PRESLHY

Survey of RCS and Best Practices for Liquid Hydrogen

KIT, April 17, 2018 *HySafe (Andrei V. Tchouvelev)*

Pre-normative REsearch for Safe use of Liquid HYdrogen

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   i. Goal, Objectives, Vision
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Motivation: Areas of Concern

- Public H_2 fueling infrastructure (cars, buses, trains, boats, residential use)
- LH_2 transport, storage and use in urban areas
- Significantly different operating conditions and environment vs industrial and aerospace applications and lack of experience with LH_2 in distributed energy applications –> higher potential public (individual and societal) exposure
- Different potential accident scenarios

Based on call topic FCH-04-4-2017.

PRESLHY RCS Goal

With the new knowledge generated by this research work, science based and validated tools, which are required for hydrogen safety engineering, and risk-informed, performance based, LH_2 specific, international standards will be developed.

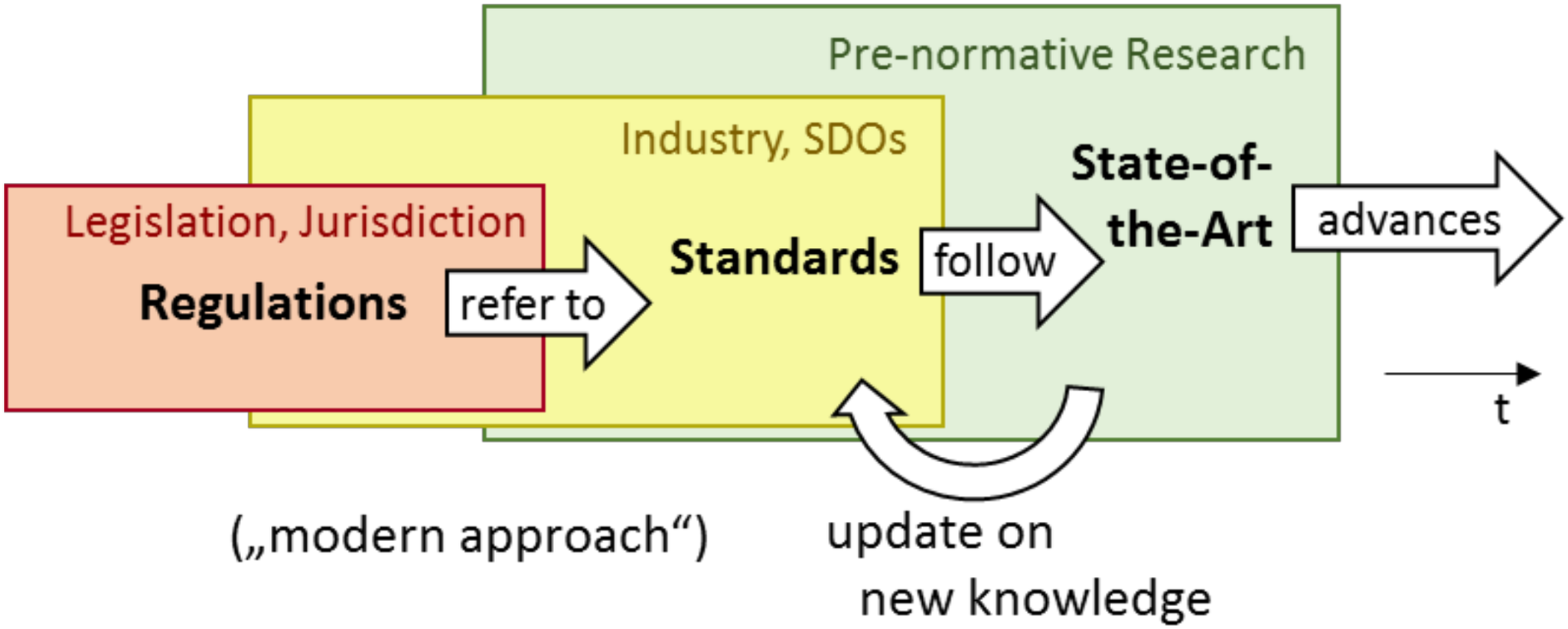
PRESLHY Application, Chapter 1 “Excellence”, page 3.

PRESLHY RCS Objectives

- Provide a report on the initial state-of-the-art, specific knowledge, specific international standards, safety strategies in existing installations and knowledge gaps with priorities related to the envisaged use of LH_2
- Derive together with the standards developing organisations a list of priorities, which shall highlight those phenomena associated with highest risk scenarios, least knowledge and lack of reference guidelines and standards
- Provide a specially tailored summary report to support the international Standards Developing Organisations SDOs, in particular ISO/IEC and CEN/CENELEC, in either updating existing standards or developing new international performance based and risk informed standards

PRESLHY Application, Chapter 1.1 “Objectives”, pages 4-5.

PRESLHY RCS Vision



Interrelations between development of regulations, standards and state-of-the-art

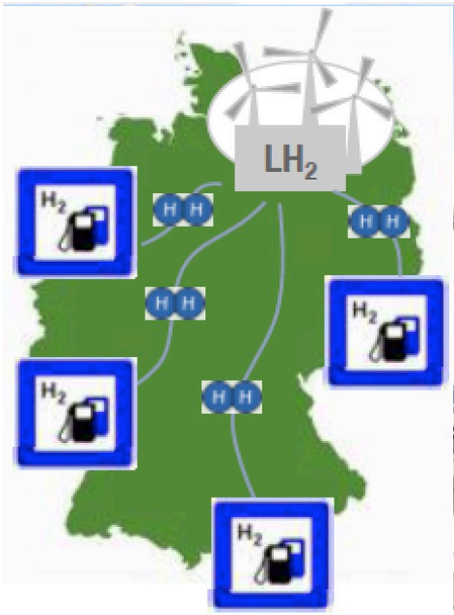
Note: “modern approach” refers to “New Approach” formulated by HarmonHy project –> EU Regulations refer to international standards

