European Train the Trainer Programme for Responders

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)
Grant Agreement Number 875089

European Emergency Response Guide

Lead authors: ENSOSP (Laurent LECOMTE)
Contributing authors: ENSOSP (Franck VERRIEST and Wilfried STÉFIC)

Version: December 2022
Dissemination level: Public

Co-funded by the European Union

This page intentionally left blank.

Note: the first edition of this document was developed within the HyResponse project, this has been built upon within HyResponder. The document history covers the entire development process.

Document history

Revision	Date	Modifications made	Author(s)
V1	29/04/2015	Elaboration of this document (ToC)	
V2	26/11/2015	Comments on the ToC (Basics of hydrogen are added based on Description of Work)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir; Makarov Dmitriy
V3	08/12/2015	Draft of UU contributions (draft of hydrogen basics of emergency respond guide for fuel cell vehicles)	Li Zhiyong; Tretsiakova-McNally Svetlana
V4	16/12/2015	Revision of UU contributions (add terms and definitions in a form of glossary)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir
V5	22/12/2015	Revision of UU contributions (reorganize the emergency response guide for fuel cell vehicles)	Li Zhiyong; Molkov Vladimir
V6	18/02/2016	Revision of UU contributions (more emergency response info from credible sources is added)	Li Zhiyong
V7	26/02/2016	Revision of UU contributions (revision based on the UU team discussion of both scientific and technical issues)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir; Makarov Dmitriy
V8	27/02/2016	Revision of UU contribution	Molkov Vladimir
V 9	29/02/2016	Revision of UU contribution	Svetlana Tretsiakova-McNally, Li Zhiyong
V10	31/10/2016	ENSOSP Contribution	Sebastien BERTAU
V11	2020/2021	ENSOSP Revisions	Laurent LECOMTE
V12	30/05/2021	Revision and consortium partners' contributions	Laurent LECOMTE, Sébastien BERTAU, Lukasz FARALISZ, Gerhard SCHÖPF, Tom VAN ESBROECK, Julien ROUSSEL, Gustaaf COOLS, Petter FRANZ, Renaud DE BURON BRUN, Hugo TOSELLO
V13	09/06/2021	Revision of partners' contributions	Laurent LECOMTE, Iraia OEYEN, Gustaaf COOLS, Hugo TOSELLO
V14	15/06/2021	Formatting / Phrasing	Sile Brennan
V15	25/06/2021	Tactical sheets addition	Laurent LECOMTE, Franck VERRIEST

This page intentionally left blank.

TABLE OF CONTENTS

Introduction

This Emergency Response Guide on hydrogen and fuel cell applications for First Responders was first produced within the Response project[1] and has been revised within the scope of HyResponder[2].

This guide is intended to be used by emergency response personnel, both by front-liners and commanders, from the moment they have received an emergency call until the FINAL INSPECTION. It is expected that this guide will support the decision-making personnel, who already have knowledge of emergency response operations and procedures.

This revised version includes events related to liquefied hydrogen (LH_2). New vectors of mobility and transport such as buses, trucks and trains have been added. Moreover, a new set of operational tactical sheets have been inserted and the previous version has been enriched with multiple contributions.

If you have any comments and/or questions about this Emergency Response Guide, please email*:* *formations.specialisees@ensosp.fr*

How to use this guide?

It is a two parts document with supporting appendices which intertwined academic knowledge and operational tactics.

The first part is dedicated to the Hydrogen Application and Associated Risks which realized an exhaustive definition of this element from its physical propriety (gaseous & liquid) to its contemporary applications and the threats related to it. This part provides the theoretical background to properly perform the response phase which is detailed in the second part of the guide. The reader is referred to educational lectures available on the HyResponder e-Platform if further detail on a specific topic is required. https://hyresponder.eu/

The revised tactics described in the second section emanate from a collective effort to update the strategies proposed in HyResponse. Diagrams are presented in the beginning to define safety distances according to the pressure and volume of a hydrogen tank. In addition, is included the two main tactics of intervention (offensive & defensive) and their advantages and drawbacks. Then, the complete procedure of emergency response is detailed (recognition, rescue, preparedness, incident settlement, protection, clear out) jointly with the plural threats that responders could encounters (hydrogen leak and fire). Finally, tactical sheets concisely instruct on how to operate in these situations according to the type of vehicle or unit.

This document should be considered as a compendium of information. The guidance contained should be interpreted keeping in mind national and regional specificities.

This guide constitutes one of the bases of the training realized in during the HyResponder project towards European trainers to disseminate knowledge on hydrogen risk throughout Europe. This training session combine academic and operational knowledge and capture the essential information gathered in the European Emergency Response Guide on hydrogen.

[1] http://www.hyresponse.eu/

[2] https://hyresponder.eu/

This page intentionally left blank.

PART 1 HYDROGEN, APPLICATIONS AND ASSOCIATED RISKS

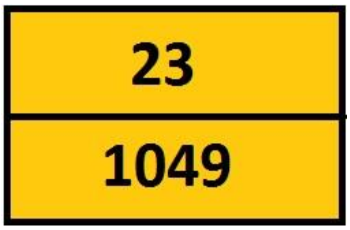
1. GASEOUS HYDROGEN

1.1. Identification

Figure 1 : Bundle V18

Figure 2 : Bottle 50 liters

1.2. ADR, IMDG, IATA



NAME: **Hydrogen** (En); Hydrogène (Fr); Dihydrogène (Fr) ; Wasserstoff (D); Hidrógeno (Sp); Idrogeno (It)

Chemical Abstracts Service (CAS) No:	1333-74-0
EC number:	215-605-7
EC index number:	001-001-00-9
Chemical formula:	H_2 ; H—H
Molar mass:	2 $g.mol^{-1}$
SDS NUMBER:	SDS-067A-CLP (air liquide)

1.3. Classification, Labelling and Packaging (CLP)

H220 - Extremely flammable gas.

H280 - Contains gas under pressure; may explode if heated.

P210 - Keep away from heat, hot surfaces, sparks, open flames, and other ignition sources. No smoking.

P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely.

P381 - Eliminate all ignition sources if safe to do so.

P403 - Store in a well-ventilated place.

P410+P403 - Protect from sunlight. Store in a well-ventilated place.

1.4. Operational relevant features:

Color:	Colorless.
Odors:	Odorless.
Melting point:	-259 °C (solid to liquid)
Boiling point:	-253 °C (liquid to gas)
Auto-ignition temperature:	560 °C
Flammability range:	4 - 77 vol % in air
Detonability range	11 - 59 vol. % [3] in air
Relative density, hydrogen/air:	0.07/1
Relative density, air/hydrogen:	14.28/1
Solubility in water:	1.6 mg/l
Ignition energy	0.017 mJ

At standard conditions of temperature and pressure STP (273.15 K-0 °C/101.325 kPa -1bar), Hydrogen:

- Is GASEOUS
- goes UP/rises due to its very low relative density compared to air
- Mixes very quickly with the atmosphere where it is released
- Has a wide flammability range
- Can be ignited by one of the lowest gas ignition energies (e.g., static electricity, rubbing, shocks, heat…)
- Spontaneous ignition of a sudden release is possible.

If the release is the result of a leak of liquid Hydrogen, the extremely cold temperature of the gas can lead the hydrogen cloud to flow horizontally or downwards after immediate release. The condensation of atmospheric humidity can make the cloud visible for a moment even if hydrogen itself is invisible.

[3](Alcock et al., 2001)

1.5. Hazardous phenomena (FC H_2 CARS)

Fuel cell (FC) electric vehicles can take two forms:

- A vehicle powered using hydrogen in a fuel cell only with a H_2 700-bar storage tank

- A hybrid electric vehicle with a battery and a H_2 range extender with a 350-bar H_2 storage tank

On-board fuel tanks have a volume around 80 L (2 tanks) or 140 L. This allows for an inventory of 5 to 7 kg of H_2.

For a fuel cell electric vehicle, the main feared events are:

- Release from Thermally activated pressure relief device (TPRD) or other equipment (e.g., piping full bore rupture, loss of tightness of connections) and consequences are:
    - blowdown of the tank without ignition
    - or ignited release:
        - with immediate ignition inducing a jet fire,
        - with delayed ignition inducing a flammable cloud and a potential unconfined vapor cloud explosion.

- Mechanical rupture of the tank inducing a blast wave.

1.5.1. Potential consequences

1.5.1.1. Release without ignition

In the case of release without ignition, Table 6 hereafter gives the blowdown duration for several tank volumes and different release diameters.

0.1- and 1-mm diameter releases are representative of an accidental leak due to tightened connections, or equipment. 2-mm and 4-mm diameter releases are more representative of a TPRD release.

These values are interesting to assess the time required to totally empty the tank and evaluate the risk of tank burst in case of fire, and the minimum duration needed to protect the tank to avoid burst.

These values were calculated using a validated tool (e-laboratory[4]) tool for an ambient temperature of 15°C.

Table 6: Tank blowdown duration for different volumes and release diameters

Tank volume	Storage pressure	Blowdown duration			
		0.1 mm	1 mm	2 mm	4 mm
80 L	350 bar	25 h	13 min 20 s	3 min 40 s	52 s
150 L	350 bar	47 h	28 min 10 s	7 min	1 min 40 s
80 L	700 bar	29 h	17 min 10 s	4 min 10 s	56 s
150 L	700 bar	54 h	32 min 20 s	8 min	1 min 50 s

1.5.1.2. Release with immediate ignition

In the case of a release with immediate ignition, a jet fire is produced with thermal effects as hazardous consequences.

Example release flowrates for a horizontal jet fire, and the resultant consequences have been calculated using a validated tool (e-laboratory[5]) and are shown in Table 7. Tank blowdown is not considered; the maximal pressure is used. Thus hazard distances are conservative in terms of safety.

Table 7: Thermal effects for jet fires considering different pressures and release diameters.

Release diameter	Storage pressure	Release flowrate	Thermal effects			
			Flame length	3 $kw.m^{-2}$	5 $kw.m^{-2}$	8 $kw.m^{-2}$
0.1 mm	350 bar	$1.5 \cdot 10^{-4}$ $kg.s^{-1}$	0.2 m	0.2 m	< 0.2 m	< 0.2 m
1 mm	350 bar	$1.5 \cdot 10^{-2}$ $kg.s^{-1}$	2.3 m	2.9 m	2.6 m	< 2.3 m

[4] https://hyresponder.eu/e-platform/e-laboratory/

[5] https://hyresponder.eu/e-platform/e-laboratory/

2 mm	350 bar	$6.0{\cdot}10^{-2}$ kg.s^{-1}	4.5 m	6.4 m	5.6 m	5 m
4 mm	350 bar	$2.4{\cdot}10^{-1}$ kg.s^{-1}	9.1 m	14 m	12 m	11 m
0.1 mm	700 bar	$2.7{\cdot}10^{-4}$ kg.s^{-1}	0.3 m	0.3 m	< 0.3 m	< 0.3 m
1 mm	700 bar	$2.7{\cdot}10^{-2}$ kg.s^{-1}	3 m	4 m	3.5 m	3.2 m
2 mm	700 bar	$1.1{\cdot}10^{-1}$ kg.s^{-1}	6.1 m	9 m	8 m	7 m
4 mm	700 bar	$4.3{\cdot}10^{-1}$ kg.s^{-1}	12 m	19 m	17 m	15 m

Another approach could be to use « harm criteria” for people described by LaChance (2010). Corresponding values are given in Table 8 hereafter.

Table 8: Separation distances for jet fires considering different pressures and release diameters.

Release diameter	Storage pressure	Thermal effects			
		Flame length	No harm	Pain threshold	3rd degree burns
0.1 mm	350 bar	0.2 m	0.7 m	0.6 m	0.4 m
1 mm	350 bar	2.3 m	8 m	7 m	4.6 m
2 mm	350 bar	4.5 m	16 m	14 m	9 m
4 mm	350 bar	9.1 m	32 m	27 m	18 m
0.1 mm	700 bar	0.3 m	1 m	0.9 m	0.6 m
1 mm	700 bar	3 m	11 m	9 m	6 m
2 mm	700 bar	6.1 m	21 m	18 m	12 m
4 mm	700 bar	12.1 m	42 m	36 m	14 m

1.5.1.3. Release with delayed ignition

For a release with delayed ignition, an unconfined vapor cloud explosion is considered (UVCE). A flammable cloud is formed, and its ignition induces a blast wave with overpressure effects as hazardous consequences, decreasing with the distance from the ignition point.

Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5; hydrogen flowrate is used and the phenomenon in the free field without or with small congestion.

Release is considered horizontal and ignition point is taken at 10%-H_2 in the axis of the release.

Table 9: Overpressure effects for UVCE considering different pressures and release diameters.

Release diameter	Storage pressure	Hydrogen mass	Overpressure effects			
			20 mbar	50 mbar	140 mbar	200 mbar
0.1 mm	350 bar	$6.6 \cdot 10^{-7}$ kg	0.8 m	0.4 m	0.3 m	< 0.3 m
1 mm	350 bar	$6.6 \cdot 10^{-4}$ kg	7.9 m	4.5 m	3 m	2.7 m
2 mm	350 bar	$5.3 \cdot 10^{-3}$ kg	16 m	8.8 m	5.9 m	5.3 m
4 mm	350 bar	$4.2 \cdot 10^{-2}$ kg	31 m	18 m	12 m	11 m
0.1 mm	700 bar	$1.9 \cdot 10^{-6}$ kg	1.1 m	0.7 m	0.4 m	< 0.4 m
1 mm	700 bar	$1.9 \cdot 10^{-3}$ kg	11 m	6.2 m	4.2 m	3.7 m
2 mm	700 bar	$1.5 \cdot 10^{-2}$ kg	22 m	13 m	8.4 m	7.5 m
4 mm	700 bar	$1.2 \cdot 10^{-1}$ kg	44 m	25 m	17 m	15 m

1.5.1.4. Mechanical rupture of the storage tank

To evaluate maximum hazardous distances, an engulfing fire is considered on a stand- alone composite tank (type IV) at maximum working pressure.

The rupture pressure is 1.9 times the maximum working pressure. Table 10 indicates characteristic overpressures.

Table 10: Overpressure effects due to tank burst considering different pressures and tank volumes.

Tank volume	Storage pressure	Overpressure effects			
		20 mbar	50 mbar	140 mbar	200 mbar
80 L	350 bar	53 m	27 m	11 m	8 m
150 L	350 bar	66 m	33 m	14 m	10 m
80 L	700 bar	67 m	34 m	14 m	10 m
150 L	700 bar	83 m	41 m	18 m	13 m

Note: Hazardous distances are very similar for a type-III storage tank.

1.6. Hazardous phenomena (FC Gaseous H_2 BUSES, TRAINS and TRUCKS)

In this section buses, trains and trucks are treated together because they are very close in terms of design (e.g., storage pressure and volume, TPRD size and location). At present, existing fuel cell buses and trains have gaseous hydrogen on-board tanks (not LH_2).

As for FCEVs, the main feared events are:

Release from TPRD or other equipment (e.g., piping full bore rupture, loss of tightness of connections) and the potential consequences are:

- Blowdown of the tank without ignition
- Or ignited release
    - With immediate ignition inducing a jet fire
    - With delayed ignition inducing a flammable cloud and a potential unconfined vapor cloud explosion
- Mechanical rupture of the tank inducing a blast wave.

Concerning TPRD, for FCEV the TPRD outlet is very close to the ground, compared to trains and busses where TPRD the outlet is (currently) located on the roof. The TPRD location varies for FC gaseous H_2 trucks; it depends on the OEM.

Storage tanks are located on the roof of buses and trains, but at the bottom for trucks.

Storage pressure is typically 350 bar with storage tanks of a higher volume than FC cars. However, it should expect that the storage pressure will be increased to 700 bar in order to increase autonomy.

Tank volumes are around 170 L (buses, trucks) or 240 L (trains). The number of on-board tanks depends on the autonomy target. Thus there can be 5 to 10 cylinders for one bus or one train coach.

The inventory of on-board H_2 ranged from 30 to 45 kg for buses and can reach 180 kg for trains.

1.6.1. Potential consequences

1.6.1.1. Release without ignition

Table 11 gives the blowdown duration (time to empty) for several tank volumes and different release diameters.

These values are useful to assess the time required to totally empty the tank and evaluate the risk of tank burst in the case of fire. The values have been calculated using a validated tool (e-laboratory[6]) and are based on venting to atmospheric pressure, considering the adiabatic approach and ambient temperature at 15°C. The increased blowdown time, compared to a car, due to the increased inventory of hydrogen should be noted.

Table 11: Tank blowdown duration for different volumes and release diameters

Tank volume	Storage pressure	Blowdown duration			
		0.1 mm	1 mm	2 mm	4 mm
170 L	350 bar	53 h	32 min	7 min 45 s	1 min 45 s
240 L	350 bar	71 h	45 min	11 min	2 min 40 s
170 L	700 bar	61 h	36 min 30 s	9 min	2 min
240 L	700 bar	> 74 h	51 min 40 s	12 min 45 s	3 min

1.6.1.2. Release with immediate ignition

In the case of a release with immediate ignition, a jet fire is produced, which has thermal effects as hazardous consequences. The pressures and diameters involved at the same as those for FC cars. Therefore the distances corresponding to thermal effects for jet fires given in Tables 7 and 8 are applicable.

[6] https://hyresponder.eu/e-platform/e-laboratory/

1.6.1.3. Release with delayed ignition

For release with delayed ignition, an unconfined vapor cloud explosion is considered (UVCE). A flammable cloud is formed, and its ignition induces a blast wave with overpressure effects as hazardous consequences. The overpressure decreases with the distance from ignition point.

Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5; hydrogen flowrate is used and the phenomenon in the free field without or with small congestion.

For buses, trains and trucks, hazardous distances are the same as FC cars and are given in Table 9.

1.6.1.4. Mechanical rupture of the storage tank

To evaluate the maximum hazard distances, the scenario of an engulfing fire on a stand- alone composite tank (type IV) at maximum working pressure is considered. Hazard distances for four overpressures are given in Table 12.

The rupture pressure is 1.9 times the maximum working pressure.

Table 12: Overpressure effects due to tank burst considering different pressures and tank volumes.

Tank volume	Storage pressure	Overpressure effects			
		20 mbar	50 mbar	140 mbar	200 mbar
170 L	350 bar	68 m	34 m	15 m	11 m
240 L	350 bar	77 m	38 m	17 m	12 m
170 L	700 bar	86 m	43 m	19 m	13 m
240 L	700 bar	97 m	48 m	21 m	15 m

It should be noted that the hazard distances are very like those above (type IV tank) for a type-III storage tank.

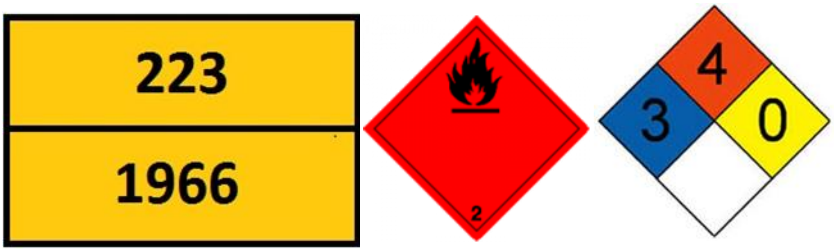
2. LIQUID HYDROGEN

2.1. Identification :

Figure 3 Fig 2: Cryogenic Hydrogen truck. Source Air Liquide Image Bank

2.2. Danger

2.3. ADR, IMDG, IATA



NAME:	Liquid Hydrogen (En); Hydrogène liquid (Fr);
Chemical Abstracts Service (CAS) No:	1333-74-0
EC number:	215-605-7
EC index number:	001-001-00-9
Chemical formula:	H_2; H—H
Molar mass:	2 $g.mol^{-1}$
SDS NUMBER:	SDS-067R-CLP (air liquide)

2.4. Classification, Labelling and Packaging (CLP)

H220 - Extremely flammable gas.

H281 - Contains refrigerated gas; may cause cryogenic burns or injury

P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely.

P381 - Eliminate all ignition sources if safe to do so.

P336 - Thaw frosted parts with lukewarm water. Do not rub affected area.

P315 - Get immediate medical advice/attention.

P403 - Store in a well-ventilated place.

P410 - Protect from sunlight.

2.5. Operational relevant features:

Color:	Colorless.
Odors:	Odorless.
Melting point:	-259 °C (solid to liquid)
Boiling point:	-253 °C (liquid to gas)
Auto-ignition temperature:	560 °C
Flammability range:	4 - 77 vol % in air
Detonability range	11 - 59 vol. % [7] in air
Relative density, hydrogen/air (gas):	0.07/1
Relative density, air/hydrogen (Gas):	14.28/1
Volumetric ratio of LH_2 to GH_2	**1: 848**
LH_2 density (at NBP)	70.78 kg/m^3
Solubility in water:	1.6 mg/l
Ignition energy	0.017 mJ

At standard conditions of temperature and pressure STP (273.15 K-0 °C/101.325 kPa -1bar), Hydrogen:

- Is GASEOUS
- goes UP (rises) due to its very low relative density/Air
- Mixes very quickly with the atmosphere where it is released
- Has a wide flammability range
- Can be ignited by one of the lowest gas ignition energies (e.g., static electricity, rubbing, shocks, heat…)
- Spontaneous ignition of a sudden release is possible

[7](Alcock et al., 2001)

If the release is the result of a leak of liquid Hydrogen, the extremely cold temperature of the gas can lead the hydrogen cloud to flow horizontally or downwards after immediate release. The condensation of atmospheric humidity can make the cloud visible for a moment even if hydrogen itself is invisible. Due to the volumetric ratio of LH2 to GH2 (1:848), the vaporisation of LH2 in a closed vessel will lead to a violent increase of pressure.

2.6. Hazardous phenomena

For liquid on-board hydrogen storage, the main feared events are:

- Liquid cryogenic release
  - unignited release:
    - with cryogenic burns and/or insufficient oxygen (anoxia) in confined spaces
  - ignited release:
    - with immediate ignition inducing a jet fire
    - with delayed ignition inducing a direct flammable cold cloud and a potential unconfined vapor cloud explosion or a cryogenic liquid pool followed by a flammable cloud due to hydrogen vaporisation
- Mechanical rupture of the tank inducing a blast wave.

2.6.1. Potential consequences

2.6.1.1. Release without ignition

As previously said, in case of release without ignition, the main risks for first responders are cryogenic burns and/or oxygen depletion (anoxia).

Appropriate individual protection can be used to protect first responders against these hazards.

2.6.1.2. Release with immediate ignition

In the case of release with immediate ignition, a jet fire results where the primary hazard is thermal effects.

Release flowrates, and consequences were calculated using a validated tool (e-laboratory[8]).

Table 13: Thermal effects for jet fires considering different pressures and release diameters.

Release diameter	Storage pressure	Liquid release flowrate	Thermal effects			
			Flame length	3 kw.m^{-2}	5 kw.m^{-2}	8 kw.m^{-2}
0.1 mm	1 bar	$8.7 \cdot 10^{-6}$ kg.s^{-1}	0.1 m	< 0.1 m	< 0.1 m	< 0.1 m
1 mm	1 bar	$8.7 \cdot 10^{-4}$ kg.s^{-1}	0.8 m	0.9 m	0.8 m	0.7 m
2 mm	1 bar	$3.5 \cdot 10^{-3}$ kg.s^{-1}	1.5 m	1.7 m	1.5 m	1.4 m
4 mm	1 bar	$1.4 \cdot 10^{-2}$ kg.s^{-1}	3.1 m	3.8 m	3.3 m	3 m

Table 14: Separation distances for jet fires considering different pressures and release diameters.

Release diameter	Storage pressure	Thermal effects			
		Flame length	No harm	Pain threshold	3rd degree burns
0.1 mm	1 bar	0.1 m	0.4 m	0.3 m	0.2 m
1 mm	1 bar	0.8 m	2.8 m	2.4 m	1.6 m
2 mm	1 bar	1.5 m	5.3 m	4.5 m	3 m
4 mm	1 bar	3.1 m	10.9 m	9.3 m	6.2 m

2.6.1.3. Release with delayed ignition

For releases with delayed ignition, an unconfined vapor cloud explosion is considered (UVCE). A flammable cloud is formed, and its ignition induces a blast wave with overpressure effects as hazardous consequences. The overpressure decreases with the distance from ignition point.

