safety Organisation.</p> <p>Tubes every half year by operators + manufacturers regulations.</p> <p>Also: 24 months after start-up and every three years.</p>

Italy	<p>No specific protocol exists. General procedure for conventional or, better, CNG refuelling station will apply. Only the first inspection during the plant start-up will be carried out by all inspecting bodies simultaneously. In Italy the responsible authority for workers safety (ASL) is present at the start-up inspection and may carry out further inspections during operation. The fire brigades make an inspection every three years.</p>
Spain	<p>No specific protocol exists. Fire brigade applies general checklist. Owner does visual checks. Supplier of equipment completes a 6 monthly check or, the time suggested by the device manufacturer. This, however, is primarily because of the experimental character of the Madrid and Barcelona HRS. Technical reliability of the HRS is determined by equipment supplier. Owner is alerted when replacements are due.</p>
Netherlands	<p>No specific protocol exists. Fire brigade applies general checklist. Owner does regular (once a week or so) visual checks. Supplier of equipment does a weekly check. This, however, is primarily because of the novelty and the experimental character of the Amsterdam HRS. Also VROM will apply ‘general’ inspection techniques. Technical reliability of the HRS is determined by equipment supplier, and monitored by the software. Owner is alerted when replacements are due. There is an increasing tendency in the Netherlands to have private notified bodies perform the obliged controls of the installation. However, such a notified body for HRS’s does not exist yet.</p>
USA	<p>The states are not involved in conducting periodic (i.e., annual or unannounced) inspections of hydrogen refuelling stations. Uniformly, this is the responsibility of the local fire marshal and/or fire department. Local fire protection authorities, in general, have the authority to cite project operators for violations of safety regulations or shut down a facility if they believe that there is an imminent fire safety hazard. In nearly all projects, the operators and/or vendors have documented systematic inspection protocols.</p>

Table 34: Inspection protocols used in various countries

14.10 Contingency planning

Emergency response organisations like the fire brigade, ambulance services and the police should be prepared for accidents that might occur. In most countries the leading party regarding contingency planning is the fire brigade. Many of the interviewed parties indicated that they would like to see the intervention measures for the various incident scenarios at HRS’s explicitly stated in the HyApproval handbook.

France	<p>Dedicated plans to be made:</p> <ul style="list-style-type: none"> - “Plan d’operation interne” under the responsibility of the owner (when installation under authorisation regime) - “Plan particulier d’intervention” under the responsibility of the prefect (when installation under authorisation regime)
Germany	<p>Action plan of the fire brigade and safety response plan Fire fighters or the agency for fire-prevention should be involved in an early stage as officials often want to have their point of view regarding emergency planning and access to the HRS</p>
Italy	<p>Similar to ordinary and CNG refuelling stations</p>
Spain	<p>Similar to ordinary refuelling stations</p>
Netherlands	<p>The environmental permit states that the establishment should have an emergency plan and a plan of attack for the fire brigade based on the possible scenarios. The environmental permit states the contents of the plan of attack as well. The fire brigade identified the possible scenarios and their response.</p> <p>A contingency plan should not be mono disciplinary (only assistance by the fire brigade) but also refer to the role of the GHOR (Health Assistance in the event of Accidents and Disasters) and the Police.</p>
USA	<p>Required, regardless of the governmental/ approval agency</p>
China	<p>Fire brigade, ambulance services and police are all involved in contingency plan</p>

Table 35: Contingency planning

14.11 Dissemination of the handbook

Table 36 presents the response of the interviewees on the subject dissemination of the handbook.

France	<p>Organisations would use the handbook if it would contain relevant information to particular problems. However, the handbook has no legal status. It can therefore only be referred to as best practice information.</p> <p>Dissemination through DDSC¹¹ (Department at governmental level in charge of fire services)</p>
Germany	<p>Some interviewees answered that the handbook will not be used because it has no legal status</p>
Italy	<p>Organisations would use the handbook if it contained information related to their field of responsibility. Formal recognition of the handbook by Italian authorities would greatly help its dissemination and acceptance.</p>
Spain	<p>Organisations would use the handbook if it contained relevant information to problems such as:</p> <ol style="list-style-type: none"> 1. What functions and buildings are allowed near HRS's? 2. Technical Standards 3. Intervention measures
Netherlands	<p>Organisations would use the handbook if it would contain relevant information to problems such as:</p> <ol style="list-style-type: none"> 1. What functions and buildings are allowed near HRS's? 2. Technical Standards 3. Intervention measures
USA	<p>Based on a survey of states that are actively involved in pursuing hydrogen technology and implementing HRS projects, they are not familiar with the handbook</p>
China	<p>Organisation would use the handbook If it contained relevant information with respect to their particular problems (such as safety).</p>

Table 36: Dissemination of the Handbook

¹¹

DDSC: Direction de la Defense et de la Sécurité Civile

As can be expected from the response the use of the handbook will depend on the relevance of the information in the book to the problems that the various stakeholders are confronted with.