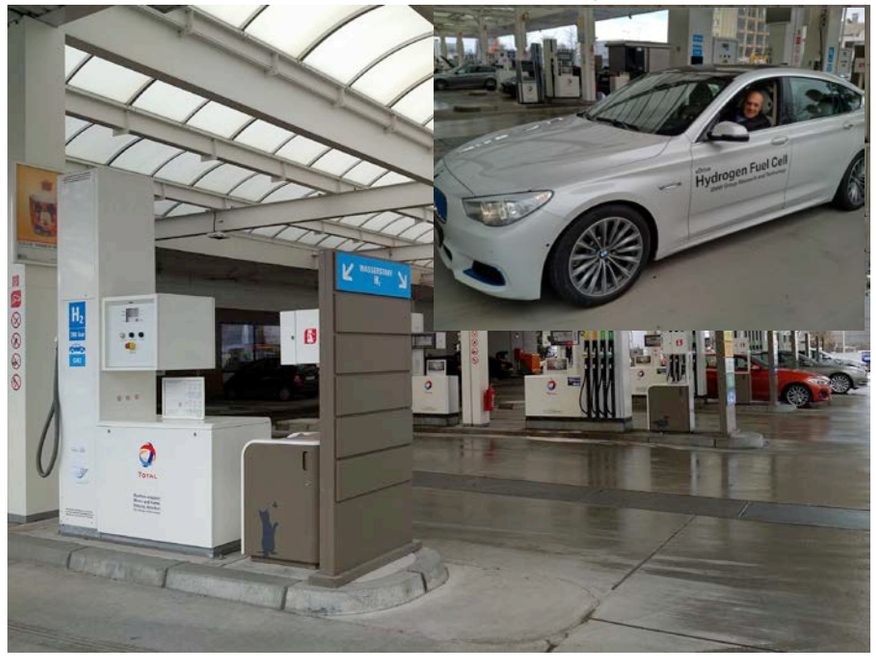
RCS Task Objective

This task is dedicated to the survey on the existing Regulations, Code and Standards (RCS) as well as the industry best practices from European Industrial Gas Association (EIGA) and Compressed Gas Association (CGA). The existing RCS developed for small scale LNG applications (trucks, boats) will be also examined considering the analogy in the applications. Based on this survey, recommendations and prioritization on the subjects covered by RCS will be given. This task will be in collaboration with ISO TC197 members from AL and HYSAFE.

Task 2.2 description from PRESLHY application.

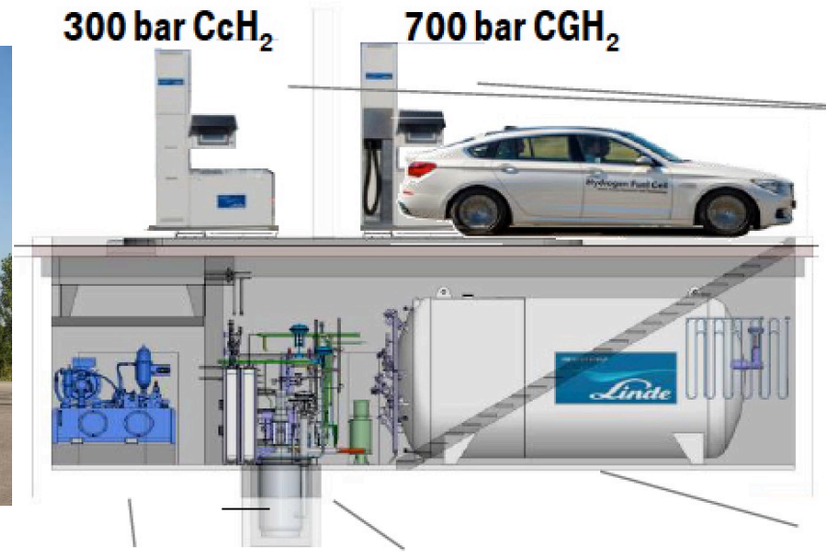
Visuals for RCS Priority Topics





Density LH_2 / CGH_2 (@35MPa)
Temperature -250°C
Liquid Phase

→ **4 t LH_2** vs. **0,5t CGH_2** per trailer
→ **Cooling capacity** at filling station
→ **Transfer from vessel to vessel** w/o loss of expended energy (e.g. pressurization)



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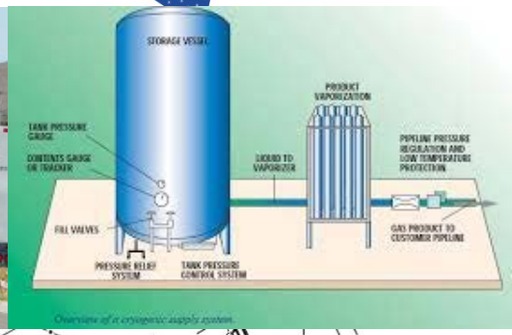