[8] https://hyresponder.eu/e-platform/e-laboratory/ applying Helmholtz free energy-based equation of state, and Schefer approach.

Indicative overpressure distances were calculated and are presented in Table 15. These were calculated with the TNO Multi-Energy approach, considering a level 5; hydrogen flowrate is used, and the phenomenon is considered in the free field without or with small congestion. The release is considered as horizontal and ignition point is taken at 10%-H_2 in the axis of the release.

Table 15: Overpressure effects for UVCE considering different pressures and release diameters.

Release diameter	Storage pressure	Hydrogen mass	Overpressure effects			
			20 mbar	50 mbar	140 mbar	200 mbar
0.1 mm	1 bar	$2.5 \cdot 10^{-8}$ kg	0.3 m	0.2 m	< 0.2 m	< 0.2 m
1 mm	1 bar	$2.5 \cdot 10^{-5}$ kg	2.6 m	1.5 m	1 m	0.9 m
2 mm	1 bar	$2.0 \cdot 10^{-4}$ kg	5.3 m	3 m	2 m	1.8 m
4 mm	1 bar	$1.6 \cdot 10^{-3}$ kg	10.5 m	6 m	4 m	3.6 m

2.6.1.4. Mechanical rupture of the storage tank

To evaluate maximum hazard distances, the scenario of a stand- alone cryogenic tank (type I) in an engulfing fire at maximum working pressure is considered. Hazard distances for a range of overpressures are presented in Table 16.

The rupture pressure is 1.9 times the maximum liquid pressure.

Table 16: Overpressure effects due to tank burst considering different tank volumes.

Tank volume	Maximum liquid pressure	Overpressure effects			
		20 mbar	50 mbar	140 mbar	200 mbar
0.5 m^3	13 bar	32 m	16 m	7 m	5 m
1 m^3	13 bar	41 m	20 m	9 m	6 m
15 m^3	13 bar	100 m	50 m	22 m	15 m

3. HYDROGEN DANGERS

Hydrogen is an odourless, colourless, tasteless, non-toxic, non-corrosive, but highly flammable gas. It can be stored in a gaseous phase at ambient temperature, by high pressure compression or in a liquid phase by cryogenic liquefaction. Hydrogen dangers are associated with its chemical and physical properties.

3.1. Asphyxiation

Hydrogen, when released in enclosed/confined areas, can replace oxygen in the atmosphere and then cause asphyxiation by oxygen depletion (anoxia). The effects begin if oxygen content in the air is below 18%. (Normal oxygen level in the air is 20-21%).

3.2. Pressure

Gaseous hydrogen is stored in tanks, pressurised up to 700 bar. The rupture of tanks or flexible tubes under pressure may cause major injuries.

The liquid to gas phase change causes the occupied volume to increase from 1 to 845. Consequently, the pressure in a confined space will increase extremely quickly.

3.3. Noise

Due to the high pressure needed for storage (350-700 bar), a gaseous hydrogen leak produces a noise that can reach 130-140dB. (ear damage can occur above 90dB and pain can be experienced from 120 dB).

3.4. Embrittlement

Hydrogen is the smallest molecule of all known elements. The interaction of hydrogen with the containment material lattice can cause a loss of structural strength and lead to embrittlement of tanks and pipes causing their eventual rupture.

3.5. Cryogenics

At ambient pressure, liquid hydrogen must be kept a 20.3°K (-252.85°C/-423.13ºF). This is an extremely low temperature. Direct skin contact with liquid or cold gaseous hydrogen causes instantaneous cold burns.

3.6. Combustion

Hydrogen is highly flammable and explosive. The flammability range in air is 4-75% [% v/v] and the minimum ignition energy is 0.02 mJ. Hydrogen has a wider detonability range compared to other fuels. The widest detonability range of hydrogen in air 11-59 vol. % [9]. Hydrogen burns with pale-blue flames and emits neither visible light in daytime or smoke unless some materials or particles are entrained and burned along with the combustible mixture. In air, a hydrogen flame is only visible along 30% of its length. Compared to hydrocarbons, hydrogen flames radiate significantly less heat. Thus, a human may not physically feel this heat until direct contact is made with the flame. A hydrogen fire may

[9] Alcock et al., 2001

remain undetected and will propagate despite any direct monitoring by people in the areas where hydrogen can leak, spill, or accumulate and form potentially combustible mixtures.

3.7. Feared events and phenomena reminder

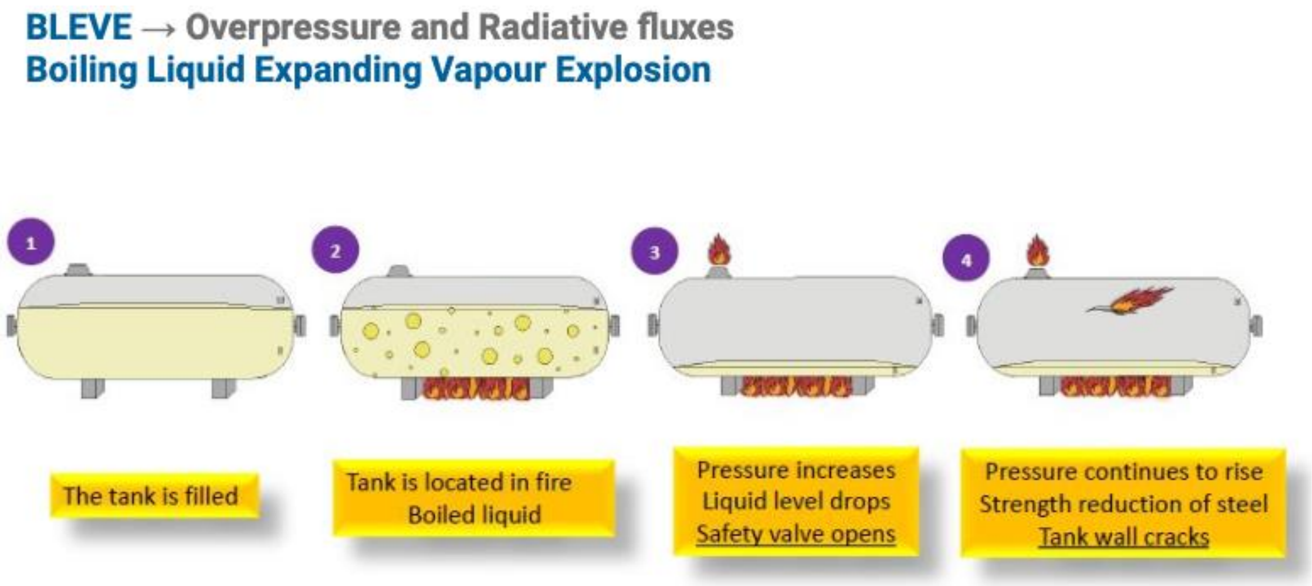


Figure 4 : BLEVE effect representation - Source Air Liquide Image Bank

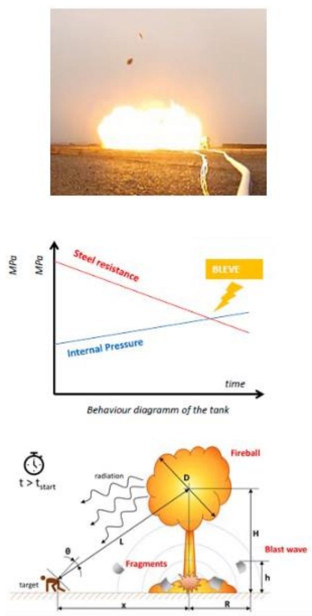


Figure 5: BLEVE effect representation - Source Air Liquide Image Bank

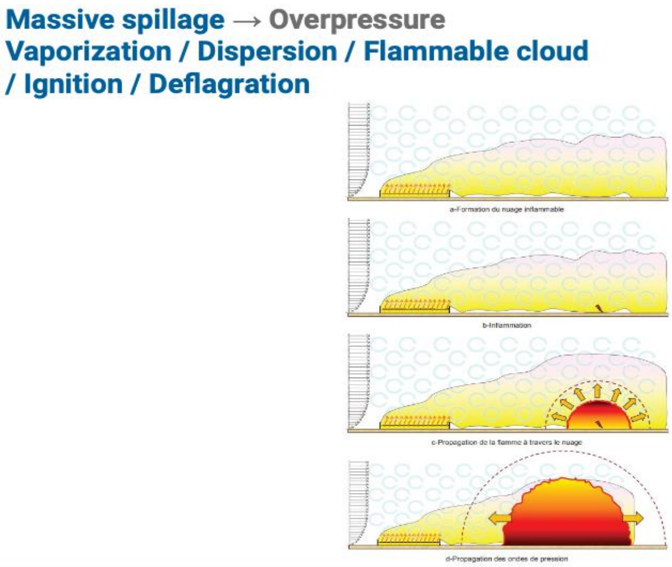


Figure 6: Massive spillage representation. Source Air Liquide Image Bank

RPT → Overpressure
Rapid Phase Transition

Liquid hydrogen at cryogenic temperature into contact with water → quick heating and violent vaporization → cold explosion, flameless *(very low probability for LH_2)*

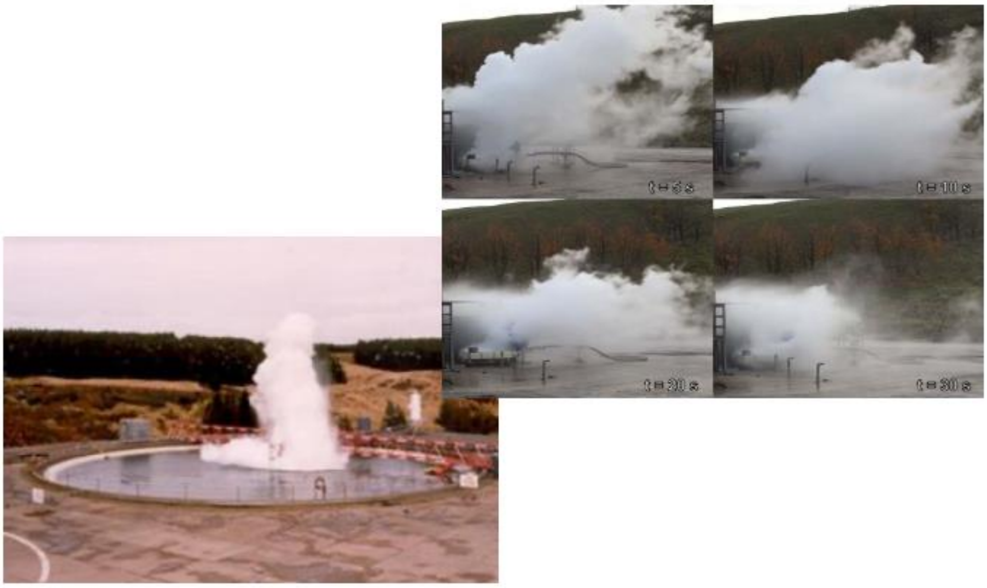


Figure 5: Rapid Phase Transition representation. Source Air Liquide Image Bank

LH_2 release - unignited → Flammable cloud

Figure 6: LH2 release (unignited) - Source Air Liquide Image Bank

LH_2 release - ignited → Radiative heat fluxes

Figure 7: LH2 release (ignited) - Source Air Liquide Image Bank

4. SPECIFIC TOOLS

4.1. Thermal Imaging Equipment

First responders can use a thermal imaging device to make the hydrogen flame in air visible as shown in Figures 8 - 10.

A laser thermometer can also be used to identify safely high or low temperature items.

Figure 8 : H2 tank fire (700b) (ENSOSP 2014).

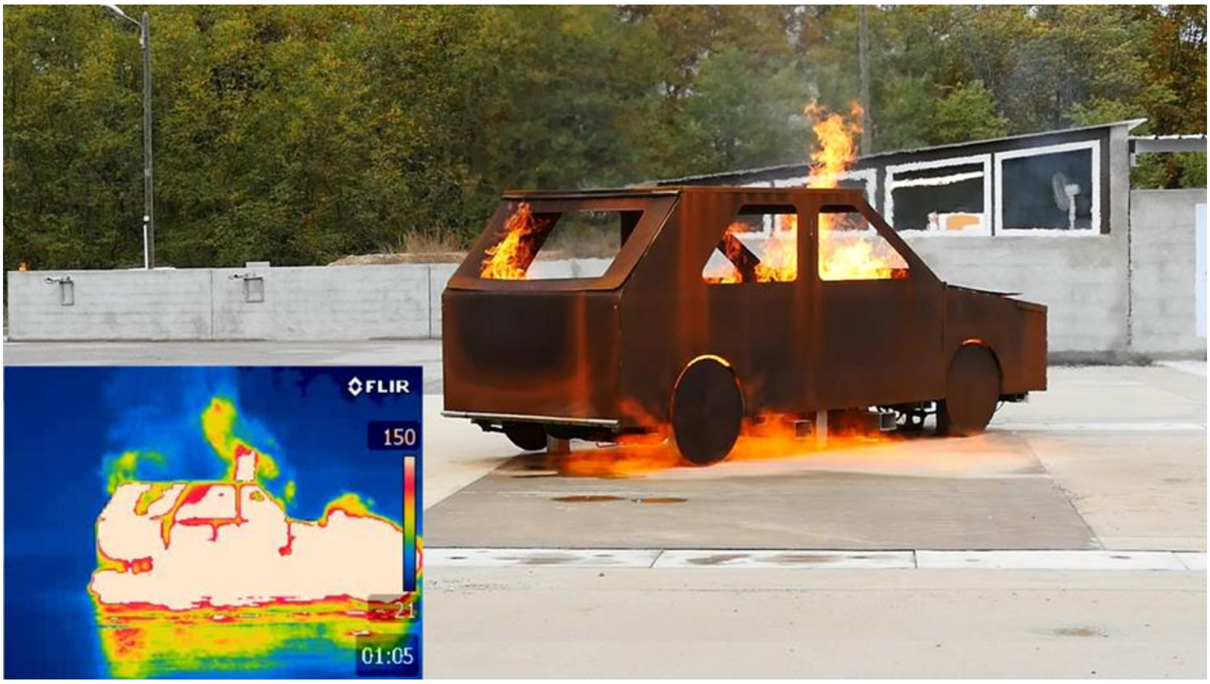


Figure 9: Hydrogen Flame under a mockup H2 Car (ENSOSP 2016)

Figure 10: H2 horizontal flame on ENSOSP operational platform (only visible with thermal imaging device

4.2. Single-gas monitor

Single-gas or multi-gas monitors continuously display gas concentrations in the atmosphere. They can be used to monitor O2 and H2 levels. Such equipment is useful for first responders to assess the threat zone and create or refine the danger area.

Note that a catalytic detector for other flammable gases can detect the presence of hydrogen, but the concentration displayed will not be reliable.

5. FUEL CELLS

5.1. Principle

The fuel cell is an electrochemical generator which produces electricity, heat, and water (pure), from a fuel (hydrogen) and a combustible gas (oxygen which can be pure or resulting from the ambient air).

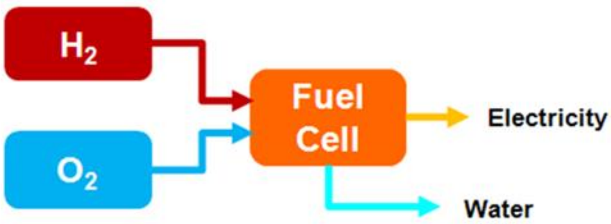


Figure 11: principle of fuel cell

There are different types of hydrogen fuel cell. The most common is a Proton Exchange Membrane (PEM) fuel cell

5.1.1. Proton Exchange Membrane Fuel Cell

At the anode, the hydrogen H2 molecules are dissociated in H+ protons and electrons e- under the effect of a catalyst: H2 → 2H+ + 2 e-,

These protons are led to cathode through the membranes and the electrons pass through the external electrical circuit.

At the cathode, the oxygen O2 molecules are recombined with the protons and the electrons to form water: ½ O2 + 2H+ + 2e- → H2O.

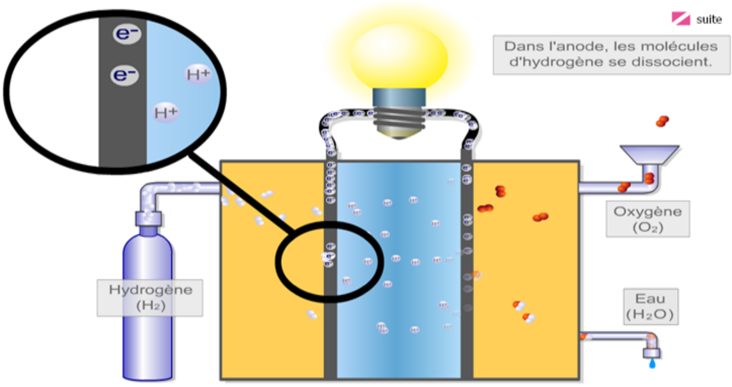


Figure 12: Schematic principle of fuel cell functioning

The electrodes (anode and cathode) and the membrane are associated to form a Membrane Electrode Assembly (MEA).

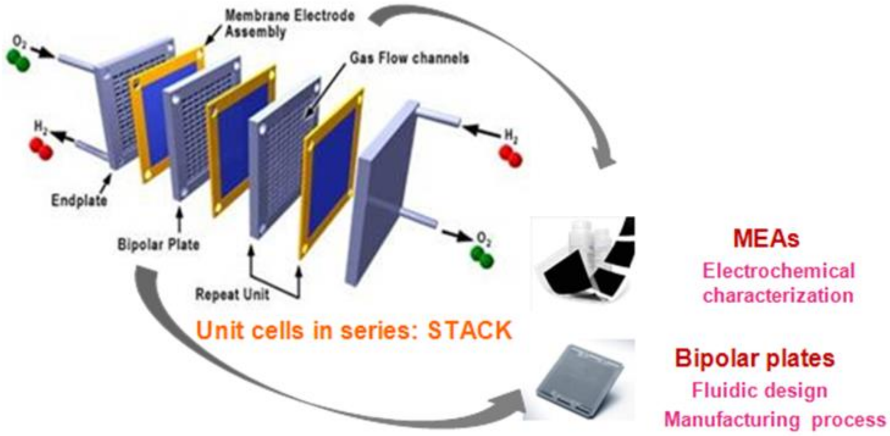


Figure 13: Membrane Electrode Assembly (MEA)

Figure 14: Fuel cell backup power coupled to the IP Energy data center.

5.2. Main risks associated with fuel cells

- High voltage equipment
- Flammable gas (hydrogen) under pressure
- Equipment under pressure.
- Possible indoor gas accumulation

6. ELECTROLYSERS

6.1. Principle

An electrolyser produces Hydrogen and oxygen from water and electricity.

Figure 15: Principle of electrolyser

6.2. Proton exchange Membrane electrolyser

A PEM Electrolyser converts electrical energy into chemical energy and can be seen as the opposite of the Fuel Cell. Conversion takes place in two rooms which are separated by a Proton Exchange Membrane (PEM). By application of a continuous tension, water is dissociated into hydrogen (H_2) at the negative pole and oxygen (O_2) at the positive pole.

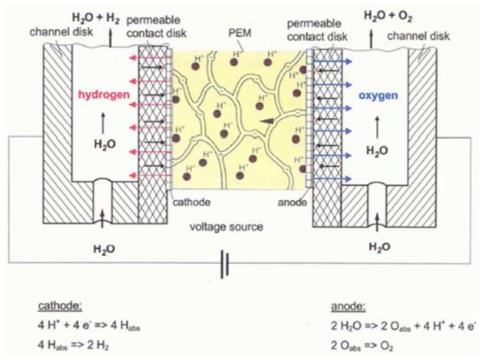


Figure 16 : PEM Principle

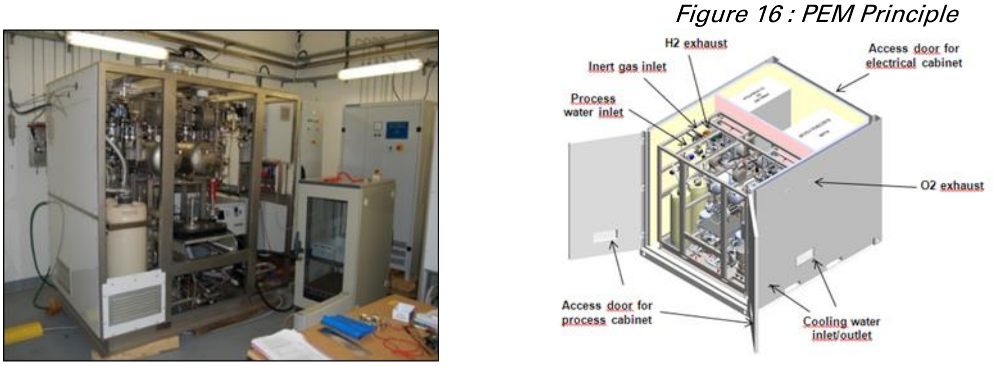


Figure 17 : Technical specification and picture of AREVA Energy storage New Stack PEMFC generation

6.3. Alkaline Electrolyser

Alkaline electrolysers are characterised by having 2 electrodes immersed in a liquid alkaline electrolyte composed of a caustic potash (potassium hydroxide or KOH) solution at a level of 25% at 80°C up to 40% at 160°C. The 2 electrodes are separated by a diaphragm. This diaphragm has 2 functions: first to keep the product gases (namely hydrogen and oxygen) apart from another and secondly to be permeable to the hydroxide ions (OH-) and water molecules.

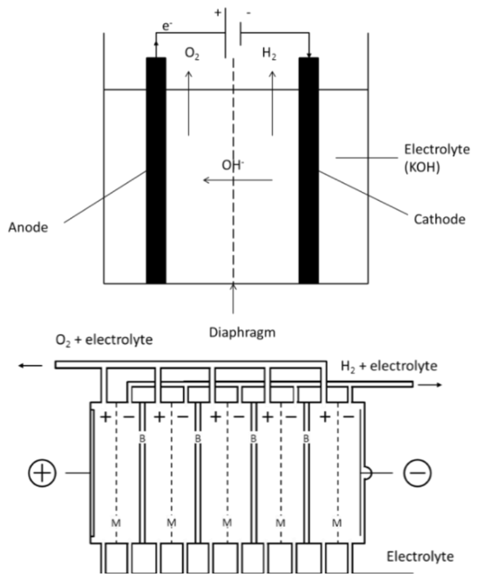


Figure 18 : principle of alkaline electrolyser

At the anode:

$2\,OH^- \rightarrow \frac{1}{2}\,O_2 + H_2O + 2\,e^-$

At the cathode:

$2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$

Total reaction: $H_2O \rightarrow H_2 + \frac{1}{2}\,O_2$

Figure 19: Alkaline electrolyser IHT type S-556, 760 Nm3/h and 30 bars

6.4. Main risks associated with electrolysers:

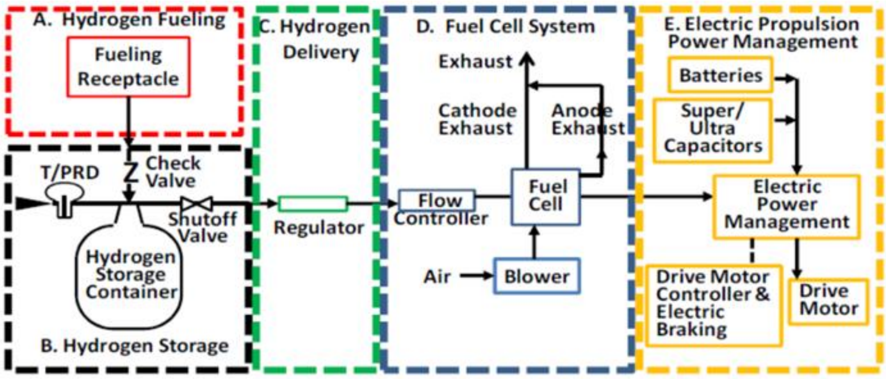
- High voltage equipment
- Flammable gas (hydrogen) under pressure
- Combustible/comburent gas (oxygen) under pressure
- Alkali solution at high temperature
- Equipment under pressure.
- Possible indoor gas accumulation

7. FUEL CELL VEHICLES

7.1. Principle

A hydrogen vehicle is an electrical vehicle (E) combined with a Hydrogen fuel cell system (A-B-C-D).