A point to be noted is that the (legal) status of the handbook will also affect its use.

14.12 Remarks / other issues / gaps

The importance of involving the local community at an early stage in the approval process is mentioned by various countries.

Some of the interviewees felt the fact that the labour inspectorate had not been involved in the approval process in their country (except Germany) as an omission.

In Italy the labour inspectorate was not involved in the HRS approval process so far. The main responsibility for workers safety lies within ASL – the local health service.

In the USA, both permitting officials and HRS project developers emphasize the importance of community involvement in implementing projects – the earlier that involvement, the better.

France considers that the classification of the risks is based on the quantity of hydrogen stored on site, regardless of the pressure, type of tanks and location of the tanks. The quantity of hydrogen stored mainly affects the administrative status of the refuelling station (declaration or authorisation regime) and therefore the amount of documents to prepare for authorities. Authorisation regime always applies when hydrogen is produced on-site.

The risks associated with “non classical” technical solutions (buried storages for instance) would also be interesting to develop.

14.13 Conclusions and Recommendations

In all interviewed countries either explicitly or implicitly three stages of safety assurance could be distinguished in the approval process of an HRS:

1. Prevention of accidents by application of technical standards
2. Creation of a safety zone or safety distance.
3. Optimal preparation of emergency services (contingency planning).

Ad 1.

Conclusion:

There was good agreement on the first of these stages between all 5 EU countries. They all used the same technical standards (EU regulations) sometimes augmented with local regulations. Also some American standards (most notably NFPA-standards) are used sometimes.

The USA has their own technical standards, although many are similar to EU regulations.

China has no existing regulations especially for HRS, but there is related code GB50177-2005.

Recommendation:

The handbook should contain a detailed technical description of the HRS; thereby making sure it is in good agreement with all regulations applicable.

Ad. 2

Conclusions:

Although all countries do mention the use of safety zones it is not always clear how they are derived and which criteria acceptability levels are used.

The Dutch standards are very clear concerning external safety, which are also used for land-use planning and they calculate the Location Based risk (PR) and Societal Risk (GR). Acceptance levels are $PR < 10^{-6}/\text{yr}$ and $GR < 10^{-3}/N^2$, in which N represents the cumulative number of fatalities.

Also in France risk based criteria for external Safety came into force recently. In addition to fatalities (as in the Netherlands) injuries to persons are used as a criterion. Acceptability levels are not clearly defined, but agreed during discussions between stakeholders

Italy assessed the consequences according to damage limits provided for in DM 9/5/2001. No acceptance levels are stated by laws. Acceptance levels have to be negotiated and agreed upon by interested parties with authorities having jurisdiction. Based on pilot studies on a few early HRS's and the long experience with CNG, it has already been decided that safety distance as provided by DM 31 August 2006 can be used. If the HRS complies with DM 31 August 2006 then a QRA is required only for the in-situ hydrogen production section of the HRS. If the safety distances of the HRS do not comply with DM 31 August 2006 then a QRA is required on the whole HRS to convince the authorities that the safety characteristics of the non-compliant HRS are equivalent to those of a compliant HRS.

In the USA safety distances are set on a state-by-state basis, using their adopted codes and standards or regulations. No generally applied method or criteria exist. Choice of suitable methods is often left to the builder / contractor / owner of the HRS.

Spain has not adopted specific safety distances that are related to the possible risks of the HRS. Due to the situation of the HRS (inside bus station perimeter, not open to the public) the safety distances are the same as used for the bus station itself (City Council's general plan).

Germany reports the use of safety distances. It is however unclear how they are derived, which criteria are used and what the acceptability levels are.

Recommendations:

All safety studies reported should be sufficiently detailed such that individual countries can extract the information that is useful for their particular safety approach or policy. This means effect / safety distances should be reported as a minimum (deterministic approach). Probability of corresponding scenario could also be proposed.