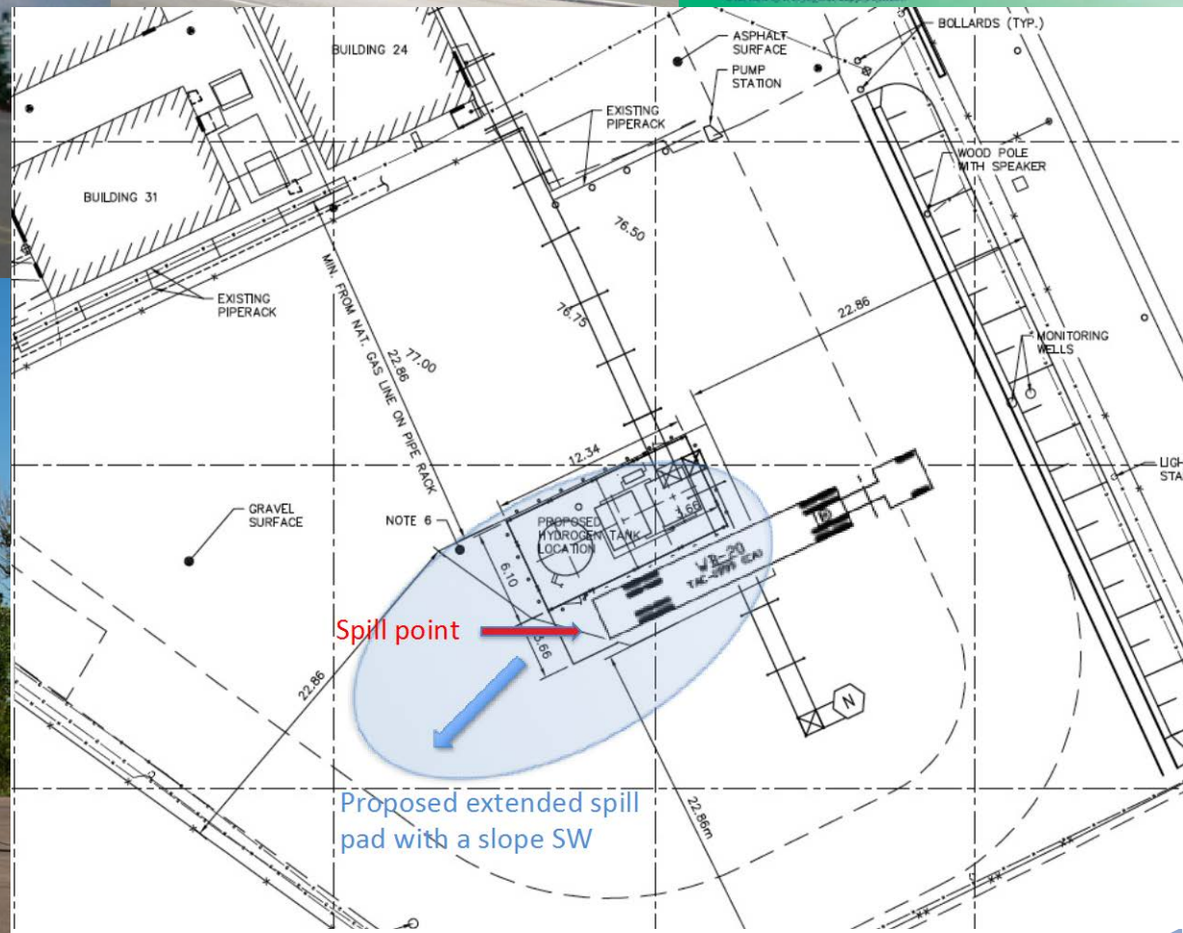

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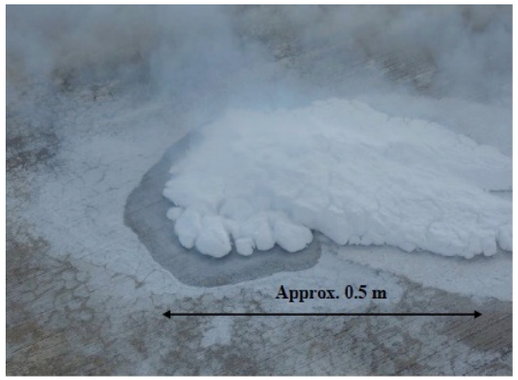
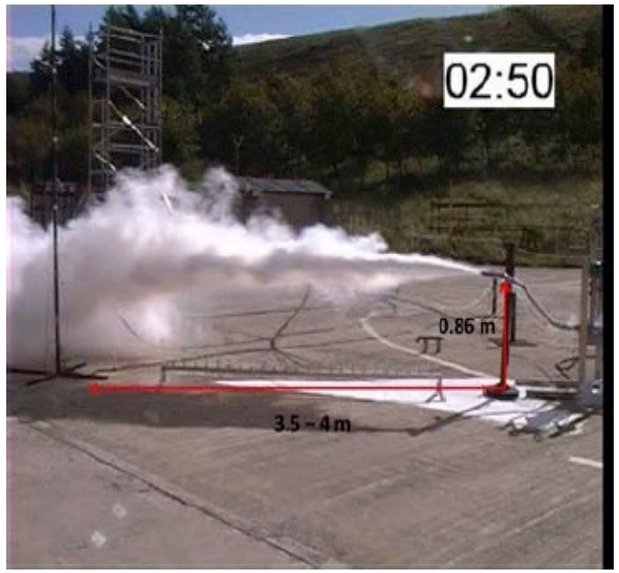
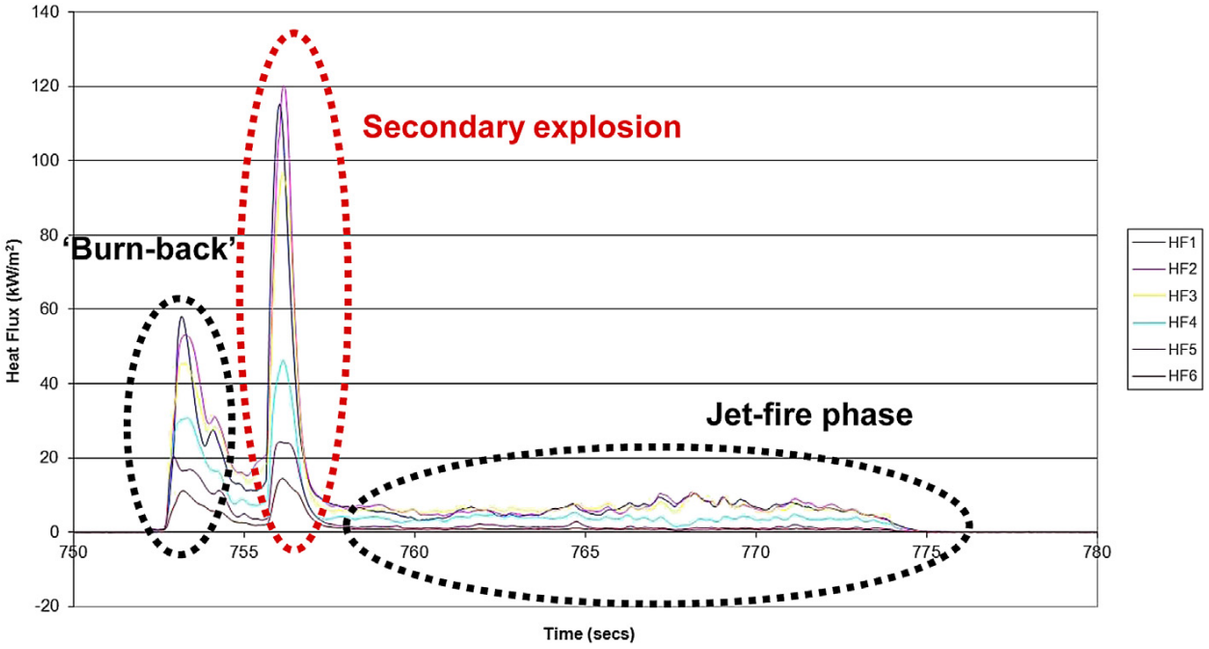






Recommended RCS Priority Topics

- Safety / separation distances:
  - Cold gas venting (delayed ignition, thermal)
  - Pool fire (thermal)
  - Solid air / oxygen effect (over pressure)
- Hazardous areas:
  - Should they be different than for GH2?
- Vent stacks design for cold gas venting:
  - Orientation, pipe diameter, elevation
- LH_2 transport and transfer:
  - Spill control / prevention
  - Spill mitigation (e.g. prevention of pooling)

Is This Type of Survey Useful?