The fuel cell is supplied with Hydrogen and oxygen (from the ambient air) and produces the electricity necessary to charge batteries and operate electrical motors.



7.2. Types of FUEL CELL vehicles

Several types of vehicles can be powered by hydrogen. The most common are cars, buses, and forklifts. Prototypes exits for bikes and motorbikes.

7.2.1. Cars

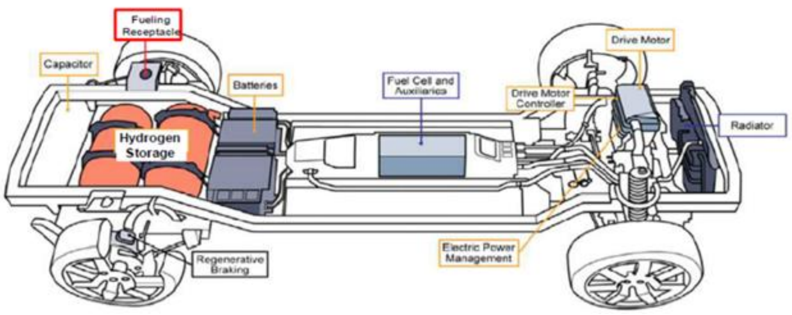


Figure 20: Fuel cell car principle (GTR, Hydrogen Fuelled vehicle UNE-ECE 2012)

7.2.2. Forklifts

Figure 21: Forklift powered with hydrogen. Source: Air Liquide (2018)

Forklift applications and infrastructures use gaseous hydrogen:
- at 200 bar for storage
- up to 1000 bar for intermediary storage in buffers
- at 350 bar in forklift on-board storage

7.2.3. Buses

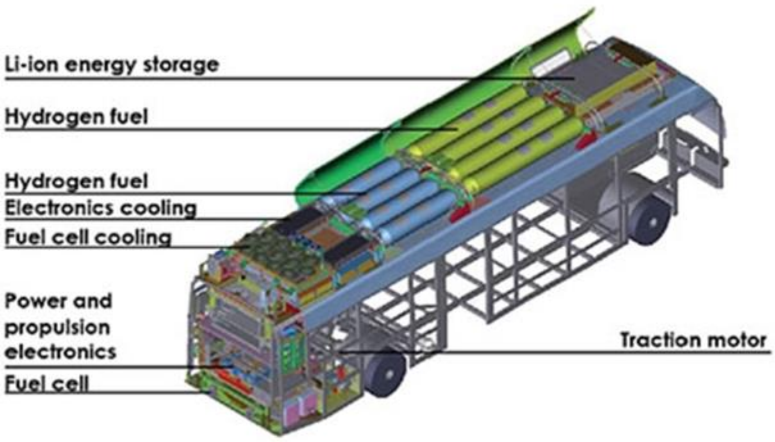
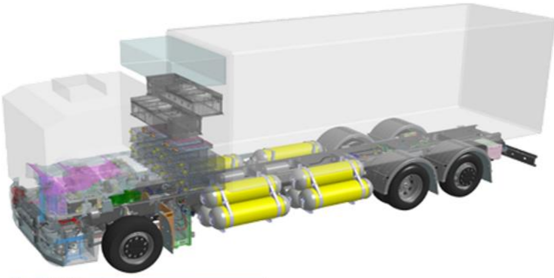


Figure 22: Fuel cell bus principle

7.2.4. Trucks

*Information for HyResponder : user case Hydrogen Truck by **GreenGT***

Porteur/Rigid Truck (26 tons) + trailer (18 tons)	
Hydrogen Pressure	350 bars (next version 700 bars 2022)
Number of Tanks	12
Physical shielding	Lateral Metal skirts
Piping rupture mitigation	Excess flow valve
Number of TPRD	24 (2 per tank)
Total Weight	45 kg
Certification	EC79
Safety concept	Auto shut off



For training purposes only
Do not diffuse outside EERG scope

Figure 23 : Hydrogen Truck (44 tons) key elements

7.2.5. Trains

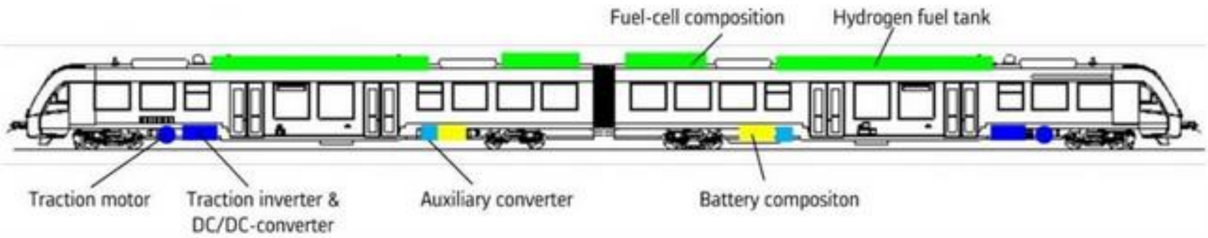
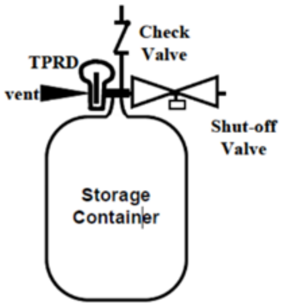


Figure 24: Hydrogen train presentation (iLint) source: Alstom

7.3. Hydrogen on board the fuel cell vehicles

7.3.1. Hydrogen storage

Hydrogen is typically stored as a gas under pressure in tanks onboard the vehicle. The pressure in tanks can be 350 bar for buses to 700 bars for cars.



The main danger with tanks is rupture resulting from an increase in pressure due to an increase in temperature.

To prevent tank rupture due to an increase in pressure, each tank is equipped with a Thermal Pressure Relief Device (TPRD). This TPRD is designed to open when the surrounding temperature reaches 110°C (230°F) and vent the hydrogen in the atmosphere.

The vent line is on the roof for the buses, on the side for forklifts, and can be on the roof for cars but more frequently is located between the rear tyres oriented towards the back of the vehicle.

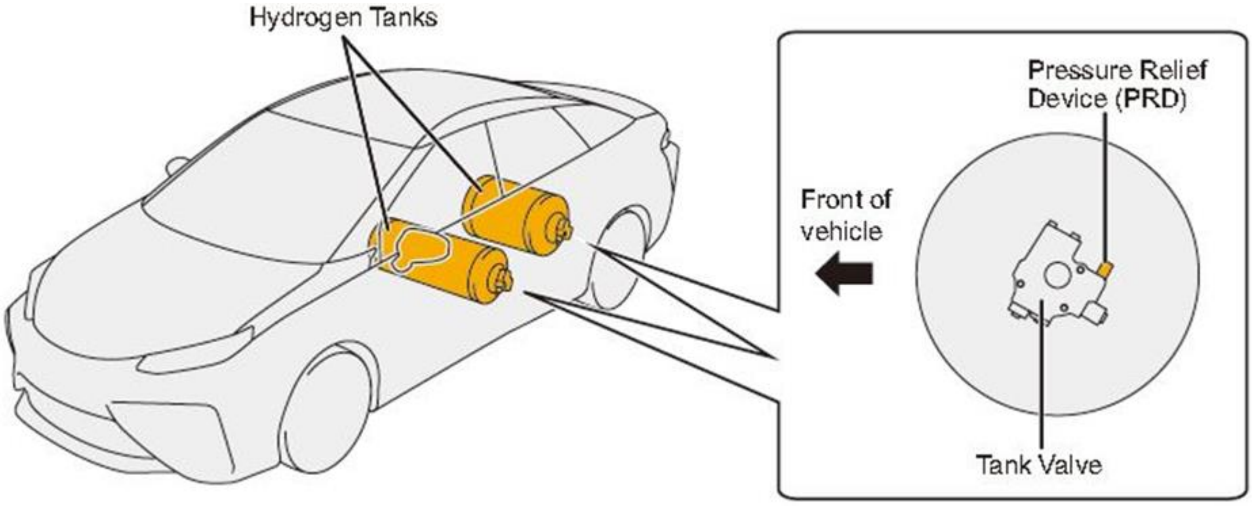


Figure 25: TPRD location (Toyota Emergency response guide)

7.3.2. Refuelling

Hydrogen tanks are filled in refueling stations through a specific filling hole.

Figure 26: Toyota Mirai Filling hole.

7.4. Risk associated with Fuel Cell Vehicles

Fuel Cell vehicles are also electrical vehicles. The associated risks are:

In case of malfunction, fire and/or road traffic accident, extrication activities:

Risk	Origin	Situation
Electrocution	Batteries Super-capacitors	Electrical Shock due to Malfunction, Fire, accident, extrication
Burns	Metal alloys combustion	Projections of molten metal du to Use of an unsuitable agent (water) to extinguish such fire
Violent inextinguishable fire	Batteries	Batteries runaway when involved in fire
Poisoning	Toxicity of Batteries Electrolyte leakage	fire or containment failure (accident)

But the specificity of using Hydrogen adds several risks:

Risk	Origin	Situation
Asphyxiation	Hydrogen (simple asphyxiator)	Unignited Hydrogen leak in confined space
Burns	Invisible H2 flame	Vehicle Fire AND activation of TPRD
Shock wave	bursting of H2 tank	Vehicle Fire AND failure of the TPRD/envelope failure
Shock wave & heat wave	Explosion of H2 cloud (UVCE)	H2 leak and Ignition source

7.5. Identification of Fuel Cell Vehicles

Figure 27: H2 Label

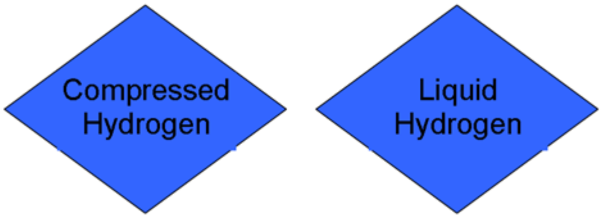


Figure 28: Blue diamonds (US)

Figure 29: badge on the vehicle (Ix35 Toyota emergency response guide)

Figure 30 : Label proposed by CTIF to ISO (project)

FUEL CELL VEHICLES

This page intentionally left blank.

8. REFUELLING STATIONS

8.1. Principle

The main function of a hydrogen refueling station (HRS) is to fill the tanks of vehicles (forklift truck, bus, car) powered by fuel cells with hydrogen. The majority of refueling stations provide gaseous hydrogen. The gaseous hydrogen, contained initially in storage at a pressure of 200 bar, is compressed in the high pressure (HP) storage. During the filling, the tank is filled by a balancing of the pressure.

The pressure in HP storage is between 450 bar for forklift truck and bus and 1000 bar for car.

The pressure in a vehicle tank is between 350 bar for forklift truck and bus and 700 bar for car.

To fill a car as quickly as possible, hydrogen may be cooled during filling using cryogenic liquid nitrogen storage or a cold unit.

The dispenser could be located in a dedicated building or outdoors.

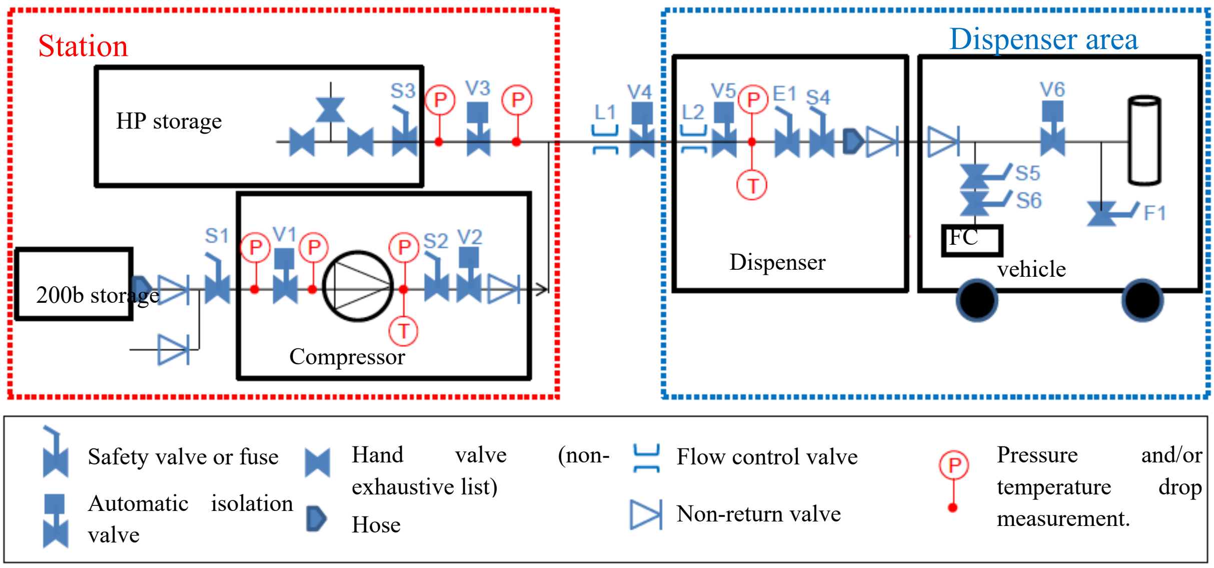


Figure 31: Diagram of an HRS installation

8.2. Examples of refuelling stations

Figure 32: Refuelling station (Air Liquide Germany)

Figure 33: Refuelling station (Vattenfall Hamburg)

Figure 34: Forklift dispenser (Air Liquide)

Figure 36: Dispenser 350 bar
(Vattenfall Hamburg)

Figure 35 : Dispenser 700 bar
(Vattenfall-Hamburg

Figure 37 : Indoor refuelling station for forklift (dispenser)

Figure 38 : Refuelling station low pressure storage 200 bar

Figure 39 : refueling station high pressure storage 1000 bar

Figure 40 : Refueling station ESD away from dispenser (Hamburg airport)

8.3. Risks associated with refuelling stations

Electrical equipment

Flammable gas (hydrogen) under pressure

Equipment under pressure.

Possible indoor gas accumulation

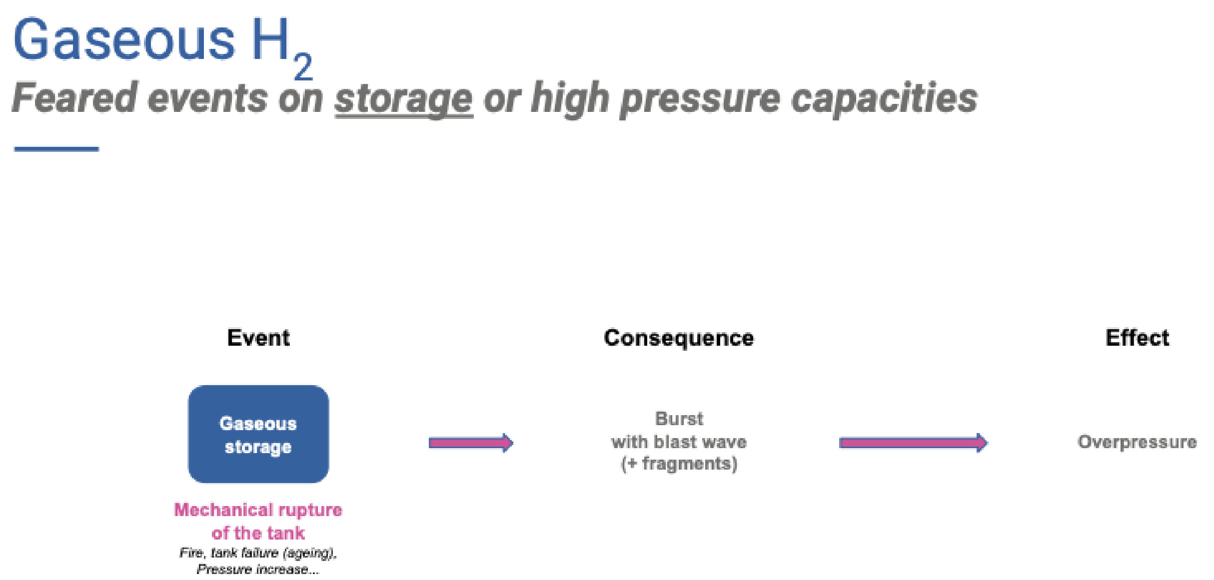
8.4. Hazardous phenomena (gaseous hydrogen trailers and refuelling stations)

Trailers and refuelling stations are very similar in terms of size and feared events. That is the reason why they are treated in the same section.

For refueling stations based on gaseous hydrogen storage, in the majority of cases a trailer is used as storage at the station. A swap system is operated i.e., “full or empty” exchange. The majority of trailers are composed of 200-bar steel tubes (i.e., type I vessels) of 2-m^3 each.

To increase capacity, new trailers have been designed with type IV vessels, with a capacity of 350-L each, allowing storage pressure of up to 700 bar of to be reached.

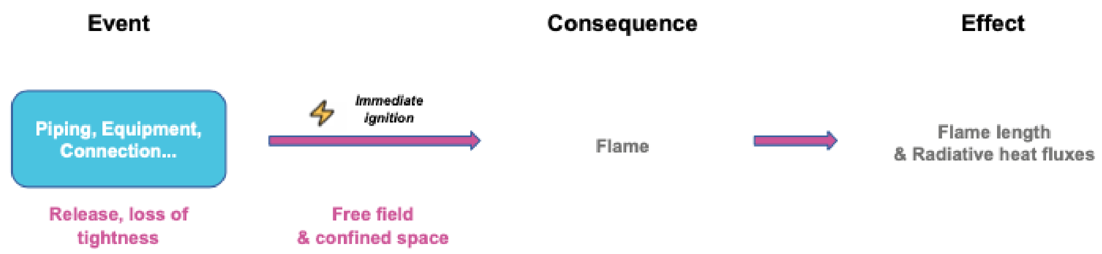
The images in the following sections present the main feared events for gaseous trailers and refuelling stations.



Gaseous H_2

Feared events on connections or other releasing equipment

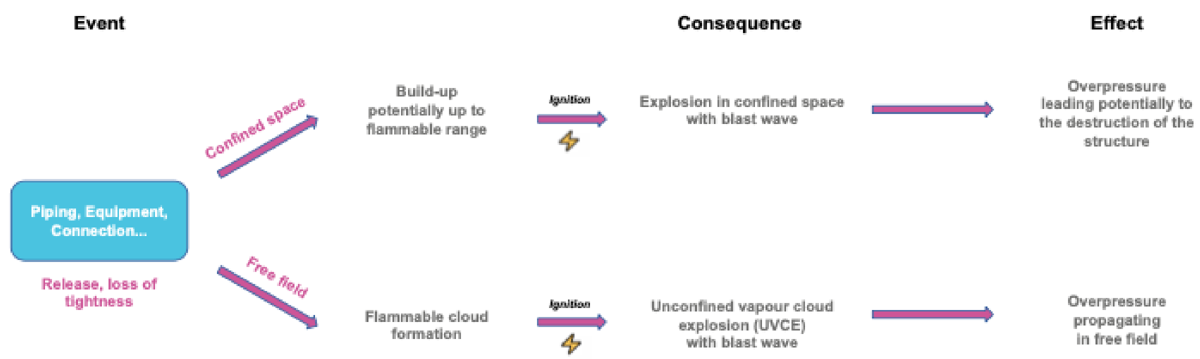
Release with <u>immediate</u> ignition



Gaseous H_2

Feared events on connections or other releasing equipment

Release with <u>delayed</u> ignition



8.4.1. Potential consequences

8.4.1.1. Release without ignition

For the case of a release without ignition, Table 17 gives the blowdown duration for storage tanks and associated maximum working pressures potentially available on a refuelling station.

A validated tool (e-laboratory)[10] was used to assess these blowdown durations from storage pressure to atmospheric pressure[11].

Table 17: Tank blowdown duration for different volumes and storage pressures

Tank volume	Storage pressure	Blowdown duration			
		1 mm	2 mm	4 mm	6 mm
2 m^3	200 bar	5 h 30 min	1 h	16 min 40 s	9 min 10 s
350 L	700 bar	1 h	16 min 40 s	4 min 20 s	1 min 50 s

A 1-mm diameter release is characteristic of an accidental leak due to a default of tightness on a connection or equipment. Diameters of 2, 4, and 6-mm diameter are more representative of a TPRD release.

8.4.1.2. Release with immediate ignition

Hazard distances for two representative scenarios are presented in Table 18. The hazard distances are based on thermal effects of the jet fire. The flowrates considered to carry out the calculations were 60 $g.s^{-1}$ for car refuelling stations and 120 $g.s^{-1}$ for bus refuelling stations.

Two cases were evaluated for each flowrate namely:

- Hose full bore rupture: full section but limited at 60 $g.s^{-1}$ for cars and 120 $g.s^{-1}$ for buses,
- and 3%-section.

[10] https://hyresponder.eu/e-platform/e-laboratory/

[11] considering an adiabatic approach and ambient temperature at 15°C

Table 18: Thermal effects for jet fires considering different release flowrates.

Effects	$60\ g.s^{-1}$		$120\ g.s^{-1}$	
	100%-section	3%-section	100%-section	3%-section
Flowrate	$60\ g.s^{-1}$	$1.8\ kg.s^{-1}$	$120\ g.s^{-1}$	$3.6\ g.s^{-1}$
Flame length	4.7 m	0.8 m	6.7 m	1.1 m
$3\ kW.m^{-2}$	6.6 m	0.8 m	9.8 m	1.5 m
$5\ kW.m^{-2}$	5.8 m	< 0.8 m	8.5 m	1.2 m
$8\ kW.m^{-2}$	5.2 m	< 0.8 m	7.6 m	1.1 m

8.4.1.3. Release with delayed ignition

Hazard distances for delayed ignition based on two representative scenarios are presented in Table 19. The hazard distances are based on overpressure. The flowrates considered to carry out the calculations were $60\ g.s^{-1}$ for car refuelling stations and $120\ g.s^{-1}$ for bus refuelling stations.

Two cases were evaluated for each flowrate:

- Hose full bore rupture: full section but limited at $60\ g.s^{-1}$ for cars and $120\ g.s^{-1}$ for buses,
- and 3%-section.

Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5.

Table 19: Overpressure effects for UVCE considering different release flowrates.

Effects	$60\ g.s^{-1}$		$120\ g.s^{-1}$	
	100%-section	3%-section	100%-section	3%-section
Flowrate	$60\ g.s^{-1}$	$1.8\ kg.s^{-1}$	$120\ g.s^{-1}$	$3.6\ g.s^{-1}$
Flammable mass	$5.4 \cdot 10^{-3}$ kg	$2.8 \cdot 10^{-5}$ kg	$1.5 \cdot 10^{-2}$ kg	$7.8 \cdot 10^{-5}$ kg
20 mbar	16 m	3 m	22 m	4 m
50 mbar	9 m	2 m	13 m	2 m
140 mbar	6 m	1 m	8.5 m	1.4 m
200 mbar	5 m	< 1 m	7.5 m	1.2 m

8.4.1.4. Mechanical rupture of the storage

Hazard distances for two representative scenarios are presented in Table 20. The hazard distances are based on overpressure resulting from mechanical rupture of storage.

Two cases were investigated:

- type I vessels at 200 bar working pressure,

- and type IV vessels at 700 bar working pressure.

Table 20: Overpressure effects due to tank burst.