Ad.3

Conclusions:

In all countries contingency planning was reported to be a factor to consider. Most countries reported a leading role for the fire brigade in this area.

In the Netherlands their advice is binding.

In France they prepare a dedicated plan (Plan d'Organisation Interne – POI) for installations falling under the authorisation regime. A POI defines contingency procedures and related emergency resources in order to protect employees, neighbours and the environment in case of an accident. This plan is written by the owner of the installation under his/her responsibility. Fire services should be consulted. It is not likely that a POI will be requested for hydrogen refuelling stations.

In Germany they prepare an action plan and safety response plan.

In Italy, emergency planning is coordinated by the local authorities, either for a township, province or region, depending on the extension of the interested area. The region is responsible for the implementation of the Seveso Directive in the case of high-risk plants. The Fire Brigades are always a key actor. No specific emergency plan for HRS was mentioned during the interviews.

In Spain Fire brigades visit the HRS, are informed about risks and safety devices and propose safety response recommendations.

For the USA, there are no Federal regulations regarding contingency planning. Contingency planning requirements (where they exist) are established at the state and/or local government level.

In China, the fire brigade plays the leading role.

Recommendation:

The role of the fire services should be outlined and an emergency response plan should be in the HyApproval handbook. In this plan the intervention measures for the various incident scenarios at HRS's should be explicitly stated in the handbook. Most of the interviewed parties indicated that they would like to see this. At least emergency measures should be outlined.

General recommendations:

Communication between stakeholders

Good coordination between the stakeholders in the approval process involved was seen as an important issue by the interviewees. This should also be emphasised in the handbook, whereby it must be clear which authority has the coordination role. It is advisable that the parties involved seek agreement on potential discrepancies in an early stage.

This includes Community relations. To facilitate community acceptance community concerns should be addressed as otherwise the implementation of the project could be

seriously delayed, particularly because of the novelty of HRS's, with (certainly to the general public) unknown risks.

Inspection regime

An inspection regime would have to be set in accordance with the risk imposed by the HRS. A number of countries reported that no specific inspection protocol exists. An (example of an) inspection protocol should be given in the handbook.

Dissemination

The use of the handbook in the approval process of a HRS is not a requirement as long as its status is not recognised. A statement from the competent authorities concerning the conditions under which they will endorse the use of the handbook would be welcome.