INTERNATIONAL STANDARD

ISO 13984

First edition
1999-03-15

Liquid hydrogen — Land vehicle fuelling system interface

Hydrogène liquide — Interface des systèmes de remplissage pour véhicules terrestres

ISO

Reference number
ISO 13984:1999(E)

Not Really!

Scope

This International Standard specifies the characteristics of liquid hydrogen refueling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refueling procedure and thus to provide a reasonable level of protection from loss of life and property.

This International Standard is applicable to the design and installation of liquid hydrogen (LH2) fuelling and dispensing systems. It describes the system intended for the dispensing of liquid hydrogen to a vehicle, including that portion of the system that handles cold gaseous hydrogen coming from the vehicle tank, that is, the system located between the land vehicle and the storage tank.

Important Lesson Learned:
NFPA55:2013 & NFPA2:2016 Separation Distances

Table 10.3.2.1(a) Minimum Distance (D) from Outdoor Bulk Hydrogen Compressed Gas Systems to Exposures — Typical Maximum Pipe Size

Pressure Internal Pipe Diameter (ID) d_{mm}	>15 to ≤250 psig >103.4 to ≤1724 kPa $d = 52.5_{mm}$		>250 to ≤3000 psig >1724 to ≤20,684 kPa $d = 18.97_{mm}$		>3000 to ≤7500 psig >20,684 to ≤51,711 kPa $d = 7.31_{mm}$		>7500 to ≤15000 psig >51,711 to ≤103,421 kPa $d = 7.16_{mm}$	
Exposures Group 1	**m**	**ft**	**m**	**ft**	**m**	**ft**	**m**	**ft**
(a) Lot lines	12	40	14	46	9	29	10	34
(b) Air intakes (HVAC, compressors, other)								
(c) Operable openings in buildings and structures								
(d) Ignition sources such as open flames and welding								

Correct science was misused via wrong methodology!

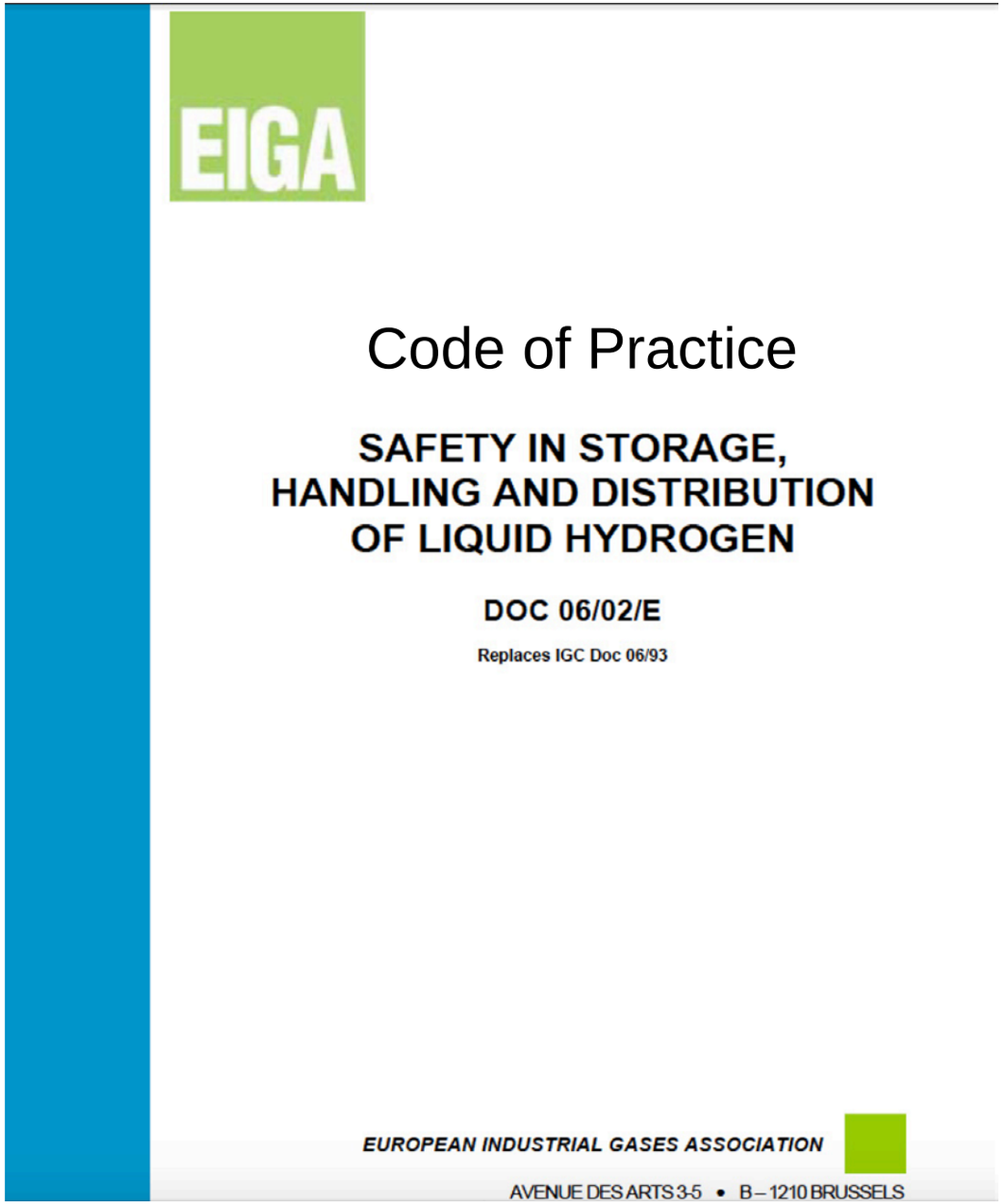
NFPA2:2016 LH_2 Separation Distances

Table 8.3.2.3.1.6(A) Minimum Distance from Bulk Liquefied Hydrogen [LH_2] Systems to Exposures