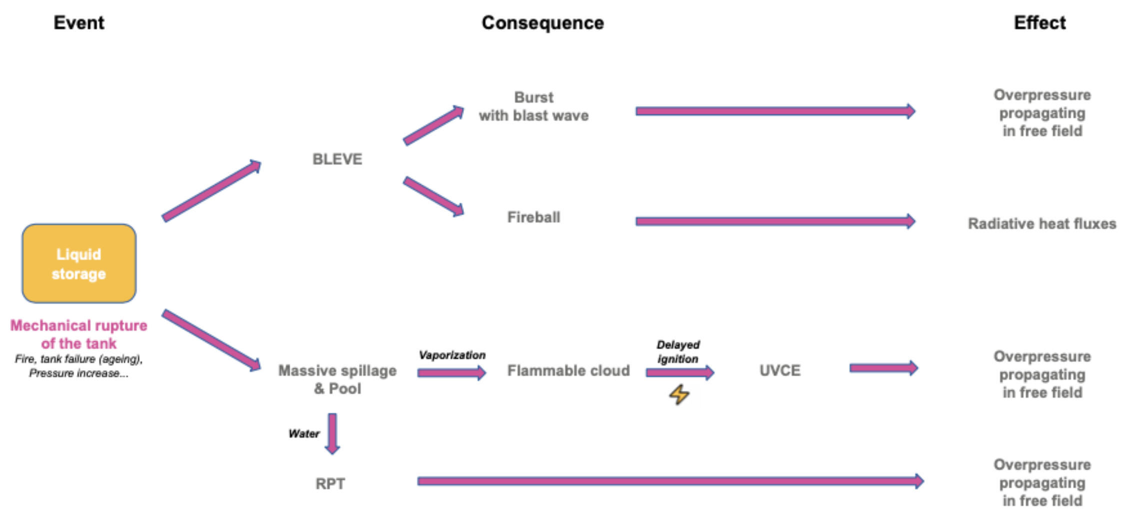
Tank volume	Working pressure	Overpressure effects			
		20 mbar	50 mbar	140 mbar	200 mbar
2 m^3 (type I)	200 bar	129 m	65 m	28 m	20 m
0.35 m^3 (type IV)	700 bar	91 m	46 m	20 m	14 m

8.5. Hazardous phenomena (Liquid hydrogen trailers and refuelling stations)

The images in the following sections present the main feared events for liquid trailers and refueling stations.

Liquid H_2

Feared events on storage or high pressure capacities

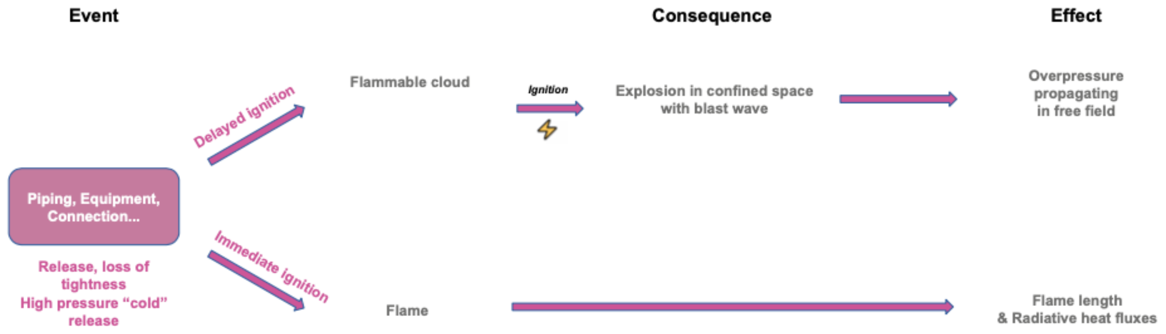


Liquid H_2

Feared events on connections or other releasing equipment

Release
with delayed or immediate ignition

No liquid hydrogen in confined space



8.5.1. Potential consequences
8.5.1.1. Release without ignition

Liquid trailers and liquid storage for liquid refuelling have a volume around 20 m^3 (1t- H_2).

Tank rupture due to major external impact or fall of the tank (e.g., collision, seism, ageing) can induce a massive spillage of the liquid hydrogen.

A cryogenic pool of hydrogen will be formed on the ground, will vaporise, and will induce a flammable cloud.

For 20-m^3 storage, based on a validated simulation approach it can be shown that the size of the pool could be 17 m x 17 m with a thickness of 5 cm. Table 21 presents the potential size and characteristics of a flammable vapor cloud associated with typical cryogenic storage.

Table 21: Flammable cloud characteristics induced by a massive spillage of liquid hydrogen

Flammable cloud characteristics	Values
Flammable volume	26700 m^3
Explosive mass	650 kg
4%-H_2 horizontal length	263 m
8%-H_2 horizontal length	146 m
10%-H_2 horizontal length	116 m
4%-H_2 maximum height	36 m
8%-H_2 maximum height	30 m
10%-H_2 maximum height	29 m

It should be noted that the values presented in Table 21 are indicative only and can vary with weather conditions (temperature, wind) and environment (obstacles, congestions, nature of the ground, building etc.) Dispersion of this flammable cloud is relatively quick and has been estimated to be less than 2 min, but further research studies are required to provide more accurate estimates.

8.5.1.2. Release with immediate ignition

Hazard distances due to thermal effects of a jet fire from a reference diameter of 45 mm and pressure of 10 bar are given in Table 22. Flowrates were calculated using a validated tool (e-laboratory[12]) tool and thermal effects are based on a validated approach by Schefer.

Three cases were evaluated:

- Full bore rupture: full section = 45 mm diameter,
- 3%-section,
- and 1%-section (NFPA on-going study).

Table 22: Thermal effects for jet fires considering different release diameters

Effects	100%-section	3%-section	1%-section
Flowrate	6.2 kg.s^{-1}	0.19 kg.s^{-1}	0.06 kg.s^{-1}
Flame length	46 m	8 m	5 m
3 kW.m^{-2}	84 m	14 m	8 m
5 kW.m^{-2}	72 m	12 m	4 m
8 kW.m^{-2}	63 m	10 m	3 m

8.5.1.3. Release with delayed ignition

Hazard distances are presented here for overpressures following delayed ignition. Two scenarios are considered: a release characteristic of storage and a release characteristic of that from piping or equipment.

Storage

For the case of massive spillage, the characteristics of a flammable cloud were given in the previous section. Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5; hydrogen flowrate is used and the phenomenon in considered as occurring in the free field without or with small congestion. Hazard distances associated with ignition of this flammable cloud are given in Table 23.

[12] https://hyresponder.eu/e-platform/e-laboratory/

Table 23: Overpressure effects due to the ignition of a flammable cloud induced by the massive spillage of a 1-t liquid hydrogen storage.

Overpressure thresholds	Hazardous distances
50 mbar	284 m
140 mbar	139 m
200 mbar	108 m

Piping / connection / failed equipment

The reference diameter considered is 45 mm, and an initial pressure of 10 bar.

Three cases were evaluated:

- Full bore rupture: full section = 45 mm diameter,
- 3%-section,
- and 1%-section (NFPA on-going study).

Hazard distances due to UVCE are presented in Table 24. The overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5.

Table 24: Overpressure effects for UVCE considering different release diameters.

Effects	100%-section	3%-section	1%-section
Flowrate	6.2 $kg.s^{-1}$	0.19 $kg.s^{-1}$	0.06 $kg.s^{-1}$
Flammable mass	6.7 kg	0.04 kg	0.007 kg
20 mbar	146 m	26 m	15 m
50 mbar	72 m	13 m	7.4 m
140 mbar	41 m	7 m	4.2 m
200 mbar	34 m	6 m	3.5 m

8.5.1.4. Mechanical rupture of the storage

Two cases were investigated:

1. 100%-gaseous hydrogen storage where an external event provokes the rupture of the tank due to an increase of the pressure, with overpressure effects.
2. The storage contains mainly liquid hydrogen, and an external event provokes an increase of the temperature and the vaporisation of the liquid, with thermal effects dominating compared to pressure effects.

Hazard distances for the two cases are given in Table 25 (case 1) and Table 26 (case 2).

Table 25: Overpressure effects due to tank burst considering 100% gaseous hydrogen.

Tank volume	Working pressure	Overpressure effects			
		20 mbar	50 mbar	140 mbar	200 mbar
20 m^3	10 bar	141 m	70 m	30 m	22 m

Table 26: Thermal effects due to tank burst considering mainly liquid hydrogen.

Tank volume	Working pressure	Fireball characteristics			Thermal effects		
		Diameter	Hemispherical diameter	Duration	3 $kW.m^{-2}$	5 $kW.m^{-2}$	8 $kW.m^{-2}$
20 m^3	10 bar	75 m	94 m	7 s	52 m	47 m	< 47 m

This page intentionally left blank.

PART 2 EMERGENCY RESPONSE

9. NOMOGRAMS

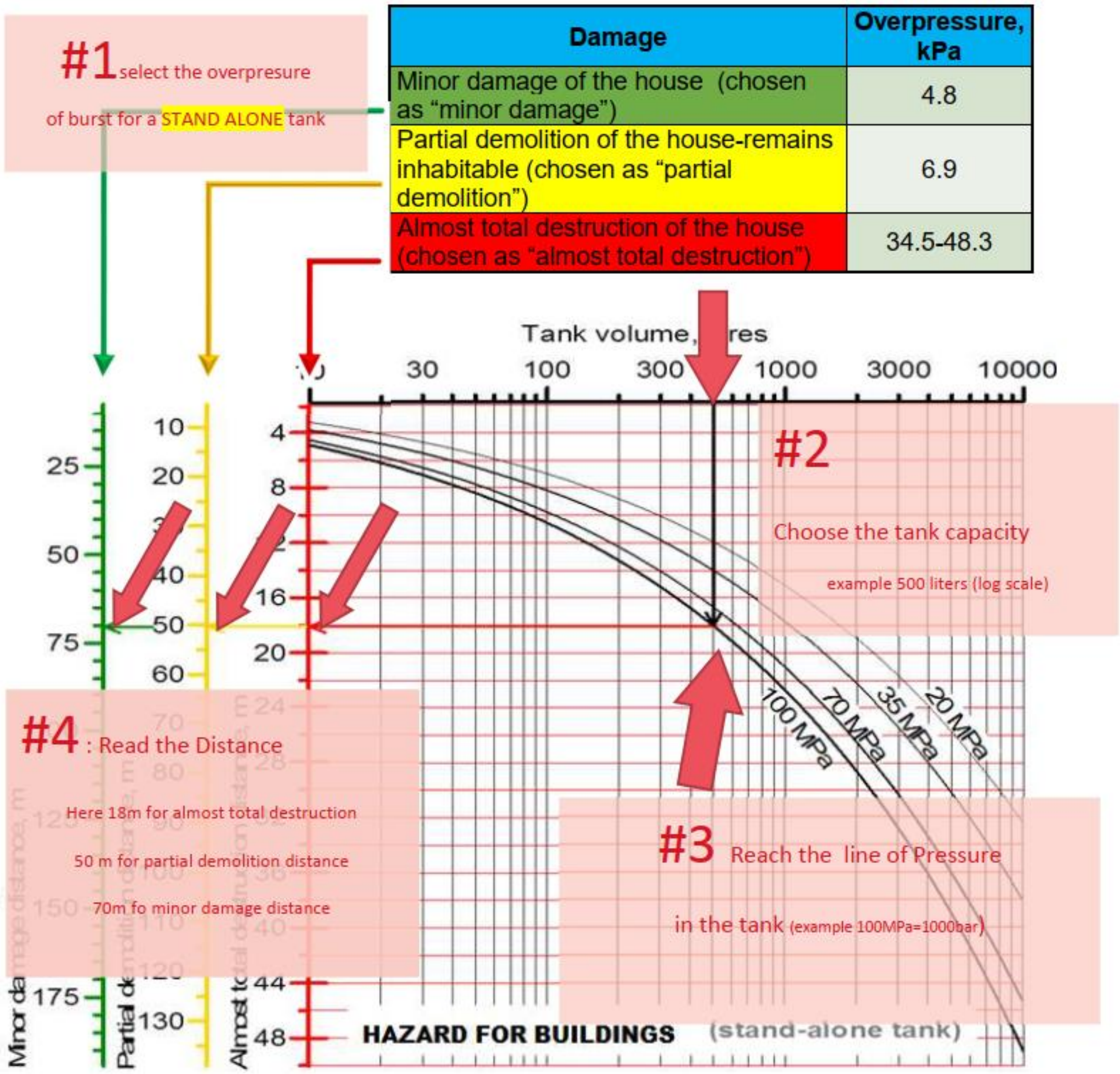
9.1. How to use the nomograms

The aim of these nomograms is to define hazard distances depending on

- The pressure of a hydrogen tank
- The volume of the tank

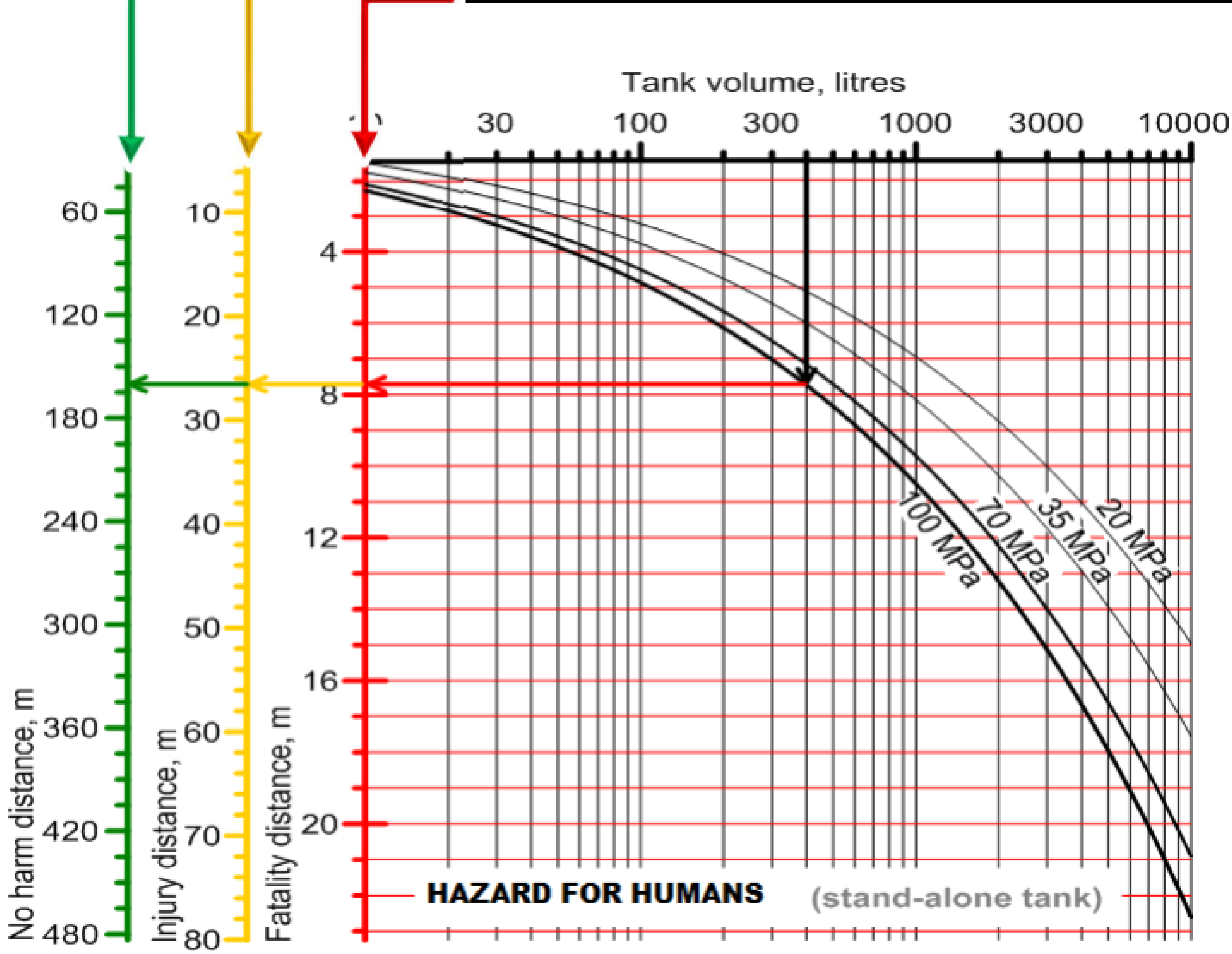
Refer to appendix 3 for complete instructions on how to use these nomograms.

9.2. Harm to humans from rupture of a STAND-ALONE tank in a fire



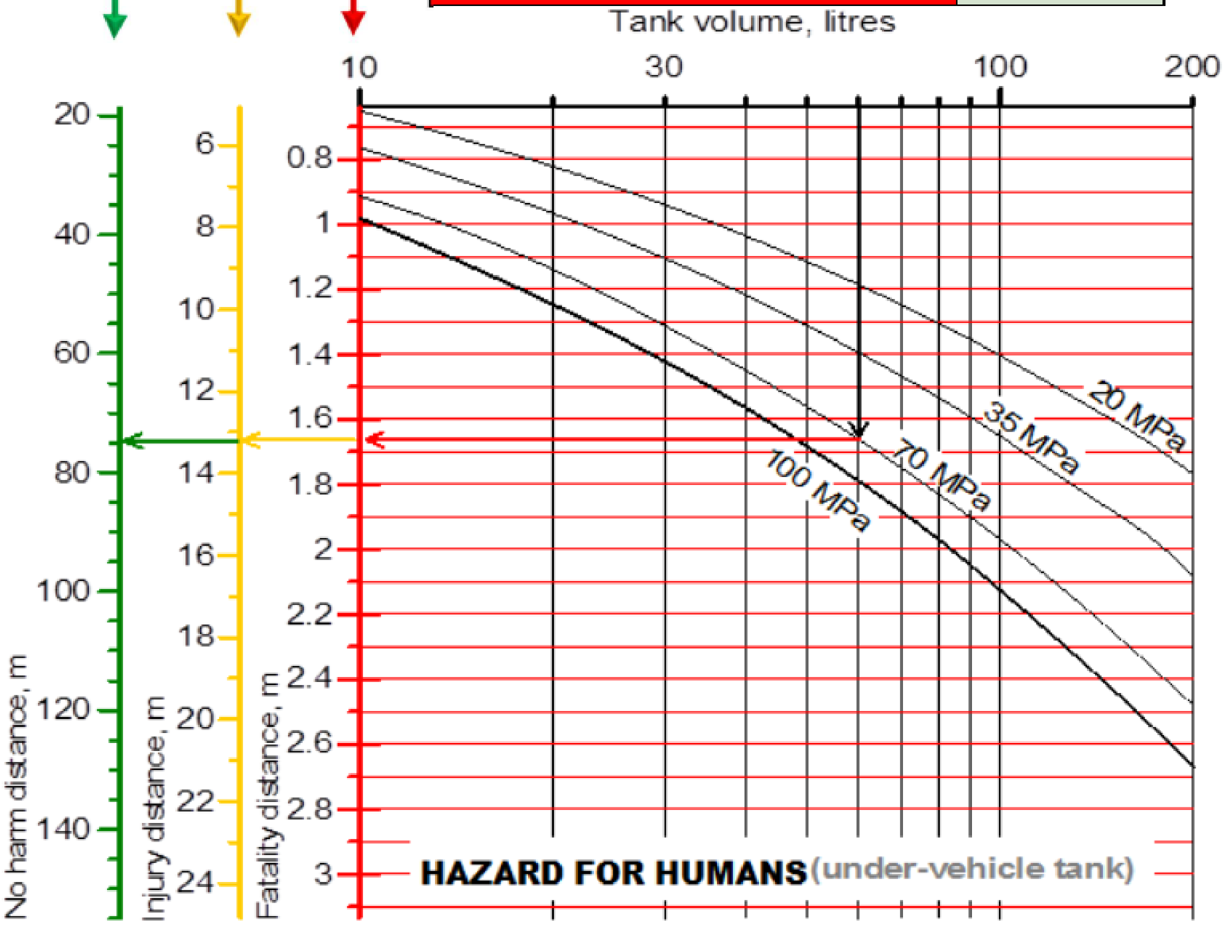
10 HARM TO HUMANS FROM RUPTURE OF A STAND-ALONE TANK IN A FIRE.

Harm criteria (selected thresholds)	Overpressure, kPa
Temporary threshold shift (Baker, 1983): “no harm” hazard distance (evacuation perimeter)	1.35
1% eardrum rupture probability (Mannan, 2005): “injury” distance	16.5
1% fatality probability due to lung haemorrhage (Mannan, 2005): “fatality” hazard distance	100



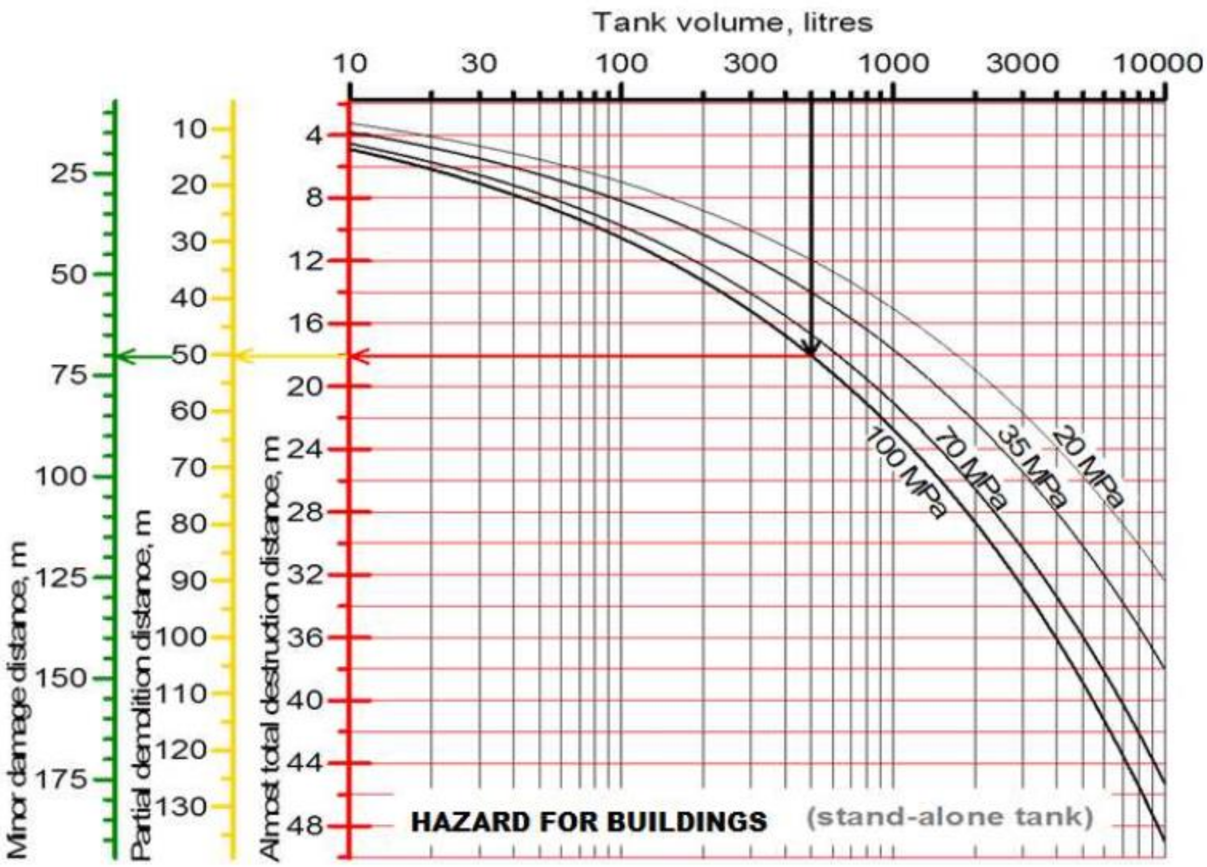
11. HARM TO HUMANS FROM A RUPTURE OF AN UNDER-VEHICLE TANK IN A FIRE

Harm criteria (selected thresholds)	Overpressure, kPa
Temporary threshold shift (Baker, 1983): "no harm" hazard distance (evacuation perimeter)	1.35
1% eardrum rupture probability (Mannan, 2005): "injury" distance	16.5
1% fatality probability due to lung haemorrhage (Mannan, 2005): "fatality" hazard distance	100