14.14 Flow charts of the approval process in China, Italy, Germany, France, Spain and the Netherlands

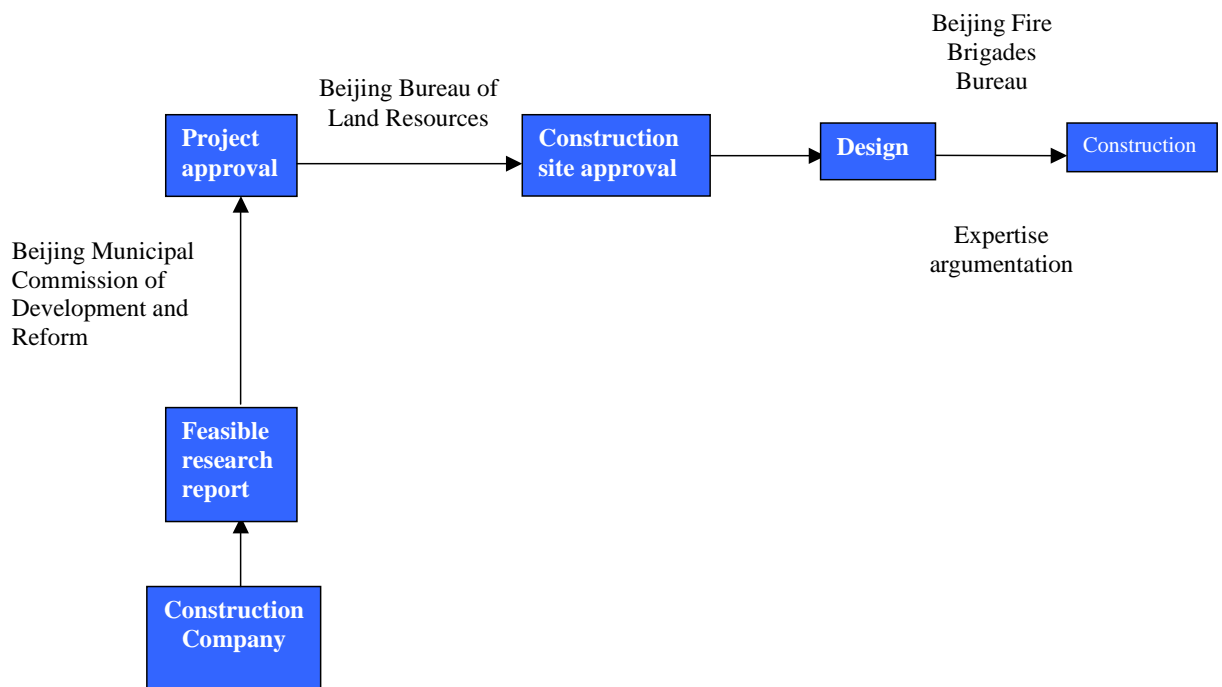


Figure 39: Flowchart of the approval process in Beijing, China

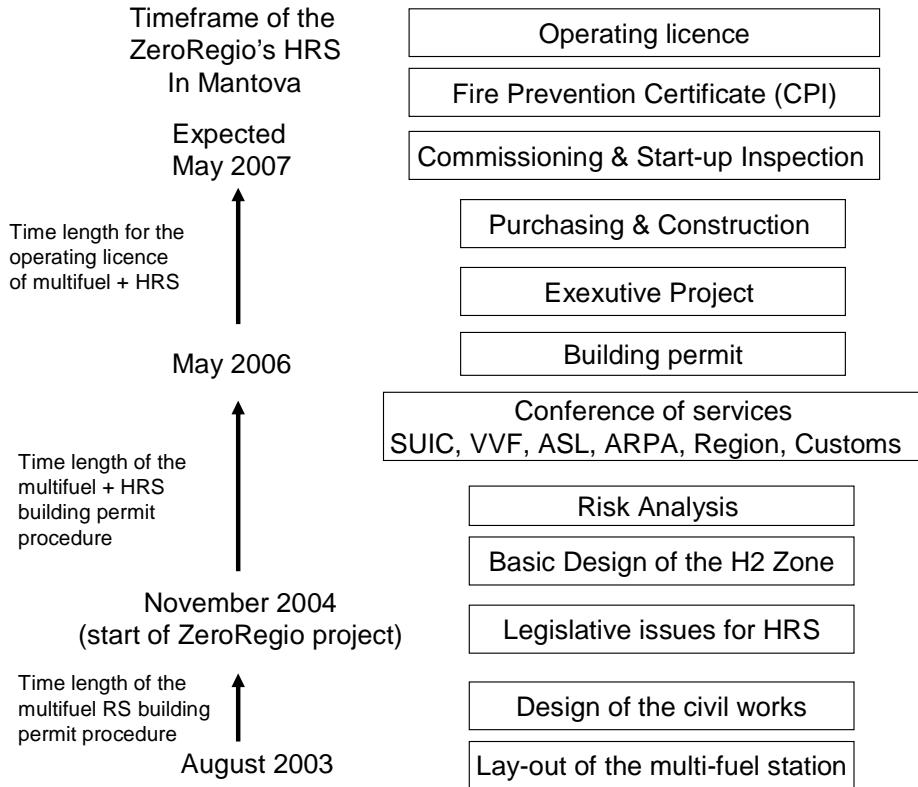


Figure 40: Flowchart of approval process in Italy

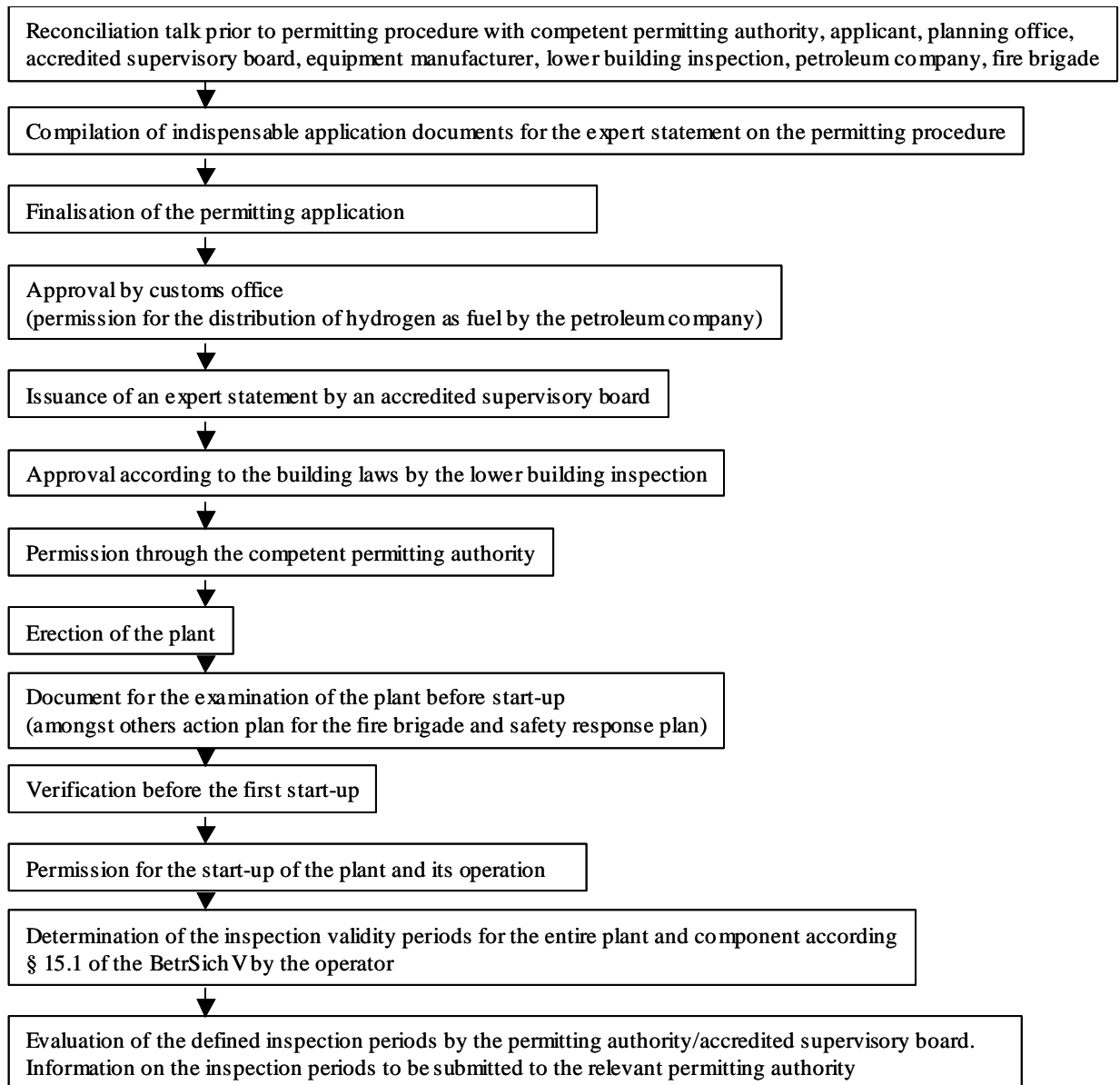