Type of Exposure	Total Bulk Liquefied Hydrogen [LH_2] Storage					
	39.7 gal to 3500 gal	150 L to 13,250 L	3501 gal to 15,000 gal	13,251 L to 56,781 L	15,001 gal to 75,000 gal	56,782 L to 283,906 L
	ft	m	ft	m	ft	m
Group 1						
1. Lot lines	25	7.6	50	15	75	23
2. Air intakes [heating, ventilating, or air conditioning equipment (HVAC, compressors, other]	75	23	75	23	75	23
3. Wall openings						
Operable openings in buildings and structures	75	23	75	23	75	23
4. Ignition sources such as open flames and welding	50	15	50	15	50	15
Group 2						
5. Places of public assembly	75	23	75	23	75	23
6. Parked cars (distance shall be measured from the container fill connection)	25	7.6	25	7.6	25	7.6
Group 3						
7. Building or structure						
(a) Buildings constructed of noncombustible or limited-combustible materials						
(1) Sprinklered building or structure or unsprinklered building or structure having noncombustible contents	5[a]	1.5	5[a]	1.5	5[a]	1.5
(2) Unsprinklered building or structure with combustible contents						
(i) Adjacent wall(s) with fire resistance rating less than 3 hours	25	7.6	50	15	75	23
(ii) Adjacent wall(s) with fire resistance rating of 3 hours or greater[b]	5	1.5	5	1.5	5	1.5
(b) Buildings of combustible construction						
(1) Sprinklered building or structure	50	15	50	15	50	15
(2) Unsprinklered building or structure	50	15	75	23	100	30.5
8. Flammable gas storage or systems (other than hydrogen) above or below ground	50	15	75	23	75	23
9. Between stationary liquefied hydrogen containers	5	1.5	5	1.5	5	1.5
10. All classes of flammable and combustible liquids (above ground and vent or fill openings if below ground)[c]	50	15	75	23	100	30.5
11. Hazardous materials storage or systems including liquid oxygen storage and other oxidizers, above or below ground	75	23	75	23	75	23
12. Heavy timber, coal, or other slow-burning combustible solids	50	15	75	23	100	30.5

Do these numbers make sense?
What are correct criteria / methodology?

EIGA Code of Practice for LH_2



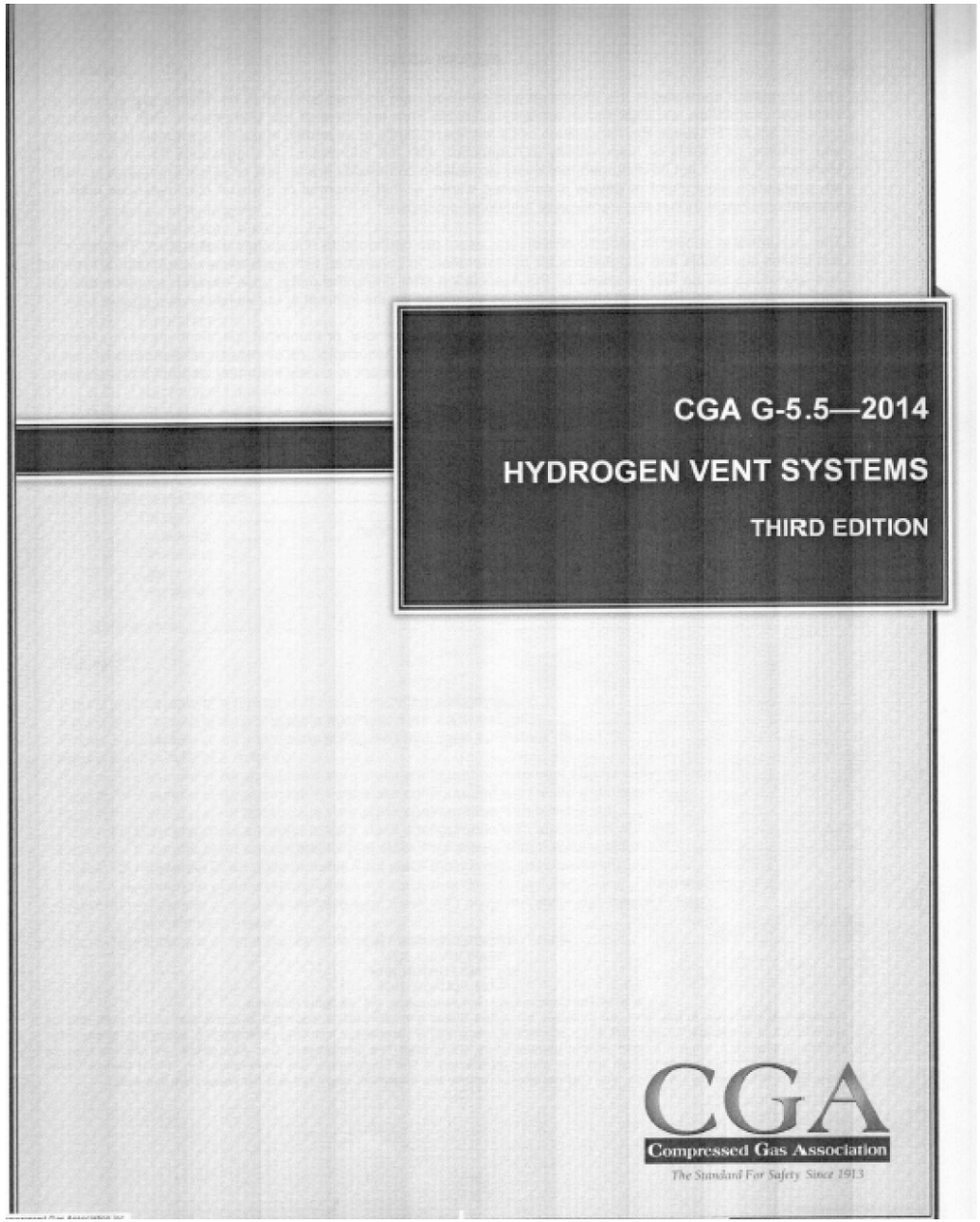
Hydrogen Vents

The height of the vent stack outlet should be either 7 metres above ground level or 3 metres above the top of the tank whichever is the greater for protection of the operating personnel and equipment.

Vapour Clouds

When siting an installation, due consideration shall be given to the possibility of the movement of vapour clouds, originating from spillage or venting; in addition wind direction and the topography shall be taken into account.