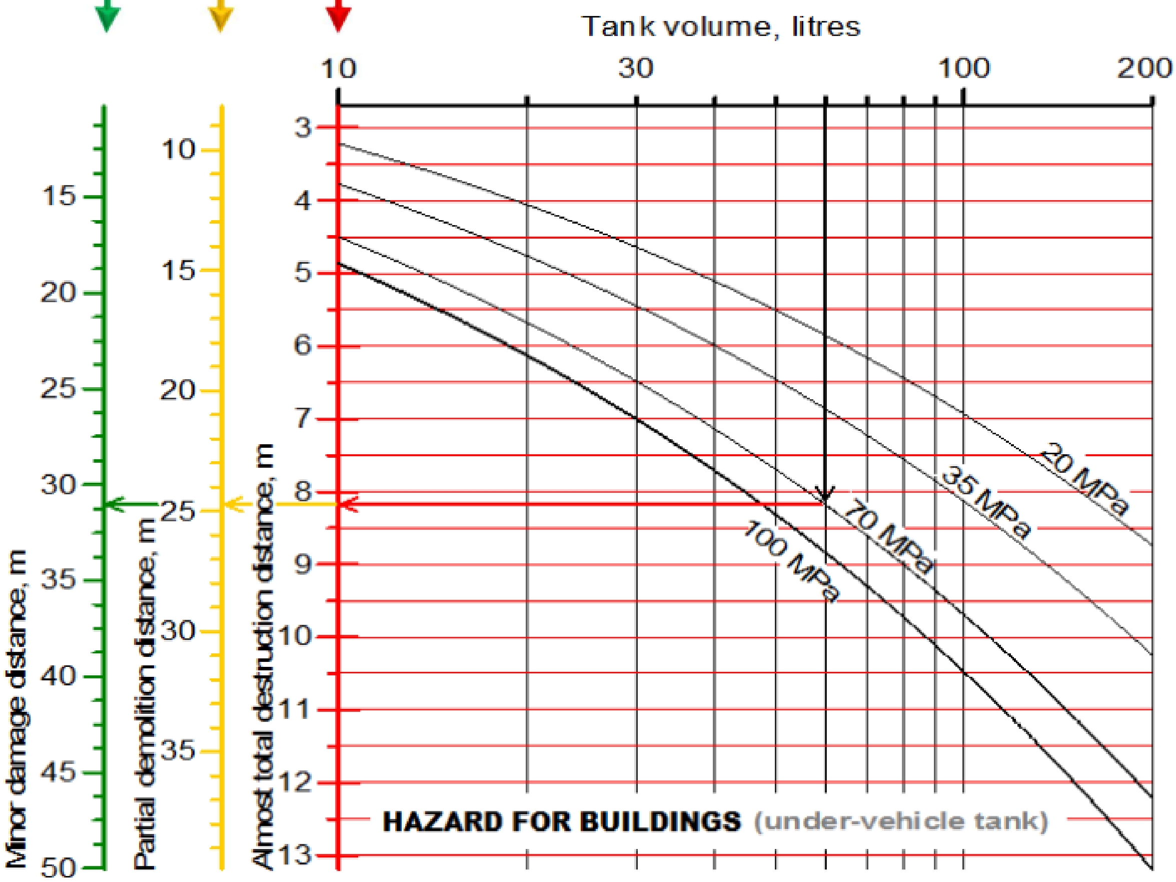
12. DAMAGE TO BUILDINGS FROM RUPTURE OF A STAND-ALONE TANK IN A FIRE

Damage	Overpressure, kPa
Minor damage of the house (chosen as "minor damage")	4.8
Partial demolition of the house-remains inhabitable (chosen as "partial demolition")	6.9
Almost total destruction of the house (chosen as "almost total destruction")	34.5-48.3



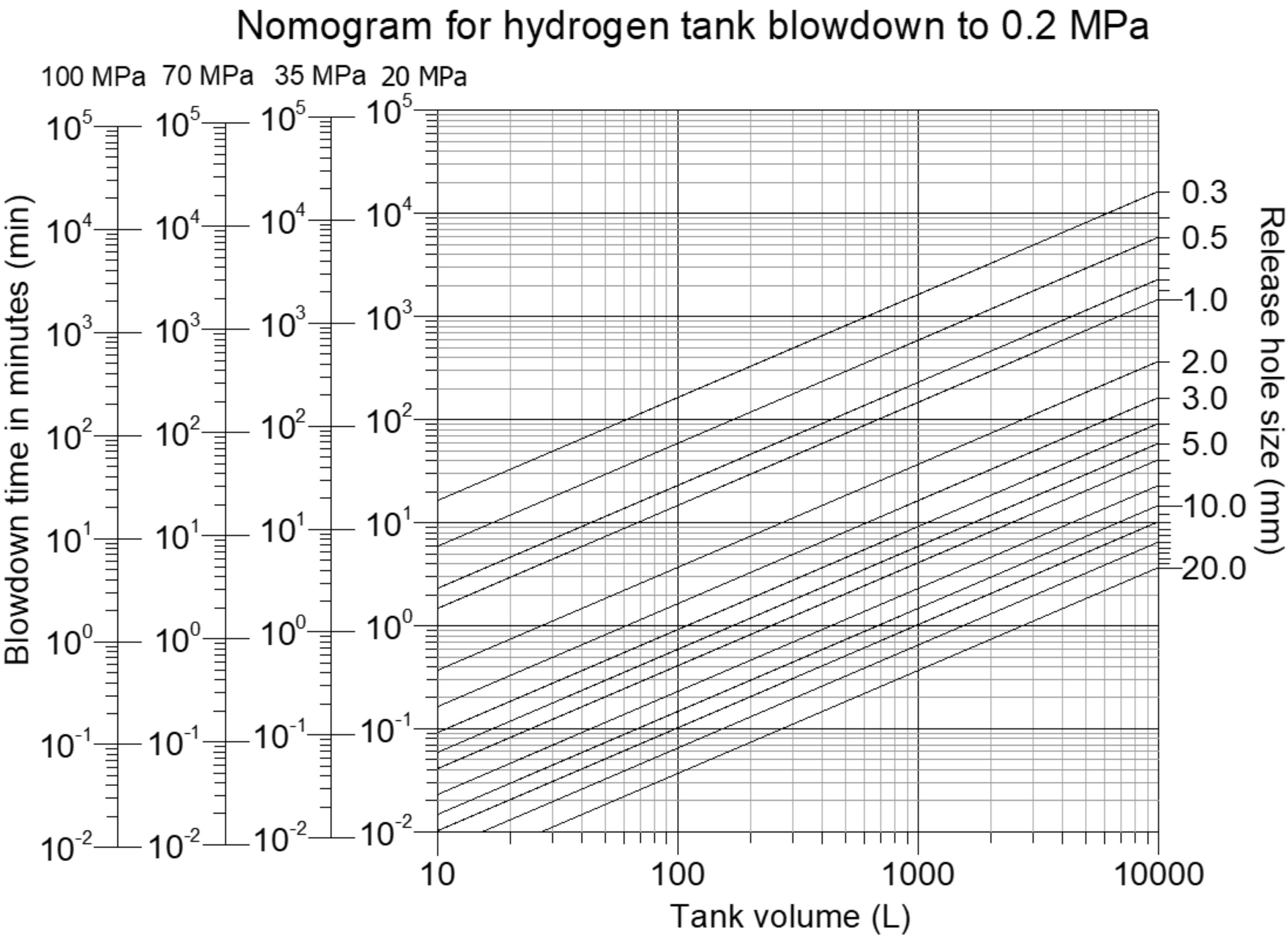
13. DAMAGE TO BUILDINGS FROM RUPTURE OF AN UNDER-VEHICLE TANK IN A FIRE

Damage	Overpressure, kPa
Minor damage of the house (chosen as “minor damage”)	4.8
Partial demolition of the house-remains inhabitable (chosen as “partial demolition”)	6.9
Almost total destruction of the house (chosen as “almost total destruction”)	34.5-48.3



14. BLOWDOWN TIME

This nomogram gives an evaluation of the blowdown time of a tank depending on the volume, the pressure and the size of the release hole.



15. STRATEGY

15.1.Strategy Definition

Building an incident settlement strategy is answering the question:

"Which goal does the organisation want to reach?"

Answering this question defines the general goal of the fire and rescue services.

Their three main goals are always the same all over the world:

N°1: Protect human life.

N°2: Protect property.

N°3: Protect environment.

In society, Strategy is a stable notion decided at a political level, according to the risk sociological acceptance. Choosing a strategy to deal with a type of incident is tightly linked with the "Stakes assessment" notion.

15.2.Stakes assessment

The three main goals (protection of life, property, and environment) must be pursued in the safest manner allowed by each unique incident situation stakes assessment. The authority in charge must take only the appropriate risks considering the salvable lives, salvable possessions and environmental situation balanced out with the available rescue forces at the moment he takes his operational decisions.

Nevertheless, the rescue of human lives overrides all other considerations.

So, strategies can be divided in two main orientations:

High stakes level situations: If nothing is done the incident will lead in a short time to the certain death of human(s), major infrastructure destructions and/or irreversible environmental effects.

Low stake level situations: The incidental situation will lead within a longer amount of time to minor effects on humans, infrastructures and/or reversible effects on environment.

16. TACTICS

16.1.Tactic definition

Using a defined tactic is the direct consequence of the chosen strategy. As the strategy is the answer to the question "Which goal do I want to reach?" a tactic is the answer to the question:

"How will I reach this goal (in the safest manner)?

Tactics is a variable concept decided at an operational level, according to the situation available at the present moment and in a near future.

For a defined situation type, it is possible to plan tactic as a step- by- step procedure that describes the actions of a first responders' team. However, from the general rules, the incident commander has always the opportunity and the duty to use the appropriate behaviour for each incident because each incident is unique.

16.2.The danger process theory

The danger process theory (Perilhon, 2007) was developed to describe the ways a danger source affects a target through a danger flux.

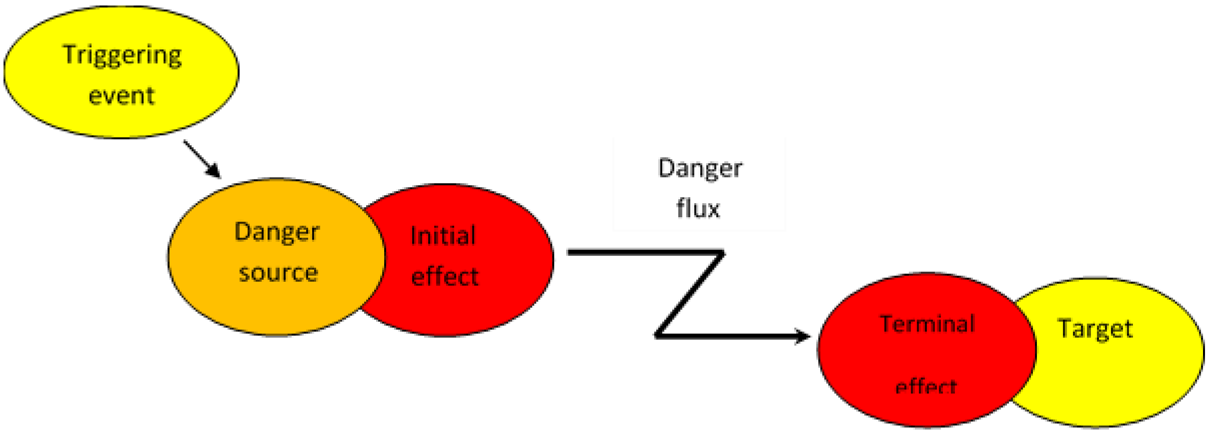


Figure 41 : danger process

During an incident and when the fire service is called, the triggering event has already occurred. So, to suppress the effect on targets, the fire services can act:

- On danger sources, thus preventing the initial effects to happen
- On danger flux, preventing the terminal effects to exist
- On targets, preventing the effects to reach the targets.

16.3.Offensive and defensive tactics

Two main types of tactics are usually in use: offensive and defensive.

Offensive tactic: (or acting on danger sources)

This tactic aims to act very quickly on the origin of the incident to prevent it to produce its effects.

> Advantages: rapid settlement of the incident, a little area is concerned; the required amount of personnel and equipment is limited
>
> Drawbacks: risky for firefighters, one shot is available

Defensive tactic: (or acting on danger flux and targets)

This tactic aims to act on the closest area of the incident preventing those effects from reaching an area which was not concerned beforehand.

> Advantages: safer for crews
>
> Drawbacks: it needs more preparedness, the settlement of the incident takes a long time, and the area finally concerned by the incident is wider. Hydrogen specificities in emergency situations

17. EMERGENCY CALL MANAGEMENT

The incident begins when the emergency call arrives to the control room. People who call the emergency services are usually over-excited or terrorised. Despite this, essential information must be gathered:

- Type of incident (electrical malfunction, gas leak, explosion, fire, etc.)
- Location of the incident
- Number of persons killed, injured, or threatened by the incident.
- With that information, the emergency answering service can select the nearest available emergency equipment and provide useful advice to the person who called:

As an example, if the emergency call concerns an FC vehicle involved in a fire in the street the following steps must be considered:

- Look for identification graphics placed on the exterior or interior of the vehicle to establish that FC or hydrogen is involved.
- Make sure all the passengers can escape from the vehicle.
- Turn-off the ignition key
- Provide first aid to the casualties in a safe area.
- Try to extinguish the fire with a fire extinguisher if the fire is small.
- Keep the members of general public away from the burning vehicle before the fire services arrive

Before leaving the fire station, the incident commander must choose a safe route to arrive at the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

18. FIRE AND RESCUE OPERATIONAL SEQUENCE

Every fire and rescue operation follows the same “step-by-step” sequence on the incident field. Please note that those steps can be realised simultaneously, according to the real situation.

1. RECOGNITION
2. RESCUE
3. PREPAREDNESS
4. INCIDENT SETTLEMENT
5. PROTECTION
6. CLEAR OUT
7. FINAL INSPECTION

18.1.Recognition

This step aims at collecting every available piece of information on the incident field to size up the scene. The incident commander will look for the following information:

- What happened and what is happening?
- Are there casualties or people threatened by the situation?
- Was a fire dart seen? Was a loud hissing sound heard?
- What are the resources of the place?

To do so, he will set a large circle around the scene. If the scene takes place in a building, the recognition also includes the floors under and above the incident area.

During recognition, a danger area is defined, taking into account the reality of the known risks. The incident commander is at this moment able to decide the safest way to deal with the situation, enounce the objectives and choose the angles of attack.

18.2.Rescue

If a casualty is identified and located, rescue operations are launched immediately even if recognition is not complete. Casualties are taken out of the danger area and led to the first aid paramedics teams. As said before the rescue of human lives overrides all other considerations.

18.3.Preparedness

During this step, the crew will prepare the needed tools and accessories required to deal with the situation (for example, hose lines, hydrants, thermal imaging devices, gas detectors, etc.). The tools and accessories used are function of the incident situation.

18.4.Incident settlement

Considering the available information, the incident commander will, at this step, decide whether to use an **offensive** or a **defensive** tactic.

1st example:

An FCH car is burning on a small road in the countryside. The driver is safe and out of the danger area. A large flame is visible with the thermal imaging device and a loud hissing sound is heard.

Analysis: the TPRD of H2 tank is opened and in a very short time the ignited leak will blowdown. Nothing is threatened by the flame.

Tactical choice:
Use a defensive tactic: close the road in both directions, wait for the blowdown of the tank while preparing the hose lines and then extinguish the car fire, using the electrical car fire procedures.

2nd example:
An FCH car is burning in a crowded street, close to a 10-storey building, no sound is heard, and the fire began 2 minutes ago.

Tactical choice:
Use an offensive tactic: close the road in both directions, prevent anybody from approaching less than 100 meters from the car, stretch two hose lines and attack immediately the car fire simultaneously with two teams, from safe angles (see below) before TPRD opens. Keep cooling the tanks, after the fire is put out.

18.5.Protection

The "protection" step aims to avoid destructions caused by the incident (the fire) or by what was used to extinguish it (the water).

As an example, if the fire occurs in a bus parking lot, the buses closest to the fire are protected using water jet curtains, and those which are a little bit further can simply be driven away from the incident area.

In the buildings and the industrial plants, the effects of the water or foam sprays can also be destructive. The incident commander must use the only necessary amount of water or foam. During this step, shoring-up can also be necessary.

18.6.Clear out.

At the end of a fire, it is important to clear out the incident scene, remove and sprinkle all burnt pieces of material to be sure that no ignited materials remain underneath.

18.7. Final Inspection

After the end of extinguishing operations and the incident settlement, the first responders must not leave the fire ground too early.
The temperature decrease of the burnt tank must regularly be checked.
A ~~OVERHAUL~~ final inspection of the fire ground must be steadily done, until no further risk still exists.

18.8. Incident tactics for FCH applications

18.8.1. Type of incidental situations

The situations encountered with FCH application are varied. They can be classified in 5 main situations:

1 RESCUE on a FCH application

2 IGNITED HYDROGEN LEAK

3 UNIGNITED HYDROGEN LEAK

4 FIRE on a FCH application

5 FIRE THREATENING a FCH application

The 5 following tables (extracted and translated from the French guidelines) explain the operational sequences on how to deal with the related situations.

18.9. Rescue

Situations covered by this sequence are:

- Injured person in a FCH application.
- Asphyxiation caused by an H2 leak in a confined space.
- Electrocution.
- Burns caused by a gaseous or liquified hydrogen leak.

The indicative step-by-step sequence is listed below.

Table 1 Operational sequence for RESCUE on a FCH application

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident. - Take into account the risk of explosion of hydrogen in confined spaces. - Take into account the risk of depleted oxygen (anoxia) in confined spaces.
	Prohibit	- Prohibit the progress downwind. It is imperative to establish an exclusion zone of 50 m; - Prohibit the use of electrical or electronic devices in the non ATEX exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building
RESCUE	Act Isolate	**<u>In case of gaseous or liquified hydrogen leak in confined spaces:</u>** - Wear a self-contained breathing apparatus; - Remove the affected casualty outside the exclusion zone. **<u>If risk of electrified or electrocuted victim</u>** - Use the electro-rescue equipment to remove the victim - Avoid contact of the first responders with electrical elements;
PREPAREDNESS/ INCIDENT SETTLEMENT		- Confirm or refine the exclusion zone (50 m); - Conduct surveys using an explosimeter (from top to bottom of the installation or storage facility)
PROTECTION		**<u>-Actions to prevent a risk of anoxia:</u>** • Close the hydrogen supply valves • Ventilate the area by promoting the natural drawing (do not use electrical and thermal fans) **<u>Action on the electrical risk:</u>** Press the emergency stop button of the installation (delay of 20 minutes with the presence of residual current)
CLEAR OUT FINAL INSPECTION		The monitoring phase ceases as soon as the oxygen level in the room is normal (about 20,9 vol. %) Repeatedly check: • hydrogen presence in the atmosphere • the electrical system is secure and supported by a technician

18.10. Electrical Fire

The situation covered by this sequence is a Fire on the electrical components of a FCH application.

Table 2 Operational sequence for FIRE on the electrical components of a FCH application

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident; - Take into account the "low voltage" hazards
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building;
RESCUE		- In case of hydrogen in confined spaces: • Wear a breathing apparatus; • Remove the affected person outside the exclusion zone. - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim • Avoid contact of the first responders with electrical elements
PREPAREDNESS/ INCIDENT SETTLEMENT	Act Isolate	- Confirm or refine exclusion zone (50 m) (based on the sound of a leak under pressure, readings of explosimeter, etc.); - Proceed to the extinction of the flame based on its virulence: • With a powder or CO2 fire extinguisher at a distance more than > 1m • With variable flow-rate nozzles in, spray attack pulse at a distance of more than 3m
PROTECTION		- Operate the emergency stop punch installation (20 minutes from time with the presence of a residual current); - Take into account the flow of water during the timeout shutdown phase of the installation (electrical hazard); - Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT FINAL INSPECTION		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage; - The monitoring phase ends when it is found that the actions aimed at extinguishing measures proved effective.

18.11. External Fire

The situation covered by this sequence is a Fire threatening a FCH application or H_2/LH_2 storage

Table 3 Operational sequence for a FIRE THREATENING a FCH application or H2/LH2 storage

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident. - Take into account the risk of explosion of a hydrogen tanks under fire, with projectiles travelling several tens of meters for bottles and several hundred for trailers.
	Prohibit	- Prohibit the progress downwind and imperative to establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building;
RESCUE	Act Isolate	- In case of hydrogen in confined spaces: • Wear a breathing apparatus; • Remove the affected person/victim outside the exclusion zone; - If risk of electrified or electrocuted victim: • Use the electro-rescue equipment to remove the victim; • Avoid contact with electrical stakeholder bodies.
PREPAREDNESS/ INCIDENT SETTLEMENT		- Confirm or refine the exclusion zone (tanks or installation directly threatened by the flames); - Proceed with the extinction of fires - Provide preventive cooling of the facilities and hydrogen storage in the following ways: • Establishment of a “peacock tail “type nozzle. • Direct attack spread water jet on the hydrogen tanks using with variable flow-rate nozzles spear 250 l/min minimum (avoid directing the jets on pipes) • Establishment of spread water jet for the protection of sensitive point (power Bay ....)
PROTECTION		Operate the emergency stop punch installation (20 minutes from time with the presence of a residual current); - Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT FINAL INSPECTION		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage; -The monitoring phase ends when it is found that • the actions aimed at extinguishing proved effective. • the water spread on the hydrogen tanks do not evaporate on contact with surfaces

18.12. Ignited H2 leak

The situation covered by this sequence is an ignited H2 leak.

Table 4 Operational sequence for an IGNITED HYDROGEN LEAK

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident; - Take into account the dispersion of H_2 in premises before the ignition (possibility of UVCE unconfined vapour cloud explosion).
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.). - Prohibit the extinguishment of the hydrogen flames. - Prohibit the actions on the electrical system of the facility in case of hydrogen leak.
	Inspect	- Operate the external power cuts of the building; - Confirm the presence of an ignited leak and its length using thermal camera (hardly visible flame in its entirety, in the day light); - Pay attention to the significantly loud sound of an ignite gas leak.
RESCUE	Act Isolate	**<u>- In case of hydrogen in confined spaces:</u>** • Wear a breathing apparatus; • Remove the affected person(s) outside the exclusion zone. **<u>- If risk of electrified or electrocuted victim:</u>** • Use the electro-rescue equipment to remove the victim; • Avoid contact with electrical stakeholder bodies.
PREPAREDNESS/ INCIDENT SETTLEMENT		- Refine the exclusion area (explosimeter measurements, information on the nature of the incident ...); - Set up water curtains to prevent a fire spread; - If necessary, provide preventive cooling on hydrogen storage and facilities nearby.
PROTECTION		- Close hydrogen supply valves. - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT FINAL INSPECTION		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage. - Conduct surveys of explosimeter in confined spaces prioritizing high points. - Press the emergency stop button of the installation (delay of 20 minutes with the presence of a residual current).

18.13. Unignited H2/LH2 leak

The situation covered by this sequence is an unignited H2 leak.

Table 5 Operational sequence for an UNIGNITED HYDROGEN LEAK

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details on the incident. - Take into account the risk of explosion.
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.). - Prohibit the actions on the electrical system of the facility in case of hydrogen leak.
	Inspect	- Operate the external power cuts of the building
RESCUE	Act Isolate	- In case of hydrogen in confined spaces: • Wear a breathing apparatus. • Remove the affected person (s) outside the exclusion zone. - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim. • Avoid contact with electrical stakeholder bodies.
PREPAREDNESS/ INCIDENT SETTLEMENT		- Refine the security area based explosimeter measurements (from top to bottom of the installation). - Close hydrogen supply valves. - Ventilate premises facilitating natural drawing (opening existing outlets).
PROTECTION		
CLEAR OUT FINAL INSPECTION		- The monitoring phase ends when there is no risk of explosion in a secure area (complete emptying of the tank or draining in open air in a secure area monitored by the operator, efficient ventilation of the premises.) - Press the electrical emergency shutdown device of the installation (delay of 20 minutes with the presence of a residual current)

Note: the action on the emergency stop punch during the ~~OVERHAUL~~ Final inspection phase, clears electric ignition sources, intrinsic with the installation.

19. HYRESPONDERS FIRST RESPONDERS TEAM AND EQUIPMENT

All the firefighting equipment used in the HyResponder program must be in accordance with the following document:

“Catalogue des Normes Applicables aux Sapeurs-Pompiers et à la Sécurité civile Direction Générale de la Sécurité Civile et de la Gestion des Crises Sous-direction des ressources, des compétences et de la doctrine d'emploi Bureau de la Formation, des Techniques et des Équipements, Version Éditée le 27 août 2014 » and following.

19.1.The team

The typical fire equipment used in HyResponder training has the following crew:

- Equipment Chief (first incident commander)
- Driver/pump operator
- Team leader 1
- First responder 1
- Team leader 2
- First responder 2

Each first responder must wear complete fire gear composed in particular of the following elements: Helmet with face shield, hood, turnout coat, turnout pants, and fire fighter boots and gloves. All protective clothing must be worn as a complete set.