Figure 41: Flowchart of approval process in Germany

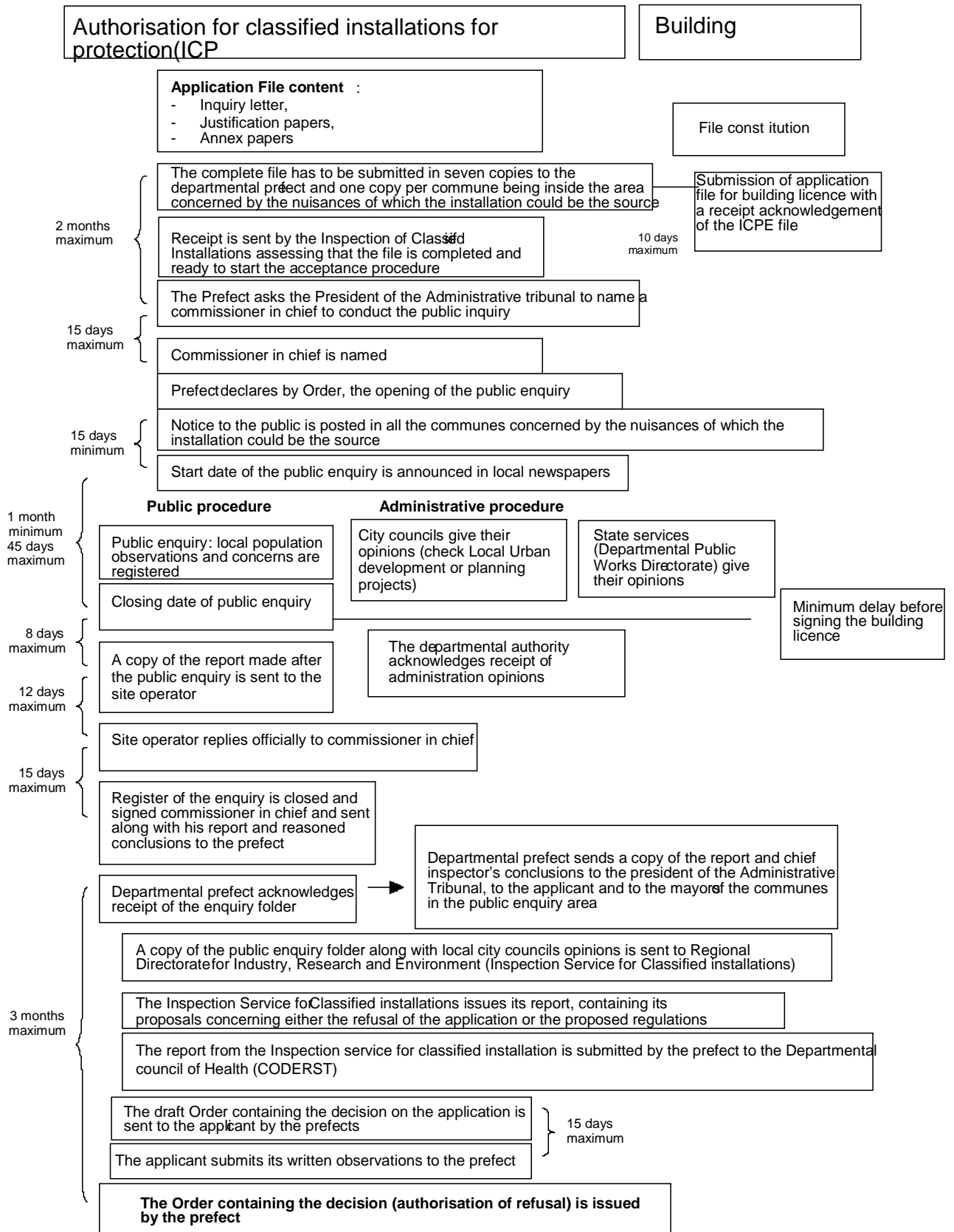


Figure 42: Flowchart of approval process in France

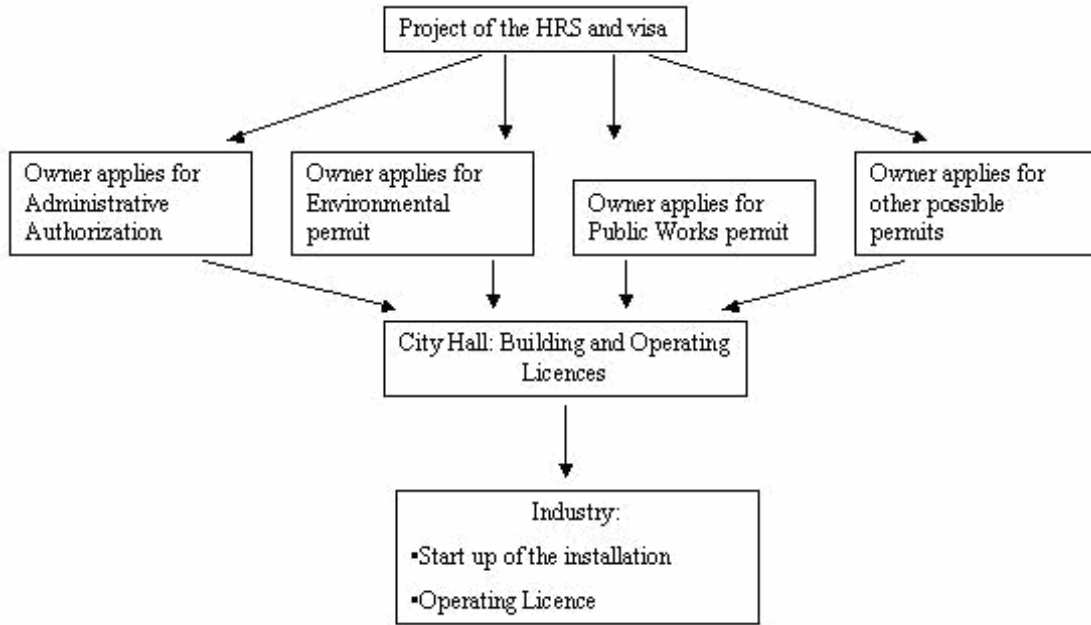


Figure 43: Flowchart of approval process in Spain

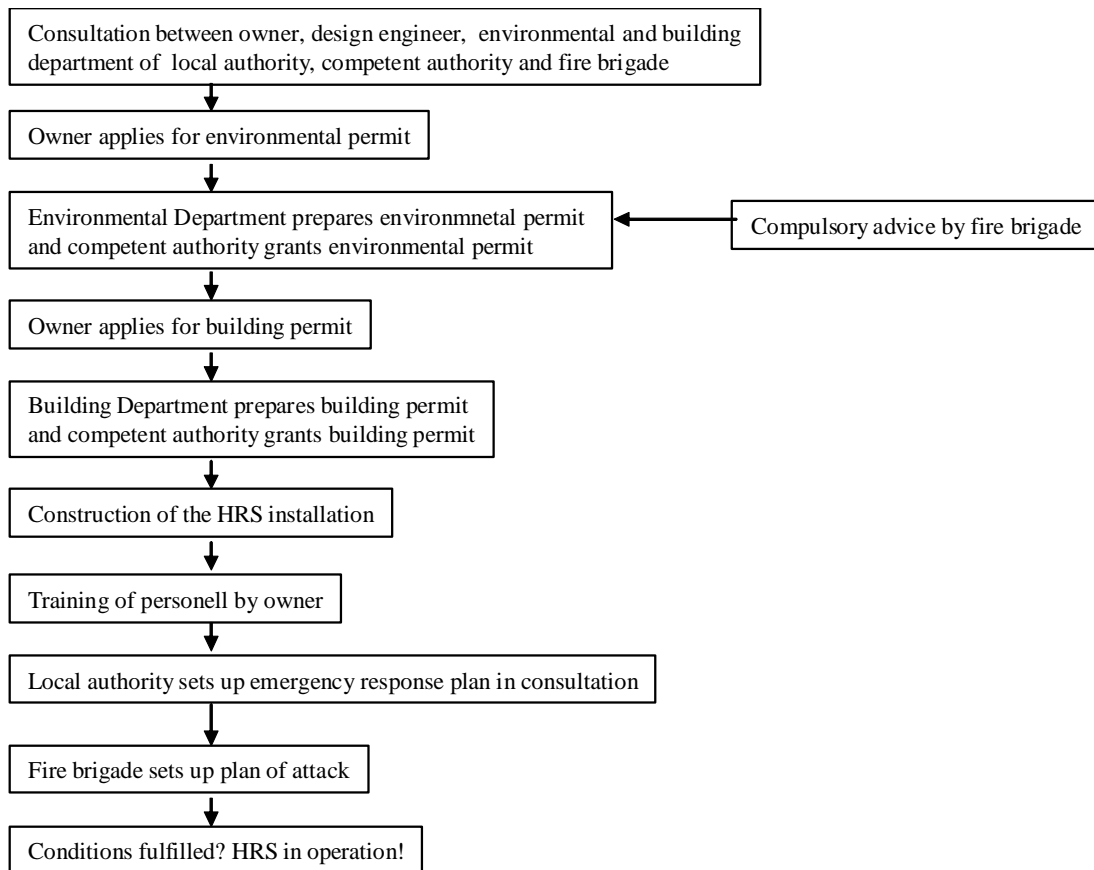


Figure 44: Flowchart of approval process in The Netherlands

15 List of appendices

Appendix I	“Safety Data Sheets for hydrogen and refrigerated hydrogen” Prepared by AL DTA	
Appendix II	“Approval requirements in five EU countries and the USA” Prepared by TNO	
Appendix III	WP4 “Emergency Response Plan” Prepared by SHELL	Dated 24/11/2006
Appendix IV	HyApproval WP4 Deliverable “Quantitative Risk Assessment of Hydrogen Refuelling Station with on-site production” Prepared by DNV	Deliverable D4.9 Revision 4 Dated 13/07/2007
Appendix V	HyApproval WP4 Deliverable “Consequence Assessment Summary Report” Prepared by NCSR D	Revision 4 Dated 23/10/2007
Appendix VI	“Vehicle description and requirements” Prepared by AL DTA with inputs from OPEL	