CGA G-5.5 Standard – H_2 Vent Stack



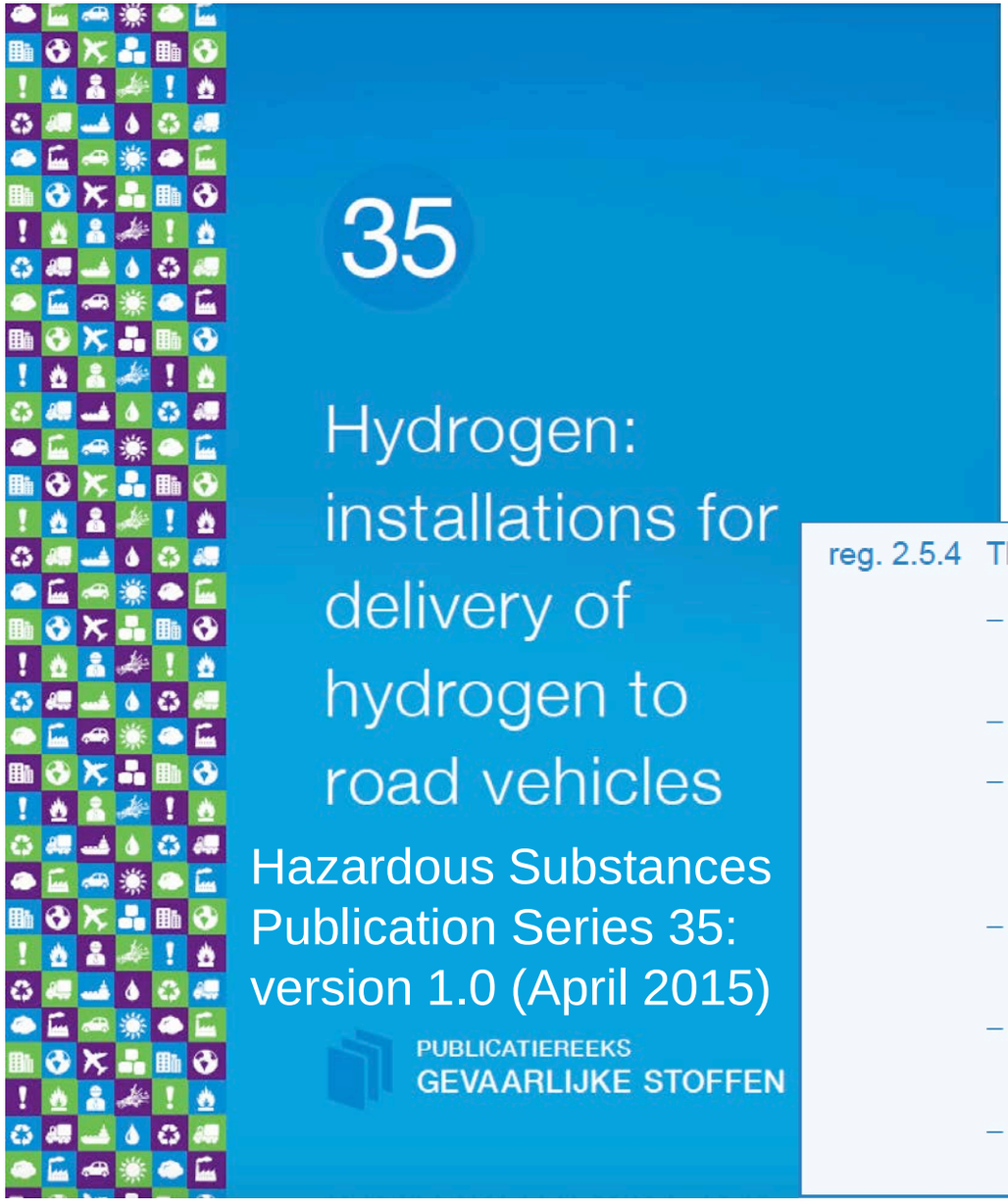
Discharge of warm gas

The vent exit elevation should be greater of the elevation determined in 6.2.3 (Thermal radiation and impingement, ref. to API 521) or 3 m above grade; or 0.61 m above adjacent equipment; or 1.5 m above rooftops.

Discharge of cold vapour

Exist of vent stacks for cold hydrogen gas releases should be at a height that is sufficient to avoid vapour clouds. Cold hydrogen vents need to be higher that warm hydrogen vents because the exiting gas can be at a higher density than the ambient air and could cause the hydrogen to accumulate.