Use of self-contained breathing apparatus is also mandatory.

19.2.The fire equipment

The vehicle used in HyResponder is the French Pump (fourgon pompe tonne). It has the characteristics specified in the European standard EN 1846-1/2/3 and to the French standard NFS 61-515. To tackle H2 fires, additional tools are required:

- Polyvalent flammable gas detector
- H2 detector
- Thermal camera
- 02 detector

19.3.Specific tactics sheets proposed for selected applications

Considering the existing knowledge about hydrogen application fires, The HyResponder project proposes the following “Tactical sheets”.

For each selected application (Car, bus, forklift, trailer, refuelling station, Stationary power generation unit (SPGS), Hydrogen-based energy storage system (H2ESS)), we propose a tactical approach for 4 incidents:

- No leak, no fire,
- H2 leak,
- Fire,
- External fire threatening the application.

For each situation we propose a step- by- step sequence, information about safety points and indicative safety distances **in case of a failure of the pressure release devices and to prevent the public from the effects of the explosion of the tanks.**

Important Notice: please keep in mind that the distances specified are INDICATIVE. The incident commander must enlarge or reduce the safety perimeter considering the reality of the situation and especially the capacities of H2 (or O2) tanks involved.

Refer to section “how to use nomograms”.

20. FUEL CELL VEHICLES

20.1.No leak, no fire

FC CAR/FC FORKLIFT/FC BUS/FC TRUCKS/FC TRAINS/FC SHIPS		
Tactic n° 1	NO LEAK, NO FIRE (technical alarm, work accident, road trafic accident)	
AT THE FIRE STATION		
TAKE USEFUL information ABOUT THE INCIDENT: • assure the precise incident location • are there any person involved in the incident? • type of vehicle concerned • what happened? WEATHER CONDITIONS • wind direction • wind speed ITINERARY choose a safe itinerary: • do not cross an eventual explosive gas cloud • do not reach scene from below • anticipate the need of a hydrant TAKE FOLLOWING TOOLS (if available use drone UAV – use ATEX device) • Gaseous hydrocarbons dectector, • H2 detector • O2 detector • Thermal imaging camera		

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident, away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 50 meters (55 yd)
- • Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened? Trapped inside?
- Which type of vehicles is affected?
- What has happened?
- Has a leak occured? Is a leak still occuring? (if a leak is still occuring refer to Tactic n°2 : leak without fire)
- Is a part of the vehicle damaged?

Check energies present in the vehicle involved (tank type, pressures, capacities, refuelling hole type, vehicle registration papers, etc)

- Demand extra support if necessary

Vehicle identification:
FC car may be recognised by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3). Or check for vehicle rescue sheet.

Operate H2 detector

RESCUE

Engage rescue as a conventional accident (a water mist might be used in this situation of no fire)
Human rescue overrides all other considerations.

EXPOSURE PROTECTION

- Use only necessary personnel
- Open the doors and hoods (if present)
- Set the hand- brake on
- Wedge the vehicle.
- Turn off the ignition key
- Press the fuel cell emergency shutdown device (for buses and forklifts)
  For buses, the emergency shutdown device is generaly located near the driver seat, on the left-hand side and another is on a fuel cell in "engine" compartment, located at the back of the bus.

- If it is not possible to reach the ignition key, remove all the fuses in the fuse boxes and then, cut the negative low voltage battery cable (12 or 24V), taking care not to create an ignition spark (turning off the general electric power supply of the vehicle). Be aware of high voltage cords and batteries.
- Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.
- Check if high temperature points exist on the vehicle by using a thermal camera (more than 150°C/302°F).
- Stretch a fire hoseline to protect the action of teams.
- Listen if a hydrogen leak jet can be heard.

INCIDENT TREATMENT

If no H2 leak and no sign of fire is detected:

- Engage incident settlement following manufacturers of Emergency Response Guides and rescue sheets.

DO NOT:

- cut or crush H2 lines
- cut or crush High Voltage Lines (orange-coloured)
- damagehydrogen tank
- damage traction Battery Stack

If a H2 leak is detected, apply tactic n°2 "H2 LEAK WITHOUT FIRE"

FINAL INSPECTION

- After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnels (idealy by the vehicle manufacturer)

20.2.Leak without fire

FC CAR/FC FORKLIFT		
Tactic n° 2	H2 LEAK WITHOUT FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location,
- type of vehicle concerned,
- what happened.

WEATHER CONDITIONS

- wind direction,
- wind speed.

ITINERARY:

choose a safe itinerary:

- do not cross an eventual explosive gas cloud,
- do not reach scene from below,
- anticipate the need of a hydrant.

TAKE the FOLLOWING TOOLS (if available use drone UAV - use ATEX device).

- Gaseous hydrocarbons dectector,
- H2 detector,
- O2 detector,
- Thermal imaging camera.

ARRIVAL ON SCENE

ARRIVAL:

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident. Away from a possible ignited flammable leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA:

- For a CAR and FORKLIFT: Set up a safety area for the public beyond a radius distance of 100 meters (110 yds)
- For a BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yds)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

Fuel cell vehicles
Leak without fire

IF A PERSON IS INSIDE THE HAZARDOUS AREA:

ENGAGE THE RESCUE OPERATIONS (conduct rescue operation with back up of charged water line).

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

Answer the following questions:

- Which type of vehicle is involved?
- What happened?
- Has a loud hissing sound being hared before the FR arrive?

VEHICLE IDENTIFICATION:

H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3)

Confirm the safety area with the H2 detector .

- If H2 is detected, refine the safety area.
- Demand extra support if necessary

Check if high temperature points exist on the vehicle by using a thermal camera (more than 150°C/302°F). Check for possible ignition source.

RESCUE

Human rescue overrides all other considerations (a water mist might also be used in this situation of a leak with no fire)

If a human is threatened or concerned by the gas leak:

- Team 1: extract the victim(s) from the danger zone by any possible means (extraction tool : use the method implemented in the country). A pump-operated system might be safer than a battery-operated, however pump should be in safe zone and respect the distance with the car.

- Team 2: stretch a fire hoseline to protect the action of the Team 1 in case of an ignition of the cloud.

Evacuate the passengers in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).

Fuel cell vehicles
Leak without fire

EXPOSURE PROTECTION
• Use only necessary personnel. • Evacuate adjacent buildings. • If the vehicle is in a building, prevent H2 accumulation by operating wide ventilation of the building. • Open the doors and hoods (if present). • Set the hand-brake. • Wedge the vehicle. • Turn off the ignition key. • Press the fuel cell (or Hydrogen system in general) emergency shutdown device (buses and forklift) For Buses, an Emergency shutdown device is generaly located near the driver seat, on the left-hand side and another is on fuel cell in "engine" compartment, located at the back of the bus. • Do not operate any other electrical breaker to avoid creation of electrical spark (during extraction be aware of high voltage). • Repeatedly check H2 presence in the atmosphere. • Refine safety area. • Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F).
INCIDENT TREATMENT
• If H2 leak continues after the protection step , close H2 valve as close as possible of the H2 tank. • If it is not possible to reach a H2 valve, allow H2 to leak safely until the tank is empty. • Deploy a water curtain with monitor.
FINAL INSPECTION
• After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnels (idealy by manufacturer).

20.3.Fire

	FC CAR/FC FORKLIFT	
Tactic n° 3	FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- type of vehicle concerned
- what happend?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary:

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL:

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident, away from a possible ignited flammable leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

- CAR and FORKLIFT: Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area.

SIZE UP THE SCENE
IF A PERSON IS INSIDE THE HAZARDOUS AREA : ENGAGE RESCUE OPERATIONS Answer the following questions: • Is someone threatened by the fire? Where? • How many vehicles are involved in the fire? • How many of these vehicles are powered by H2 or by another compressed flammable gas? • Has a loud hissing sound being heard before the FR arrive? • Where can be H2 overpressure valve be localized in the vehicle? • Did the TPRD activate? Is the flame produced? • Demand extra support if necessary Vehicle identification: H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3).
RESCUE
Human rescue overrides all other considerations. If a human is threatened or concerned by the Fire : • Team 1: extract the victim(s) from the danger zone by any possible means (figure 10). Be equiped with PBE. • Team 2: stretch a fire hoseline to protect the action of the Team 1 to evacuate the passengers in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).
EXPOSURE PROTECTION
• Use only necessary personnel • Evacuate adjacent buildings • Prevent the fire from spreading to a uninvolved vehicle(s) or building(s) • Move ajacent non involved vehicles by any way possible (driving, towing, pushing, etc) • If the vehicle is in a building, prevent combustion gases and H2 accumulation by operating wide ventilation of the building. • If possible and safe: • Open the doors and hoods (if present) • Set the hand-brake on • Wedge the vehicle • Turn off the ignition key (during extinguishing be aware of high voltage). • Press the fuel cell emergency shutdown device (buses and forklifts) For Buses, an Emergency shutdown device is generaly located near the driver seat on left side and another is on fuel cell in "engine" compartment, located at the back of the bus • Repeatedly check H2 presence in the atmosphere (preventive measure). • Refine safety area. • Repeatedly check H2 tanks temperature with thermal imaging device.

INCIDENT TREATMENT

In case of High stakes level situation :

Operate an offensive Fire attack

Each Team prepare 80 m of hoselines directly connected to the fire equipment pump (figure 4).
Be equiped with PBE.

- Team 1: aims to cool the H2 tank. This prevents the Thermal Pressure Release Device to operate.
- Team 2: aims to extinguish the vehicle fire.

The teams avoid passing through danger angles. (figures 5-6-7)

- Mind that violent reactions are possible between water and burning materials
- As soon as possible, wedge the vehicle.
- Mind that water will be polluted during extinction (especialy if battery is damaged.)
- operate its containement with adequate equipment.

If there is no identified stake:
evaluate the opportunity to let the vehicle burn safely.

FINAL INSPECTION

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- After the last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnels (idealy by the manufacturer).

20.4.External Fire threatening the application.

FC CAR/FC FORKLIFT		
Tactic n° 4	EXTERNAL FIRE THREATENING THE APPLICATION	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- type of vehicle concerned
- what happened?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if available use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

- CAR and FORKLIFT Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE
Answer the following questions: • Is someone injured, threatened or trapped inside? • What is burning? • What's the fire Strength? • What's the distance between the Fire and the FC Vehicle? • Has a hydrogen leak occured? Is a leak still continuing? Demand extra support if necessary
RESCUE
Human rescue overrides all other considerations. Be equiped with PBE. If a human is threatened or concerned by the Fire : • Team 1: extract the victim(s) from the danger zone by any possible means. • Team 2: stretch a fire hoseline to protect the action of the Team 1 • evacuate the passengers in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).
EXPOSURE PROTECTION
Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle.
INCIDENT TREATMENT
Operate a defensive Fire attack: each team prepare 80 m of hoselines directly connected to the fire equipment pump. • Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle. • Team 2: Put out the fire with water, foam or powder depending what is burning. If putting fire out is not possible, or if not enough personnel are available, attempt to move the FCH vehicle by any way possible (driving, towing, pushing) away from the radiant effect of the fire.
FINAL INSPECTION

Figure 42 : Offensive fire attack preparedness (connected to hydrant if available) ©crise-2015

Figure 43 : (In red) forbidden angles for reaching a FCH car in fire on wheels. ©Crise-2015

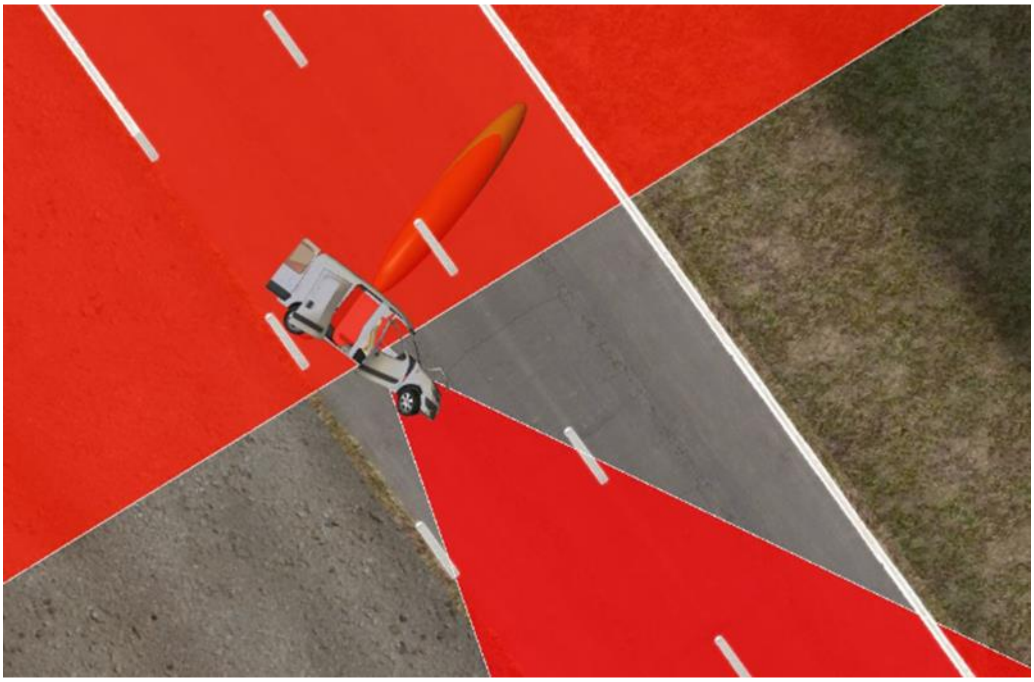


Figure 44 (In red) forbidden angles for reaching a FCH car in fire on the side (TPRD located in the roof) ©crise-2015

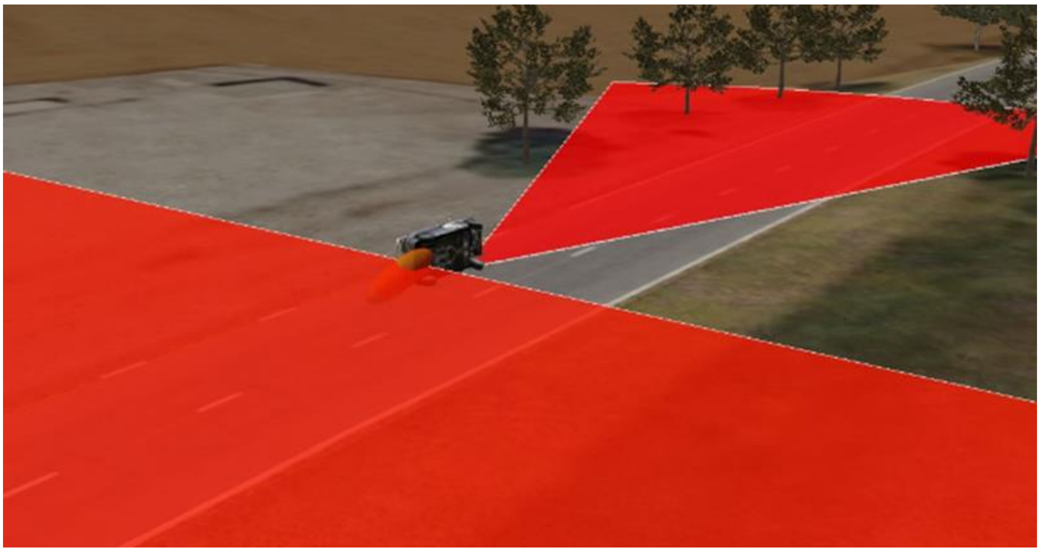


Figure 45 : (In red) forbidden angles for reaching a FCH car in fire on the side (TPRD located between the rear wheels with an angle of 45°)©crise-2015

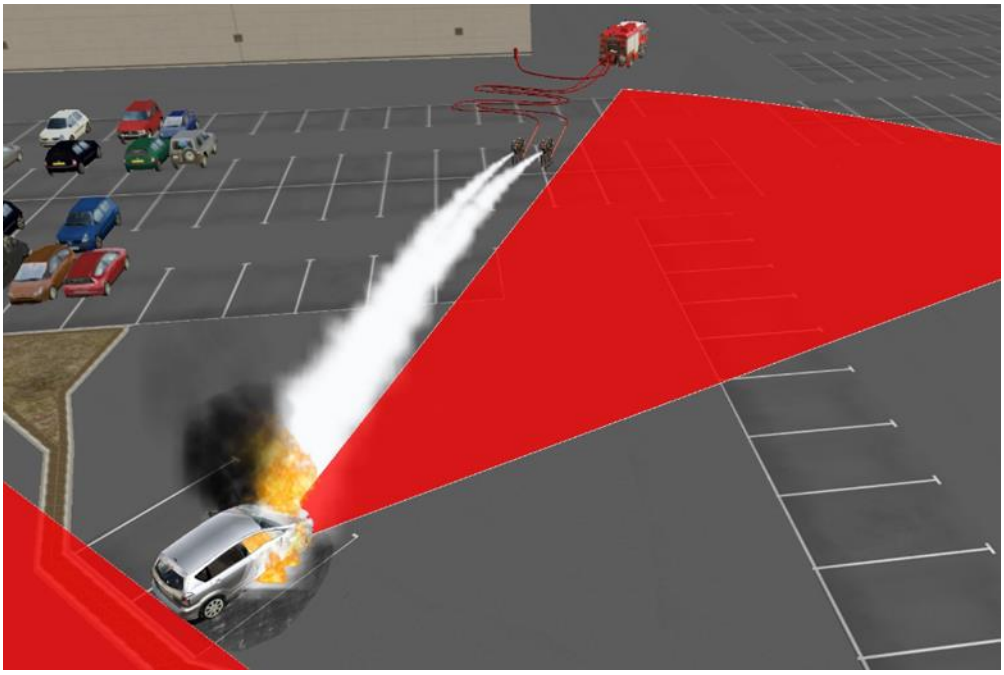


Figure 46 Offensive fire attack with two teams (1st phase) ©crise-2015

Figure 47 : Offensive fire attack with two teams (2nd phase) ©crise-2015

Figure 48: Rescue near a FCH car on fire. ©crise-2015

Figure 49: Forklift H2 release vent (on each side) ©Air Liquide-2014

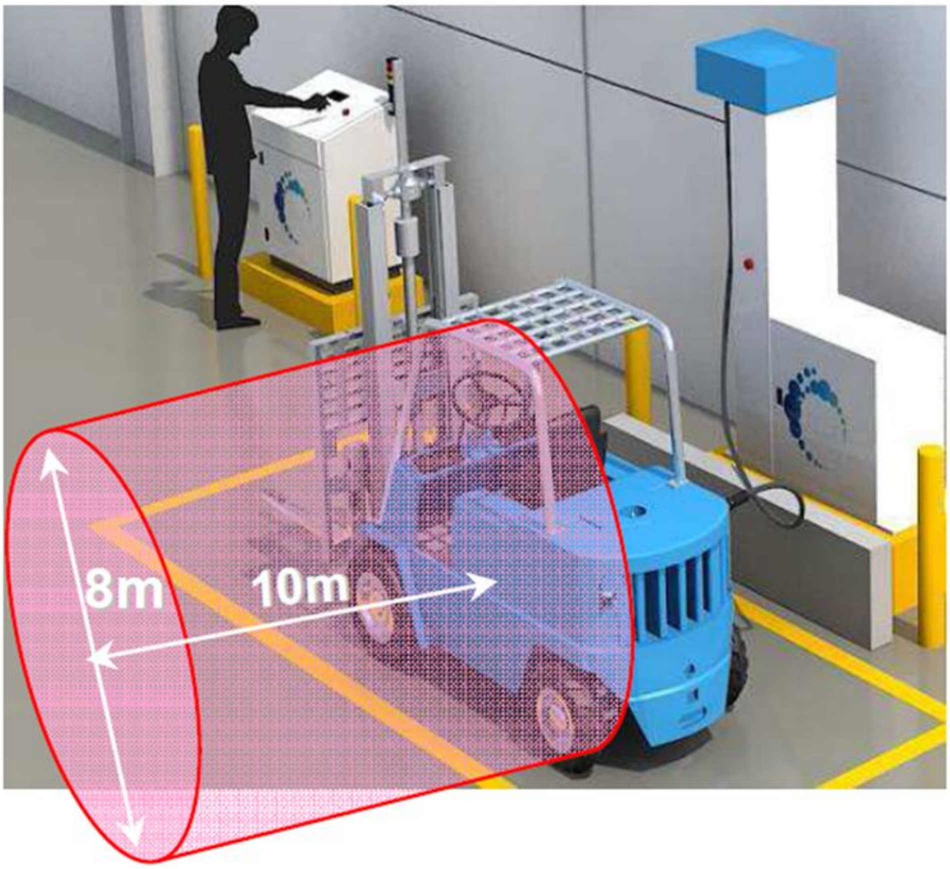


Figure 50 : gaseous Danger zone for a forklift during a TPRD H2 release (on each side for 1 minute) ©Air Liquide-2014

Figure 51 : Fire threatening the forklifts©crise-2015

Pressure in hydrogen storage tank, MPa	TPRD orifice diameter, mm	Distances to 4 vol %, m	Distance to 8 vol %, m
35	2	15	7
35	3	23	11
35	4	31	15
35	5	38	18
35	6	46	22
70	2	20	10
70	3	30	14
70	4	40	19
70	5	50	24

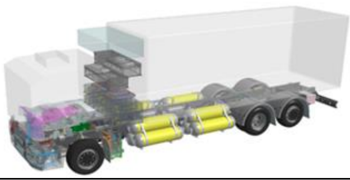
Table 6 Concentrations of hydrogen in air depending on distance to the leak (m)

Pressure in storage tank, MPa	TPRD orifice, mm	Flame length, m	SD (no harm), m	SD (pain threshold), m	SD (3rd degree burn), m
35	2	5	18	16	10
35	3	8	27	23	16
35	4	10	36	26	18
35	5	13	46	39	26
35	6	16	55	47	31
70	2	7	23	20	13
70	3	10	35	30	20
70	4	13	46	40	27
70	5	17	58	50	33
70	6	20	70	60	40

Table 7 Flame lengths and separation distances for jet fires from on-board hydrogen tanks

21. FC BUSES, FC TRUCKS, FC TRAINS

21.1. No leak, no fire

	FC BUS / FC TRUCKS / FC TRAINS	HyResponder
Tactic n° 5	NO LEAK NO FIRE (technical alarm, work accident, road trafic accident)   	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT

- Assure the precise incident location (may include using vehicle tracking)
- You can use GIS: https://www.google.com/earth/ or QR code to quickly understand the surrounding:
-
- Are there any person involved in the incident?
- You can check social media feeds (Facebook/Twitter) to collect information before the arrival on scene
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happened?

WEATHER CONDITIONS

- Wind direction
- Wind speed
- Weather App : https://www.weather-forecast.com (check the drone-weather section if you consider using a drone).

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not reach scene from below
- Anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons detector
- H2 detector
- O2 detector
- Thermal imaging camera

Link to the measuring devices available at your fire brigade

ARRIVAL ON SCENE

ARRIVAL

- Do you hear a leak ?
- Choose a safe way to get to the incident ground, preventing the fire appliance to cross a flammable gas cloud, and make sure to arrive upwind
- Only the absolute necessary forces on site
- Stop the fire appliance between 50 and 100 meters before the incident (55 to 110yd)
- Away from a possible ignited flammable liquid leak progression distance
- Engage the pump and connect the fire appliance to a hydrant

SAFETY AREA

- Set up a safety area for the public beyond a radius of 50 to 100 meters
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- Is someone injured? Threatened?
- What type of vehicle is affected?
- What happened?
- Vehicle gas tank size and content in litres
- Has a leak occured? Is a leak still occuring? Did you hear whistling?
- Is a part of the vehicle damaged?

Demand extra support if necessary

Check energies present in the involved vehicle (tank type, refuelling hole type, vehicle registration papers...)

Vehicle identification (H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle badges)

Operate H2 detector above and around the vehicle.