PGS 35 Guidelines – Netherlands

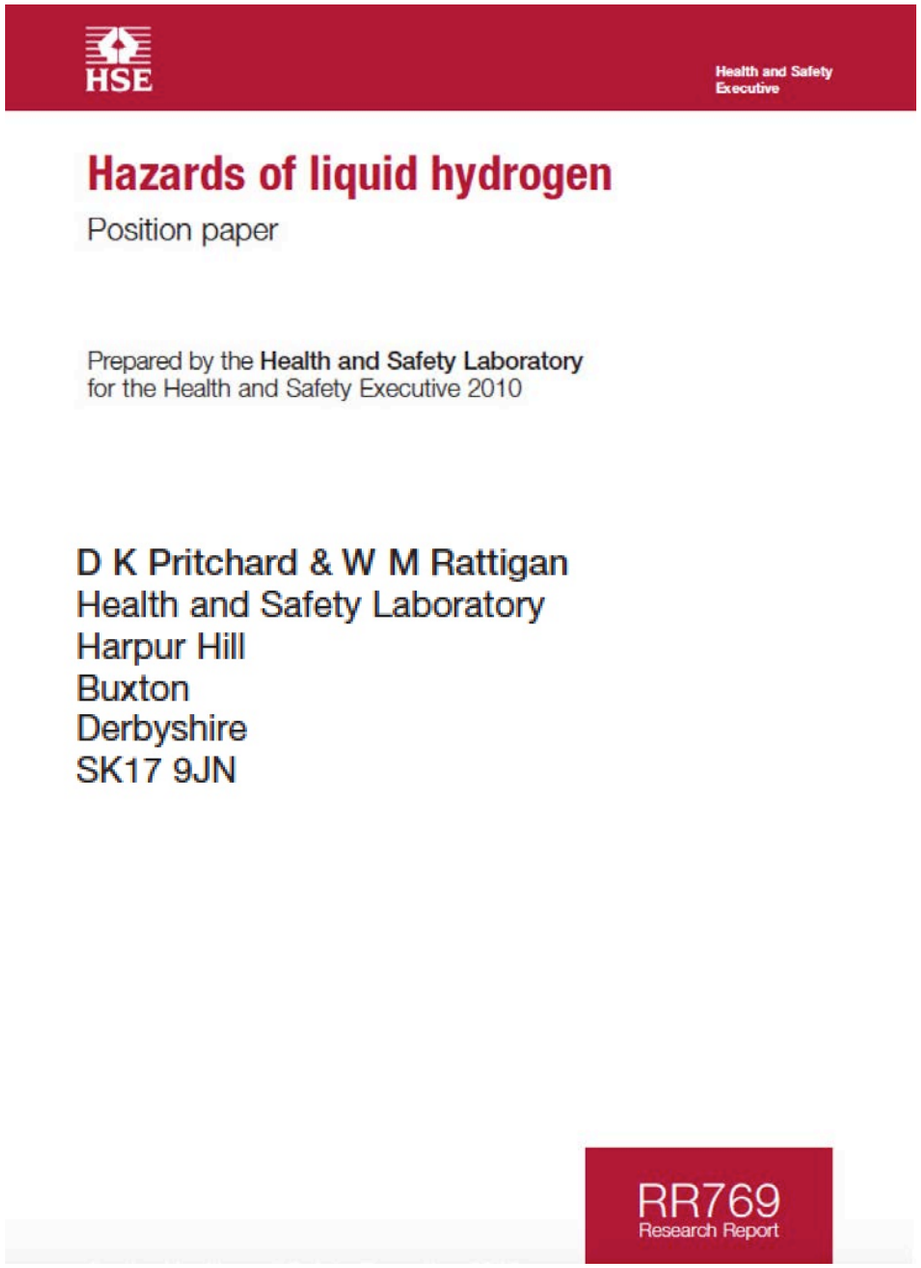


PGS comprises representatives from the authorities (the Association of Interprovincial Authorities (IPO), the Association of Dutch Municipalities (VNG), the Social Affairs and Employment Inspectorate (Inspectorate SZW), the Dutch Fire Service, the business community (VNO-NCW and MKB Nederland) and employees.

reg. 2.5.4 The outlet of liquid hydrogen shall be designed in such a way that: **Vent stacks**

- the heat radiation from a flare from the central vent stack onto neighbouring objects has been taken into account;
- this source is at least 3 m above ground level;
- the heat radiation at ground level is lower than 3 kW/m^2 within the establishment limit and lower than 1 kW/m^2 outside the establishment limit in order to protect people;
- the heat radiation intensity from a flare from the central vent stack on the gaseous hydrogen storage unit is less than 10 kW/m^2;
- the heat radiation intensity from a flare on the liquid hydrogen storage unit is less than 35 kW/m^2;
- the material of the flare can withstand the high temperatures at the exhaust (and for liquid hydrogen it can also withstand low temperatures at the intake).

HSL Position Paper on LH_2



HSE

Health and Safety Executive

Hazards of liquid hydrogen

Position paper

Prepared by the **Health and Safety Laboratory** for the Health and Safety Executive 2010

D K Pritchard & W M Rattigan
Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN

RR769
Research Report

The Health and Safety Executive have commissioned the Health and Safety Laboratory to identify and address issues relating to bulk liquid hydrogen transport and storage and update/develop guidance for such

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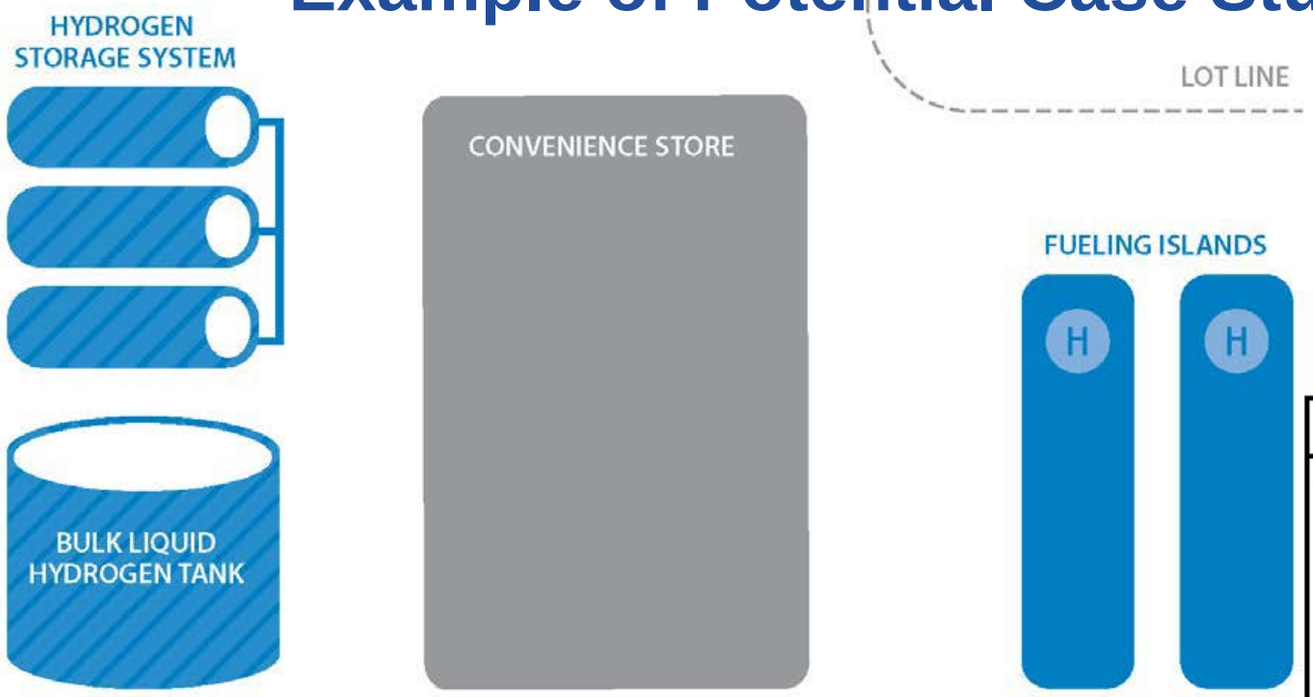
Example of Potential Case Study



Objective: Determine reasonable hazard distances for LH_2

EIGA DOC 06/02/E

ITEMS	DISTANCE (M)
90 min fire resistive walls	2.5
Technical and unoccupied buildings	10
Occupied buildings	20
Air compressor intakes, air conditioning	20
Any combustible liquids	10
Any combustible solids	10
Other LH2 fixed storage	1.5
Other LH2 tanker	3
Liquid oxygen storage	6
Flammable gas storage	8
Open flame, smoking, welding	10
Place of public assembly	20
Public establishments	60
Railroads, roads, property boundaries	10
Overhead power lines	10