RESCUE

Human rescue overrides all other considerations

Engage rescue as a conventional accident with hazmat support

EXPOSURE PROTECTION

Large Size Fuel cell vehicles
No Leak, No Fire

Use only necessary personnel
Open the doors and hoods (if present)
Set parking brake
Wedge the vehicle
Turn off the ignition key
Press the fuel cell emergency shutdown device

- For busses, an emergency shutdown device is generaly located near the driver seat on left side and another is on fuel cell in "engine" compartment, located at the back of the bus.
- For trucks, trains and ships: safety data sheets or on-board rescue sheet

If it's not possible to reach the ignition key, remove all the fuses in the fuse boxes and then, cut the negative low voltage battery cable (12 or 24V) taking care not to create an ignition spark

Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic
Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F)
Stretch a fire hoseline to protect the action of teams

INCIDENT TREATMENT

If no H2 leak and no sign of fire is detected

- Engage incident settlement following manufacturers Emergency Response Guides

DO NOT

- Cut or crush H2 lines
- Cut or crush High Voltage Lines (orange)
- Damage H2 tank
- Damage traction Battery Stack

If a H2 leak is detected, apply tactic n°2 "H2 LEAK WITHOUT FIRE"

FINAL INSPECTION

After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnell (idealy manufacturer). In order to avoid the risk of fire from batteries, operate a verification with thermal camera.

21.2. H2 leak No fire.

	FC BUS / FC TRUCKS / FC TRAINS	HyResponder
Tactic n° 6	H2 LEAK WITHOUT FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT

- Assure the precise incident location (may include using vehicle tracking)
- Are there any persons involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happened?

WEATHER CONDITIONS

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not reach scene from bellow
- Anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons detector
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL

- Choose a safe way to get to the incident ground, preventing the fire appliance to cross a flammable gas cloud, and make sure to arrive upwind
- Stop the fire appliance between 50 and 100 meters before the incident (55 to 110 yd)
- Away from a possible ignited flammable liquid leak progression
- Engage the pump and connect the fire appliance to a hydrant

SAFETY AREA

- CAR and FORKLIFT Set up a safety area for the public beyond a radius of 100 meters
- **BUS, truck, train, ship: Set up a safety area for the public beyond a radius of 200 meters**
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA, ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA, answer the following questions

- What type of vehicle is affected?
- What happened?
- Vehicle gas tank size and content in litres
- Has a loud hissing sound been heard before the FR arrive?

Demand extra support if necessary
Vehicle identification, H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle badges

Confirm the safety area with the H2 detector
If H2 is detected, refine the safety area
Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F)

RESCUE

Human rescue overrides all other considerations
Engage rescue as a conventional accident with hazmat support, if a human is threatened or concerned by gas leak.
• Team 1: extract the victim(s) from the danger zone by any possible means
• Team 2: stretch a fire hoseline to protect the action of the team 1 in case of an ignition of the cloud

According to the size of the event and the vehicle affected, adapt the plan of action by engaging additional teams.
Reminder : keep the strategy of a two teams engagement.

Evacuate passengers in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- Use only necessary personnel
- Evacuate adjacent buildings
- If the vehicle is in a building, prevent H2 accumulation by operating wide ventilation of the building. If possibe, use an ATEX air blower.
- Open the doors and hoods (if present)
- Set parking brake
- Wedge the vehicle
- Turn off the ignition key
- Press the fuel cell emergency shutdown device
  For busses, an emergency shutdown device is generaly located near the driver seat on left side and another is on fuel cell in "engine" compartment, located at the back of the bus.
  For trucks, trains and ships: safety data sheets or on-board rescue sheet
- Do not operate any other electrical breaker to avoid creation of electrical spark
- Repeatedly check H2 presence in the atmosphere
- Refine safety area
- Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F)

INCIDENT TREATMENT

If H2 Leak still exist after "exposure protection step ", close H2 valve as close as possible to the H2 tank If it is not possible to reach a H2 valve, allow H2 to leak safely until the tank is empty. In urban areas, verify the hydrogen level in the surrounding buildings.
FINAL INSPECTION
After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnell (idealy manufacturer)

21.3. Fire

	FC BUS / FC TRUCKS / FC TRAINS	HyResponder
Tactic n° 7	FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT

- Assure the precise incident location (may include using vehicle tracking)
- Are there any person involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happened?

WEATHER CONDITIONS

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not reach scene from bellow
- Anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons detector
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL

- Choose a safe way to get to the incident ground, preventing the fire appliance to cross a flammable gas cloud, and make sure to arrive upwind
- Stop the fire appliance between 50 and 100 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Engage the pump and connect the fire appliance to a hydrant

SAFETY AREA

- CAR and FORKLIFT Set up a safety area for the public beyond a radius of 100 meters
- **BUS, truck, train, ship:Set up a safety area for the public beyond a radius of 200 meters**
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA, ENGAGE RESCUE OPERATIONS then answer the following questions

- Is someone threatened by the fire? Where?
- How many vehicles are involved in the fire?
- How many of these vehicles are powered by H2 or another compressed flammable Gas?
- Has a loud hissing sound been heard before the FR arrive?

Demand extra support if necessary

Vehicle identification, H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle badges

RESCUE

Human Rescue overrides all other considerations

Engage rescue as a conventional accident with hazmat support, if a human is threatened or concerned by the fire

Be equiped with PBE.

- Team 1: extract the victim(s) from the danger zone by any possible means. A path must have been identified by thermal camera due to the multiple directions possibility of the TPRD or obstacles which would deflect the natural direction of the flame.
- Team 2: stretch a fire hoseline to protect the action of the team 1

According to the size of the event and the vehicle affected, adapt the plan of action by engaging additional teams. Reminder : keep the strategy of a two teams engagement.

Evacuate the passengers in opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- Use only necessary personnel
- Evacuate adjacent buildings
- Prevent the fire from spreading to a uninvolved vehicle(s) or building(s)
- Move ajacent non involved vehicles by any way possible (driving, towing, pushing…)
- If the vehicle is in a building, prevent combustion gases and H2 accumulation by operating wide ventilation of the building
- Open the doors and hoods (if present)
- Set parking brake
- Wedge the vehicle
- Turn off the ignition key
- Press the fuel cell emergency shutdown device
  - For buses, an emergency shutdown device is generaly located near the driver seat on left side and another is on fuel cell in "engine" compartment, located at the back of the bus.
  - For trucks, trains and ships: safety data sheets or on-board rescue sheet
- Repeatedly check H2 presence in the atmosphere
- Refine safety area
- Repeatedly check H2 tanks temperature with thermal imaging device

INCIDENT TREATMENT

In case of high stakes level situation, operate an offensive fire attack, each team prepare 80 m of hoselines directly connected to the fire engine pump

- Team 1: aims to cool the H2 tank and so doing prevent Thermal Pressure Release Device to operate
- Team 2: aims to extiguish the vehicle fire

According to the size of the event and the vehicle affected, adapt the plan of action by engaging additional teams. Reminder : keep the strategy of a two teams engagement.

Teams should avoid passing through danger angles (close to the storage zone of the vehicle : on the roof for Buses and Trains / same as cars for Trucks).

Mind that violent reactions are possible between water and burning materials
as soon as possible, wedge the vehicle

Mind that water will be polluted during extinction (especialy if battery is damaged.), operate its containment

If there is no identified stake, evaluate the opportunity to let the vehicle burn safely. Be aware that FCH can burn for a long period.

FINAL INSPECTION
• Cool the wreckage as soon as no heat point is detected by the thermal imaging device • After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnell (idealy manufacturer)

21.4. External fire threatening the application

	FC BUS / FC TRUCKS / FC TRAINS	HyResponder
Tactic n° 8	EXTERNAL FIRE THREATENING THE APPLICATION (factory, H2 station, H2 storage/production facility)	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT

- Assure the precise incident location (may include using vehicle tracking)
- Are there any person involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happened?

WEATHER CONDITIONS

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not reach scene from bellow
- Anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons detector
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL

- Choose a safe way to get to the incident ground, preventing the fire appliance to cross a flammable gas cloud, and make sure to arrive upwind
- Stop the fire appliance between 50 and 100 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Engage the pump and connect the fire appliance to a hydrant

SAFETY AREA

- CAR and FORKLIFT Set up a safety area for the public beyond a radius of 100 meters
- **BUS, truck, train, ship: Set up a safety area for the public beyond a radius of 200 meters (220 yd)**
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

Large Size Fuel cell vehicles
External fire

Answer the following questions

- Is someone injured? Threatened?
- What is burning?
- What's the fire strength?
- What's the distance between the fire and the FCH vehicle?
- Has a leak occured? Is a leak still occuring?

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations

Engage rescue as a conventional accident with hazmat support.
Be equiped with PBE.
If a human is threatened or concerned by the fire

- Team 1: extract the victim(s) from the danger zone by any possible means.
- Team 2: stretch a fire hoseline to protect the action of the team 1

According to the size of the event and the vehicle affected, adapt the plan of action by engaging additional teams.
Reminder : keep the strategy of a two teams engagement.

Evacuate the passengers in the opposite direction of wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

Team 1: attenuate the radiant heat by providing a protective spray jet between the fire and the FCH vehicle.
According to the size of the event and the vehicle, additional teams can be added to this procedure.

INCIDENT TREATMENT

Operate a defensive fire attack, each team prepares 80 m of hoselines directly connected to the fire appliance pump

- Team 1: attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle
- Team 2: put out the fire with water, foam or powder depending what is burning

According to the size of the event and the vehicle affected, adapt the plan of action by engaging additional teams.
Reminder : keep the strategy of a two teams engagement.

If putting fire out is not possible, or if enough personnel is available, move the FCH vehicle by any way possible (driving, towing, pushing) away from the radiant effect of the fire

FINAL INSPECTION

Check temperature on the FCH vehicle with thermal imaging device

22. H2 TRAILER

22.1.No leak, No Fire

H2 trailer		
Tactic n°9	NO LEAK NO FIRE (technical alarm, work accident, road trafic accident)  	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- Assure the precise incident location (may include vehicle tracking)
- Are there any person involved in the incident?
- Type of trailer concerned? Size, cargo? Is if full or empty? Search for manufacturer's emergency response guidance
- Is the cargo dismantled?
- See Twitter, facebook or other channel of information to find real-time picture

WEATHER CONDITIONS

- wind direction
- wind speed
- Use a weather app like https://www.weather-forecast.com

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipement including breathing apparatus
- Check for potential webcam in the vicinity

Additional resources : Check ISO 17840 / ERG 2020 (Guide 115)

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident.
- away from a possible ignited flammable liquid leak progression.
- Approach objects taking into account possible ignotion of leaking H2
- Engage the pump and connect the fire equipment to a hydrant.
- Deploy and arm a hose-line for safety of for a primary attack
- Only absolutely necessary staff on site . Explore the surroundings : e.g. tanks, Hydrogen Station etc. with a view of the domino effect.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 50 - 100 meters (55-110 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area
- Check for possible ignition sources, consider static electricity

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- Which Type is the involved vehicle? If available and not excessively time consuming use google lens to help identify.
- What has happened?
- Has a leak occured? Is a leak still occuring?
- Is a part of the truck damaged?
- Is the trailer dismantled? Is there a loss of cargo ?
- Demand extra support if necessary
- Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers)
- Does a flammable liquid leak exists?
- Operate H2 detector
- View the safety data sheet (if available and not excessively time consuming).

RESCUE

Engage rescue as a conventional accident. Adapt and engage rescue following conventional national and european tactics.
Human rescue overrides all other considerations.

EXPOSURE PROTECTION

- Use only necessary personnel
- set parking brake
- wedge the vehicle.
- Turn off the ignition key
- Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.
- Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F)
- Stretch a fire hoseline to protect the action of other teams
- If available, prioritise the use of non-sparking tools.

INCIDENT TREATMENT

- Check and close every H2 valve on the trailer with the protection of an armed hoseline.
- If no H2 leak and no sign of fire is detected :
- Proceed and act as in an usual road trafic accident and by the corresponding extrication guidelines. At all times keep H2 measuring active.

DO NOT:

- Cut or crush H2 lines
- Damage H2 tanks

If there is a loss of cargo or if the trailer is damaged, inspect individually each cylinder
contact the transport company hotline to evacuate safely the cylinders

FINAL INSPECTION
After a last H2 atmospheric control, make sure that the vehicle or the wreckage and the cargo is evacuated by authorised personnell (ideally transport company). Secure the environment: if possible, move tanks and other tank vehicles out of the area of activity. Consider and organise the safety precautions needed while salvage and towing

22.2.H2 leak, No fire

	H2 trailer	
Tactic n° 10	H2 LEAK WITHOUT FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- Assure the precise incident location
- What happend?
- Are there any persons involved in the incident?
- Type of trailer concerned? Size, cargo? Is if full or empty?
- Is the cargo dismantled? Or is there a loss of cargo?

WEATHER CONDITIONS

- Wind direction
- Wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipment including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters before the incident away from a possible ignited flammable liquid leak progression.
- Approach objects taking into account possible ignition of leaking H2
- Engage the pump and connect the fire equipment to a hydrant.
- Deploy and arm a hose-line for safety of for a primary attack

SAFETY AREA

- Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

- Check for possible ignition sources, consider static electricity

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :
ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:
BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS:

- What type of vehicle is involved? (Figure 22)
- What happened?
- Is the trailer dismantled? Is there a loss of cargo ?
- Demand extra support if necessary
- Has a loud hissing sound been heard before the FR arrive?
- Check for possibility of H2 in confined spaces
- Confirm the safety area with the H2 detector . If H2 is detected, refine the safety area
- Check if high temperature points exist on the vehicle by using thermal camera (more than 150°C/302°F)

RESCUE

Human rescue overrides all other considerations.

If a human is threatened or concerned by the gas leak :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : ~~stretch a fire hoseline to~~ protect the action of ~~the~~ Team 1 in case of an ignition of the cloud with the armed hose-line.

EXPOSURE PROTECTION

- Use only necessary personnel
- Set parking brake
- Wedge the vehicle.
- Turn off the ignition key
- Check if high temperature points exist on the vehicle (more than 150°C/302°F)
- ~~stretch a fire hoseline to protect the action of other teams~~ Keep the hose-line manned at all time.

INCIDENT TREATMENT

Listen for abnormal noises

Repeatedly check for H2 presence in the atmosphere (preventive measure).

Check and close every H2 valve on the trailer with the protection of an armed hoseline. Consider if it is safe to let the H2 leak in the environment, take necessary precautions.

FINAL INSPECTION

- After a last H2 atmospheric control, make sure that the vehicle or the wreckage and the cargo is evacuated by authorised personnels (ideally transport company)
- Consider and organise the safety precautions needed for salvage and towing.

22.3.Fire

H2 trailer		
Tactic n° 11	FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any persons involved in the incident?
- what happend?
- type of trailer concerned? Size, cargo? Is if full or empty?
- Is the cargo dismantled? Or is there a loss of cargo?

WEATHER CONDITIONS
- wind direction
- wind speed

ITINERARY
choose a safe itinerary :
- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if available use drone UAV – use ATEX device):
- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipement including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :
- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters before the incident (55-110 yd) away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.
- Deploy and arm a hose-line for safety for a primary attack

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :
ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:
BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS:

- Which type of vehicle is involved?
- What happened?
- Is the trailer dismantled? Is there a loss of cargo ?
- Demand extra support if necessary
- Is a cylinder involved in fire?
- Check the fire scene with the thermal imaging camera:
- Is the cylinder the cause of the ignited H2 leak?
- Is a cylinder radiated by the flames?

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the gas leak :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : protect the action of ~~the~~ Team 1 with the armed hose-line.

EXPOSURE PROTECTION

- Evacuate adjacent buildings
- Prevent the fire from spreading to a uninvolved vehicle(s) or building(s)
- Move ajacent non involved vehicles by any way possible (driving, towing, pushing) (measuring)

INCIDENT TREATMENT

In case of high stakes level situation :
Operate an offensive Fire attack:
Each Team prepare 80 to 100 m of hoselines directly connected to the fire equipment pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks (if available, consider using unmanned water monitors to cool down tanks)
- Team 2: aims to extiguish the vehicle fire. Mind that foam can be used to extinguish the truck (tractor) while water is used to cool the trailer tanks. Make sure not to flush foam with water.

THE INCIDENT COMMANDER WILL EVALUATE THE OPORTUNITY AND THE SEQUENCE ORDER TO CLOSE LEAKING TANKS AS SOON THEY ARE NO MORE SUBMITTED TO A PRESSURE INCREASE;

- If the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.
- Only extinguish the fire when you can close the leak, otherwise let the H2 burn in controlled circumstances
- Previously, the incident commander must have taken appropriate actions to prevent pressure increase in the tanks and checked the efficiency.
- Mind that violent reactions are possible between water and burning materials.
- As soon as possible, wedge the vehicle.
- Try to contain polluted water
- operate its containment.
- Consider if it is safe to let the vehicle burn, take necessary precautions. Be aware that FCH can burn for a long period.
- Mind that a cylinder or a bottle is not equiped with pressure release device and will explode if submited to a pressure increase.

FINAL INSPECTION

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnell ideally transport company).
- Consider and organise the safety precautions needed while salvage and towing.

22.4. External fire threatening the application

H2 trailer		
Tactic n° 12	EXTERNAL FIRE THREATENING THE APPLICATION	HyResponder
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any persons involved in the incident?
- what happend?
- type of trailer concerned? Size, cargo? is if full or empty?
- is the cargo dismantled? Or is there a loss of cargo?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipement including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident (due to possible BLEVE effect) away from a possible ignited flammable liquid leak progression.
- Approach objects taking into account possible ignition of leaking H2
- Engage the pump and connect the fire equipment to a hydrant.
- Deploy and arm a hose-line for safety of for a primary attack

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

Answer the following questions:

- Is someone injured? Threatened?
- What is burning?
- What's the fire Strength?
- What's the distance between the Fire and the H2 trailer?
- Has a leak occured? Is a leak still occuring?

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : ~~stretch a fire hoseline to~~ protect the action of ~~the~~ Team 1 with the armed hose-line

Evacuate passengers in the opposite direction of the wind (or in worst case as far as possible in direction of wind).

EXPOSURE PROTECTION

Team 1: try to minimalise the radiation by putting up a water spray curtain between the fire and the H2 trailer.

INCIDENT TREATMENT

Operate an defensive Fire attack:

Each Team prepare 80 m of hoselines directly connected to the fire equipment pump

- Team 1: try to minimalise the raditation by providing a water spray curtain between the fire and the H2 trailer.
- Team 2 : Put out the fire with water, foam or powder depending what is burning.

If putting the fire out is not possible, move the H2 trailer by any way possible (driving, towing) away from the radiant effect of the fire

Mind that a cylinder or a bottle is not equiped with pressure release device and will exploded if submitted to a pressure increase.

FINAL INSPECTION

- Check temperature on the H2 trailer with thermal imaging device.
- after a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorised personnell (ideally transport company)
- Consider and organise the safety precautions needed while salvage and towing.

Figure 52 : H2 Trailer ©Air Liquide-2014

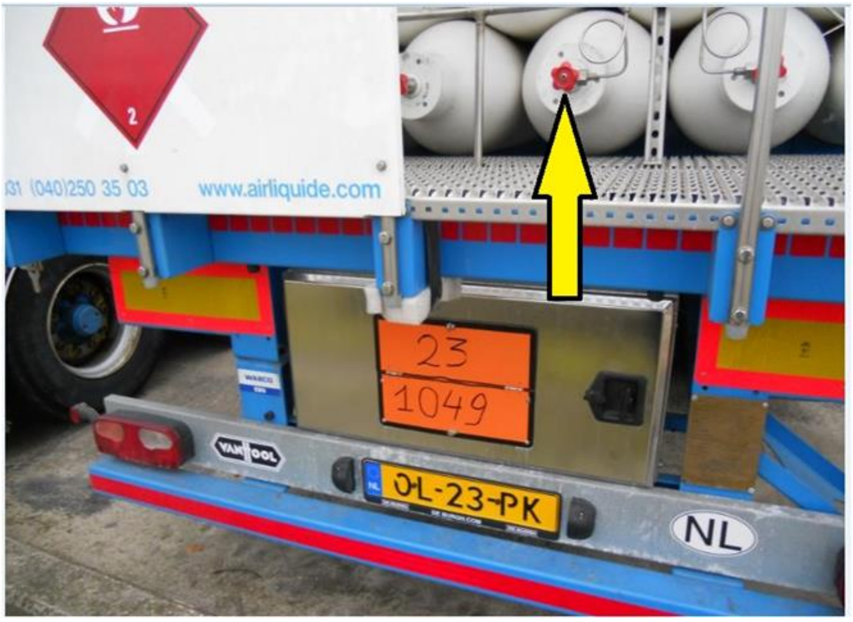


Figure 53 : Individual cylinder valve on a H2 trailer. ©Air Liquide-2014

Figure 54 : H2 trailer with vertical bottles racks. © Areva/ENSOSP 2015

Figure 55 : H2 bottles rack © Areva/ENSOSP 2015

Figure 56 Trailer Main H2 valve (outside view) © Areva/ENSOSP 2015

Figure 57 : Trailer Main H2 valve (inside view) © Areva/ENSOSP 2015

Figure 58 : Valves on a H2 bottles Rack © Areva/ENSOSP 2015

23. REFUELLING STATION

23.1.No leak, No Fire

REFUELLING STATION		
Tactic n° 13	NO LEAK NO FIRE (technical alarm, work accident, road trafic accident)	Hy Responder
AT THE FIRE STATION		
TAKE USEFUL information ABOUT THE INCIDENT: • assure the precise incident location • are there any persons involved in the incident? • are there any vehicle involved in the incident? • what happened? WEATHER CONDITIONS • wind direction • wind speed ITINERARY choose a safe itinerary : • do not cross an eventual explosive gas cloud • do not reach scene from below • anticipate the need of a hydrant TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device): • Gaseous hydrocarbons dectector, • H2 detector • O2 detector • Thermal imaging camera		
ARRIVAL ON SCENE		
ARRIVAL : • Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind. • Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident away from a possible ignited flammable liquid leak progression. • Engage the pump and connect the fire equipment to a hydrant. SAFETY AREA • Set up a safety area for the public beyond a radius of 50 meters (55 yd) • Ensure that unauthorised/untrained personnel do not enter the hazardous area		

SIZE UP THE SCENE
BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS : • Is someone injured? Threatened? • what has happened? • Has a leak occured? Is a leak still occuring? • Is a vehicle connected to the refueling sation? (if yes, apply FCH vehicle related tactic) • Check energies present in involved vehicle (tank type, refueling hole type, vehicle registration papers) • operate H2 detector Demand extra support if necessary Were the emergency shutdown devices of the refuelling station activated?
RESCUE
• Engage rescue as a conventional accident • Human rescue overrides all other considerations. • If needed, transport injured persons to special clinics (for burn injuries, chemical burns).
EXPOSURE PROTECTION
• Use only necessary personnel • Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic. • stretch a fire hoseline to protect the action of teams • push Emergency shutdown devices • if the dispenser is phyisically damaged, close the valves between the storage area and the dispenser.
INCIDENT TREATMENT
If no H2 leak and no sign of fire is detected : • engage incident settlement with conventional techniques. If a FCH vehicle is connected to the refuelling station, disconnect it and move it away. if a H2 trailer is connected to the refuelling sation storage, close the valves between the trailer and the storage and apply simultaneously the tactic related to trailers In addition, determine if the presence is required of : • Specialist advisors / experts • Companies, freight forwarder and organisations with special equipment and facilities (collecting containers, tank trucks). DO NOT: • cut or crush H2 lines • cut or crush High Voltage Lines (orange) • damage H2 tank
FINAL INSPECTION

After a last H2 atmospheric control, make sure that the refuelling station will be checked by authorised personnell before restart.

23.2.H2 leak without fire

	REFUELLING STATION	
Tactic n° 14	H2 LEAK WITHOUT FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any persons involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident
- away from a possible ignited flammable liquid leak progression.

- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA
- Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :
ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:
BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- Has a leak occured? Is a leak still occuring?
- Has a loud hissing sound been heard before the FR arrive?
- Is a vehicle connected to the refueling sation? (if yes, apply related tactic)
- Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers)
- operate H2 detector

Demand extra support if necessary

Were emergency shutdown devices of the refuelling station activated?

RESCUE

Human rescue overrides all other considerations.

If a human is threatened or concerned by the gas leak :
- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : stretch a fire hoseline to protect the action of the Team 1 in case of an ignition of the cloud

evacuate persons in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- Use only necessary personnel
- Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.
- stretch a fire hoseline to protect the action of teams
- push Emergency shutdown devices
- if the dispenser is physically damaged, close the valves between the storage area and the dispenser.