SYSTEM	EXPOSURE	SETBACK DISTANCE NFPA 2 Hydrogen technologies Code 2011 edition
Dispenser	Building, lot line	10 feet
Gaseous hydrogen (15,000 psi)	Opening in building	34 feet
Gaseous hydrogen (15,000 psi)	Public road/property line	34 feet
Liquid hydrogen (100,000 L)	Opening in building	75 feet
Liquid hydrogen (100,000 L)	Public road/property line	75 feet

Source:

Hydrogen Technologies Safety Guide

C. Rivkin, R. Burgess, and W. Buttner

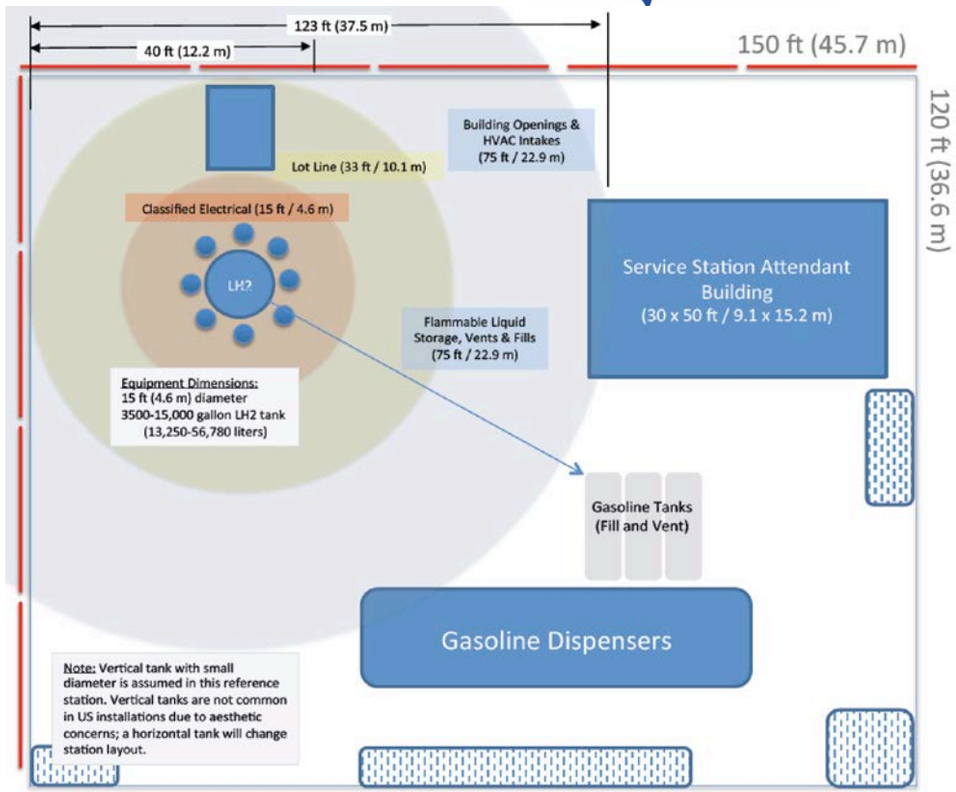
National Renewable Energy Laboratory

January 2015

Example of Potential Case Study

Table 1 –Summary of separation distances from NFPA 2 (2011 edition) – critical distances used in developing the diagrams in this report are shown in bold.

Separation Distances and Areas Required Fuel system descriptions: GH2 – 12,500 psi (862 bar) storage, 100 kg, 0.4 in (10 mm) ID tubing with a barrier wall LH2 – 3,500 - 15,000 gallon (13,250-56,780 liters) with barrier wall and insulation	GH2 ft (m)	LH2 ft (m)
Lot lines	**24 (7.3)**	**33 (10)**
Public streets, alleys	24 (7.3)	33 (10)
Parking (public assembly)	13 (4.0)	**75 (23)**
Buildings (sprinklers, fire rated)	10 (3.0)	5 (1.5)
Building openings or air intakes	**24 (7.3)**	**75 (23)**
Flammable and combustible liquid storage, vents or fill ports	10 (3.0)	50 (15)
Parking from fill concentrations on bulk storage	13 (4.0)	25 (7.6)
Class 1 Division 2 area diameter	15 (4.6)	15 (4.6)
Maximum bulk storage equipment dimension with lot lines	54 (16)	40 (12)
Minimum bulk storage equipment dimension with lot lines	49 (15)	40 (12)
Maximum bulk storage dimension with separation distances	78 (24)	123 (37)
Minimum bulk storage dimension with separation distances	68 (21)	123 (37)
Reference Area: bulk storage equipment with lot lines	2646 ft^2 (246 m^2)	1600 ft^2 (149 m^2)
Reference Area: storage with separation distances	**5304 ft^2 (493 m^2)**	**15129 ft^2 (1406 m^2)**
Note: Add 5 feet (1.5 meters) for vehicle protection on vehicle facing sides of equipment		



Source – SANDIA REPORT:
Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development
A.P. Harris, Daniel E. Dedrick, Chris LaFleur, Chris San Marchi, Apr 2014

Objective: Determine reasonable hazard distances for LH_2

F.1 Simplified diagram of options

For ISO standards development

Project stage	Normal procedure	Draft submitted with proposal	"Fast-track procedure" [a]	Technical Specification [b]	Technical Report [c]	Publicly Available Specification [d]
Proposal stage (see 2.3)	Acceptance of proposal	Acceptance of proposal	Acceptance of proposal [a]	Acceptance of proposal		Acceptance of proposal [g]
Preparatory stage (see 2.4)	Preparation of working draft	*Study by working group* [e]		Preparation of draft		Approval of draft PAS
Committee stage (see 2.5)	Development and acceptance of committee draft	*Development and acceptance of committee draft* [e]		Acceptance of draft	Acceptance of draft	
Enquiry stage (see 2.6)	Development and acceptance of enquiry draft	Development and acceptance of enquiry draft	Acceptance of enquiry draft			
Approval stage (see 2.7)	*Approval of FDIS* [f]	*Approval of FDIS* [f]	*Approval of FDIS* [f]			
Publication stage (see 2.8)	Publication of International Standard	Publication of International Standard	Publication of International Standard	Publication of Technical Specification	Publication of Technical Report	Publication of PAS

Key question: who is going to submit a NWIP and champion the work to completion?

THANK YOU FOR YOUR ATTENTION!

Questions / comments welcome!