Refuelling station
H2 leak without fire

INCIDENT TREATMENT

Close the valves between the dispenser annd the h2 storage

If a FCH vehicle is connected to the refueling station, disconnect it and move it away.

if a H2 trailer is connected to the refueling station storage, close the valves between the trailer and the storage and apply simultaneaously the tactic related to trailers

Prevent H2 to accumulate in enclosed premises

DO NOT:

- cut or crush H2 lines
- cut or crush High Voltage Lines
- damage H2 tank

FINAL INSPECTION

After a last H2 atmospheric control,

Make sure that before restart, the refuelling station will be checked be authorised personnell and the malfuction and damages repaired.

23.3.Fire

	REFUELLING STATION	
Tactic n° 15	FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY
choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if available use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :
ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:
BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- Has a leak occured? Is a leak still occuring?
- Has a loud hissing sound been heard before the FR arrive?
- Is a vehicle connected to the refueling station? (if yes, apply related tactic)
- Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers.)
- operate H2 detector

Demand extra support if necessary

Were emergency shutdown devices of the refuelling station activated?

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate passengers in opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- Evacuate adjacent buildings
- Prevent the fire from spreading to a uninvolved vehicle(s) or building(s)
- move ajacent non involved vehicles by any way possible (driving, towing, pushing)
- Push Emergency shutdown devices on the dispenser and the storage.
- close the valves between the storage area and the dispenser.

INCIDENT TREATMENT

Two cases are possible:

The fire concerns the dispenser area.

- Push Emergency shutdown devices
- prevent the fire to spread to a uninvoved part of the refuelling station with water spray curtains.
- put the fire out.

The fire concerns the storage area (high stakes level situation)

- Push Emergency shutdown devices
- prevent the fire to spread to a uninvoved part of the refuelling station with water spray curtains.
- put the fire out.

If the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

Previously, the incident commander must have taken appropriate actions to prevent pressure increase in the tanks and checked the efficiency.

Operate an offensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire.

Mind that H2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.

Mind that violent reactions are possible between water and burning materials

Mind that water will be polluted during extinction

operate its containement.

FINAL INSPECTION

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- Repeatedly check H2 presence in the atmosphere.

23.4. External fire threatening the application

	REFUELLING STATION	
Tactic n° 16	EXTERNAL FIRE THREATENING THE APPLICATION	Hy Responder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)
- Ensure that unauthorised/untrained personnel do not enter the hazardous area

Refuelling station
External fire

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- witch part of the application is concerned by the incident? (dispenser, storage, electrical equipment...)
- Has a leak occured? Is a leak still occuring?
- What is burning?
- What's the fire Strength?
- What's the distance between the Fire and the refuelling station?
- The station manager may be able to provide accurate information

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : stretch a fire hoseline to protect the action of the Team 1

Evacuate people in the opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the reffuelling station.

INCIDENT TREATMENT

Operate an defensive Fire attack:
each Team prepare 80 m of hoselines directly connected to the fire equipment pump

- Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and therefuelling station.
- Team 2 : Put out the fire with water, foam or powder depending what is burning.

Mind that a refuelling station storage is equiped with a pressure release device . A H2 leak may occur if the storage is submitted to a high temperature flux.

FINAL INSPECTION

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- Repeatedly check H2 presence in the atmosphere

24. STATIONARY POWER GENERATION UNIT

24.1.No leak, No Fire

	Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)	
Tactic n° 17	NO LEAK NO FIRE (technical alarm)	Hy Responder
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location and the concerned power
- is this stationary power generation unit known by the fire service?
- Does a firefighting plan exists? take it in the fire equipment and read it on the road.
- witch part of the installation is involed in the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- are there any persons involved in the incident?
- what happened?
- Investigate the presence of hydrants inside and around the unit

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if available use drone UAV – use ATEX device):

- Gaseous hydrocarbon dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipment including breathing apparatus

Stationary power generation unit
No leak no fire

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire truck between 50 and 100 meters (55 - 110 yd) before the incident.
- If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine
- away from a possible ignited flammable liquid leak progression (safety distance)
- Approach objects taking into account possible ignition of leaking H2.
- Engage the pump and connect the fire truck to a hydrant.
- Deploy and arm a hose-line for safety or for a primary attack

SAFETY AREA

if H2/O2 storage is concerned:

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

- Set up a safety area for the public beyond a radius of twice the height of the wind turbine

if fuel cell or electrical devices is concerned:

- Set up a safety area for the public between a radius of 50 and 100 meters (55 - 110 yd)

Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind turbine...)
- Has a leak occurred? Is a leak still occurring? Which ones?
- is the system delivering electricity? If so, what is the power produced ?
- Is a technician present on the plant area?
- Check for possibility H2 in confined spaces
- look for the emergency fire and rescue plan.
- locate dangerous areas, Emergency shutdown devices and valves.
- evaluate the amount of compressed gases present in the tanks.

Demand extra support if necessary

Stationary power generation unit
No leak no fire

RESCUE

- Engage rescue as a conventional accident
- Human rescue overrides all other considerations.
- To reach safely a casualty, it is necessary to verify that he's not submitted to an electrical current.
- Push Emergency shutdown devices, take fallen cables away with appropriate high voltage electrical equipment (gloves and boots)

EXPOSURE PROTECTION

- Push Emergency shutdown devices of the concerned area
- Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storages (each one from the others).
- Check and note every ESD or valve turned off on the emergency plan.
- Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.

INCIDENT TREATMENT

If no H2 leak and no sign of fire is detected :

- Finalize and settle the incident.

DO NOT:

- cut or crush H2/O2 lines
- cut or crush High Voltage Lines (orange)
- damage H2/O2 tank

If a H2 leak is detected, apply tactic n°2 "H2 LEAK WITHOUT FIRE"

Mind that Photovoltaic panels still produce high voltage electricity when exposed to ~~daylight~~ different type of light.

FINAL INSPECTION

After a last H2 atmospheric control, make sure that the unit will be checked by authorised personnel before restart.

24.2.H2 Leak without fire

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 18	H2 LEAK WITHOUT FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- Assure the precise incident location and the concerned power
- Is this stationary power generation unit known by the fire service?
- Does a firefighting plan exists? take it in the fire equipment and read it on the road.
- Whichmpart of the application is involved in the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Are there any persons involved in the incident?
- What happened?
- Investigate the presence of hydrants inside and around the unit

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if available use drone UAV – use ATEX device):

- Gaseous hydrocarbon dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipment including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident away from a possible ignited flammable liquid leak progression.
- If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine
- Approach objects taking into account possible ignition of leaking H2.

- Engage the pump and connect the fire truck to a hydrant.
- Deploy and arm a hose-line for safety or for a primary attack

SAFETY AREA

if H_2/O_2 storage is concerned:

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

- Set up a safety area for the public beyond a radius of twice the height of the wind turbine

if fuel cell or electrical devices is concerned:

- Set up a safety area for the public between a radius of 50 and 100 meters (55 - 110 yd)

Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- which part of the application is concerned by the incident? (Fuel cell, H_2/O_2 storage, ...)
- Has a leak occurred? Is a leak still occurring?
- is the system delivering electricity?
- Is a technician present on the plant area?
- Check for possibility H_2 in confined spaces
- look for the emergency fire and rescue plan.
- locate dangerous areas, Emergency shutdown devices and valves.
- evaluate the amount of compressed gases present in the tanks.

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations.
If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : Protect the action of Team 1 with the armed hose-line

Evacuate passengers in opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

Note that a SPGU is supposed to produce electricity as soon as it is no longer supplied by the electrical network. So it is necessary to stop the electrical production of the SPGU before any other action by Pushing Emergency shutdown devices.

- Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storage (each one from the others).

- Check and note every ESD or valve turned off on the emergency plan.
- Repeatedly check H_2 presence in the atmosphere.

INCIDENT TREATMENT

If no H_2 leak and no sign of fire is detected :

- Finalise and settle the incident.

DO NOT:

- cut or crush H_2/O_2 lines
- cut or crush High Voltage Lines (orange)
- damage H_2/O_2 tank

Fire services are not supposed to open the Fuel Cell compartment.

Locate precisely the H_2 leak

- if located in an building, operate a wide ventilation of all concerned premises.
- according to information provided by the emergency plans and the validation of the thechnicans (if available), close appropriate valves, ESD.

- Repeatedly check H_2 presence in the atmosphere.

- Mind that Photovoltaic panels still produce high voltage electricity when exposed to daylight.
- Mind that H_2 and O_2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.

FINAL INSPECTION

After a last H_2 atmospheric control, make sure that the unit will be checked be authorised personnel before restart.

24.3.Fire

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 19	FIRE	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location and the concerned power
- is this stationary power generation unit known by the fire service?
- Does a firefighting plan exists? take it in the fire equipment and read it on the road.
- which part of the application is involved? (FC, H2/O2 storage, photovoltaic panels, wind tubine)
- are there any persons involved in the incident?
- what happened?
- Investigate the presence of hydrants inside and around the unit

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY
choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below (if possible arrive downwind)
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbon dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipment including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident, away from a possible ignited flammable liquid leak progression.
- If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine. Realise a complete check of the environment with termal image camera.
- Approach objects taking into account possible ignition of leaking H2.
- Engage the pump and connect the fire truck to a hydrant.

- Deploy and arm a hose-line for safety or for a primary attack

SAFETY AREA

if H2/O2 storage is concerned:

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

- Set up a safety area for the public beyond a radius of twice the height of the wind turbine .

if fuel cell or electrical devices is concerned:

- Set up a safety area for the public between a radius of 50 and 100 meters (55 - 110 yd)

Ensure that unauthorised/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

BY QUESTIONING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- which part of is concerned by the incident? (FC, H2/O2 storage, photovoltaic panels, wind tubine...)
- Has a leak occurred? Is a leak still occurring?Which ones?
- is the system delivering electricity?
- Is a technician present on the plant area?
- Check for possibility H2 in confined spaces
- look for the emergency fire and rescue plan.
- locate dangerous areas, Emergency shutdown devices and valves.
- evaluate the amount of compressed gases present in the tanks.

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : Protect the action of Team 1 with the armed fire hose-line

evacuate passengers in opposite direction of the wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- evacuate adjacent buildings
- Prevent the fire from spreading to uninvolved buildings

note a SPGU is supposed to produce electricity as soon as it is no longer supplied by the electrical network. It is necessary to stop SPGU electrical production before any other action by Pushing Emergency shutdown devices.

- Isolate (pressure, gas supply, electricity) energy production unit, FC and storage (each one from the others).
- Check and note every ESD or valve turned off on the emergency plan.

- Repeatedly check H2 presence in the atmosphere.

INCIDENT TREATMENT

3 cases are possible if a stake is identified

The fire concerns the photovoltaic panels or wind turbine area.
- Push Emergency shutdown devices
- prevent the fire to spread to a uninvolved part of the plant with water spray curtains.
- put the fire out.

the fire concerns the Fuel cell Compartment.
- Push Emergency shutdown devices
- prevent the fire to spread to a uninvolved part of the plant with water spray curtains.
- do not open the FC compartment.

the fire concerns the storage area (high stakes level situation)
- Push Emergency shutdown devices
- prevent the fire to spread to a uninvolved part of the plant with water spray curtains.
- put the fire out with an offensive Fire attack:
- each Team prepare 80 m of hoselines directly connected to the fire truck
- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extinguish the fire.

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

The primary action of the incident commander is to prevent pressure increase in the tanks, he checks the efficacy of the cooling.

- Mind that H2 storages are equipped with Pressure release devices that may open and close several times depending on the pressure inside the tank.
- Mind that violent reactions are possible between water and burning materials
- Mind that water will be polluted during extinction
- Try to contain polluted water

If there is no identified stake:
Consider if it is safe to let the unit burn, take necessary precautions

FINAL INSPECTION

Cool the unit as soon as a heat point is detected by the thermal imaging device.
Repeatedly check H2 presence in the atmosphere.
Take necessary precautions to prevent reigniting : establish regular monitoring of the unit (fire guard)

24.4.External Fire threatening the unit

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 20	EXTERNAL FIRE THREATENING THE UNIT	HyResponder

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location and the concerned power
- is this stationary power generation unit known by the fire service?
- Does a firefighting plan exists? take it in the fire equipment and read it on the road.
- which part of the application is involved> (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- are there any person involved in the incident?
- what happened?
- Investigate the presence of hydrants inside and around the unit

WEATHER CONDITIONS

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from below
- anticipate the need of a hydrant

TAKE the FOLLOWING TOOLS (if availble use drone UAV – use ATEX device):

- Gaseous hydrocarbon dectector,
- H2 detector
- O2 detector
- Thermal imaging camera
- Wear fully protective equipment including breathing apparatus

ARRIVAL ON SCENE

ARRIVAL :

- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment between 50 and 100 meters (55 - 110 yd) before the incident, away from a possible ignited flammable liquid leak progression.
- If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine
- Approach objects taking into account possible ignition of leaking H2.
- Engage the pump and connect the fire truck to a hydrant.

- Deploy and arm a hose-line for safety or for a primary attack

SAFETY AREA

if H2/O2 storage is concerned:

- Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

- Set up a safety area for the public beyond a radius of twice the height of the wind turbine .

if fuel cell or electrical devices is concerned:

- Set up a safety area for the public between a radius of 50 and 100 meters (55 - 110 yd)
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

- Is someone injured? Threatened?
- what has happened?
- witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Has a leak occured? Is a leak still occuring?
- is the system delivering electricity?
- Is a technician present on the plant area?
- Check for possibility H2 in confined spaces
- look for the mergency fire and rescue plan.
- locate dangerous areas, Emergency shutdown devices and valves.
- evaluate the amount of compressed gases present in the tanks.

Demand extra support if necessary

RESCUE

Human rescue overrides all other considerations.

Be equiped with PBE.

If a human is threatened or concerned by the Fire :

- Team 1 : extract the victim(s) from the danger zone by any possible means
- Team 2 : Protect the action of Team 1 with the armed hose-line

evacuate the passengers in opposite direction of wind (or in worst case as far as possible in the direction of wind).

EXPOSURE PROTECTION

- evacuate adjacent buildings
- Prevent the fire from spreading to uninvolved buildings

Note that a SPGU is produces electricity as soon as it is no longer supplied by the electrical network. It is necessary to stop the electrical production of the SPGU before any other action by Pushing Emergency shutdown devices.

- Isolate (pressure, gas supply, electricity) energy production unit, FC and storage (each one from the others).

- Check and note every ESD or valve turned off on the emergency plan.
- Repeatedly check H2 presence in the atmosphere.

INCIDENT TREATMENT

2 cases are possible:

The fire threats the Fuel cell Compartment, the photovoltaic panels or wind turbine area.

- Push Emergency shutdown devices
- prevent the fire to spread to a uninvolved part of the plant with water spray curtains.
- put the fire out.
- do not open the FC comparment.

the fire concerns the storage area (high stakes level situation)

- Push Emergency shutdown devices
- prevent the fire to spread to a uninvolved part of the plant with water spray curtains.
- put the fire out with an offensive Fire attack:
- each Team prepare 80 m of hoselines directly connected to the fire equipment pump
- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire.

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

The primary action of the incident commander is to prevent pressure increase in the tanks, he checks the efficacy of the cooling.

- Mind that H2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.
- Mind that violent reactions are possible between water and burning materials
- Mind that water will be polluted during extinction
- Try to contain polluted water

IF there is no identified stake:. Consider if it is safe to let the unit burn, take necessary precautions

FINAL INSPECTION

- Cool the unit as soon as a heat point is detected by the thermal imaging device.
- Repeatedly check H2 presence in the atmosphere.
- Take necessary precautions to prevent reigniting : establish a regular monitoring of the unit (fire guard)

Figure 59 : Main electrical Emergency Shutdown © Areva/ENSOSP 2015

Figure 60 : Example of emergency plan (1) ©areva

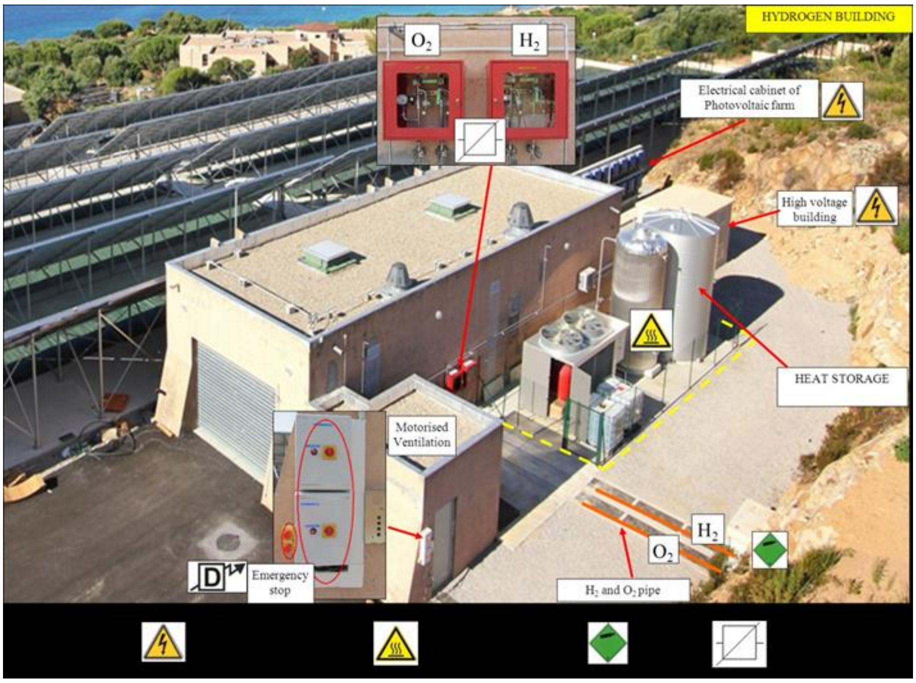


Figure 61 : Example of emergency plan (2) ©areva

Stationary power generation unit External Fire

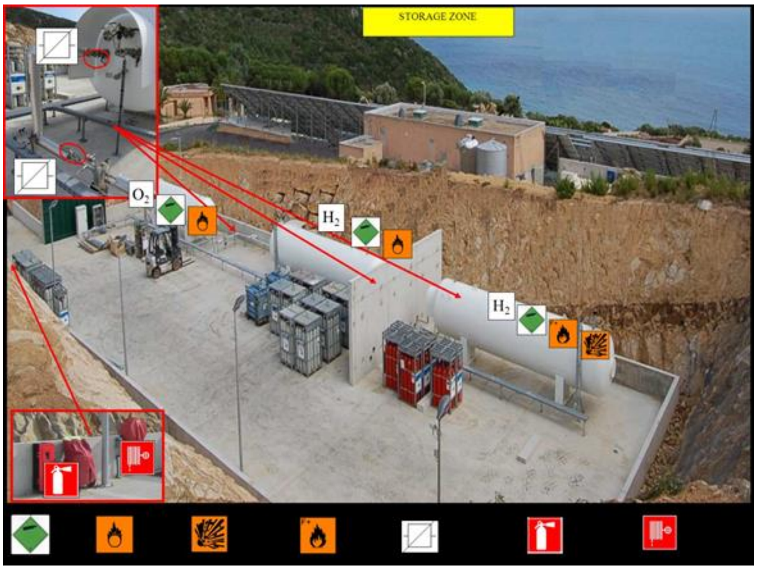


Figure 62 : Example of emergency plan (3) ©areva

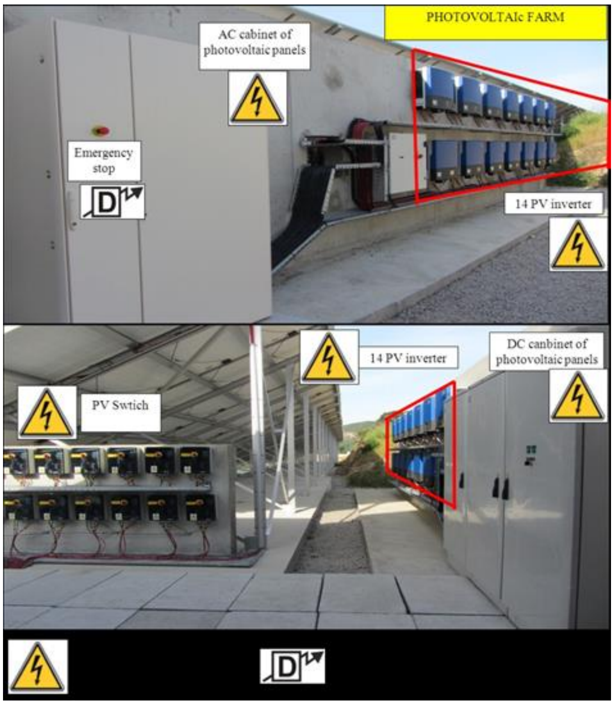


Figure 63 : Example of emergency plan (4) ©areva

Stationary power generation unit
External Fire

Figure 64 : Areva backup System global view ©AREVA/ENSOSP 2015

Figure 65 : Areva backup System (fuel cell compartment) ©AREVA/ENSOSP 2015

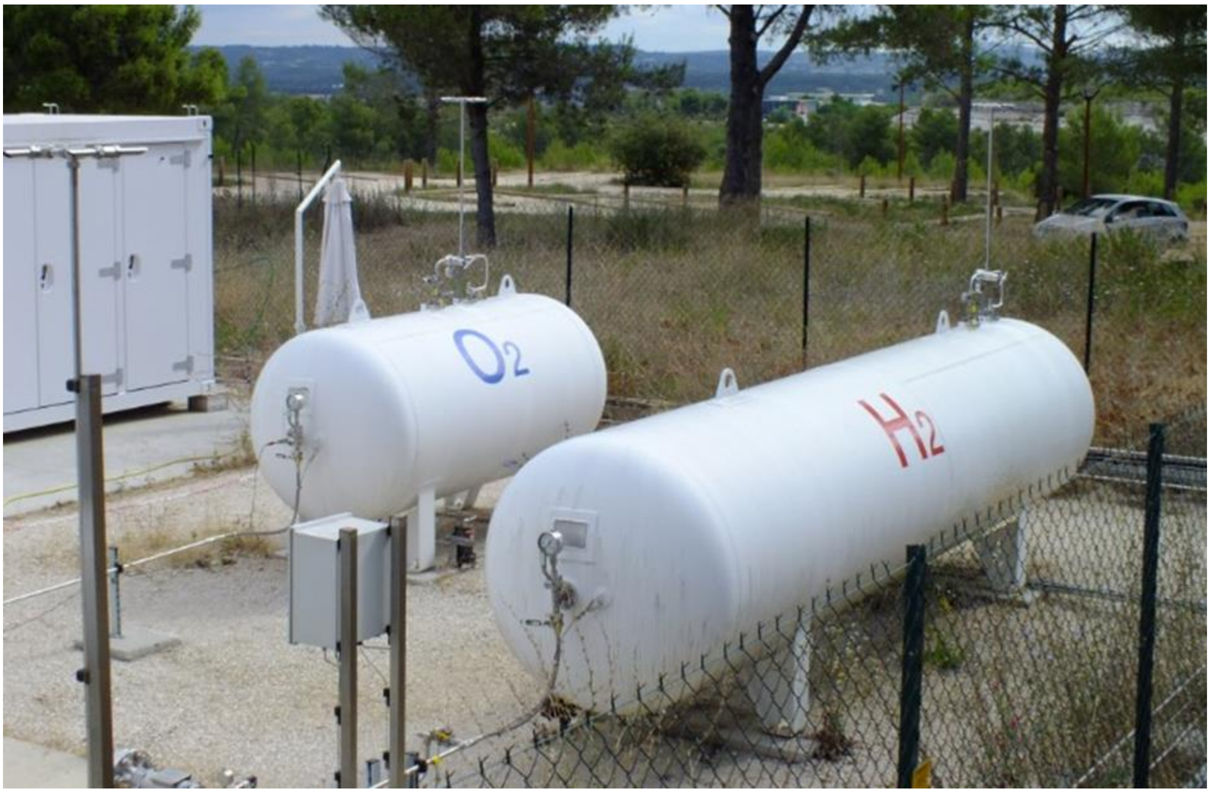


Figure 66 : Areva backup System (H2 and O2 storages) ©AREVA/ENSOSP 2015

Figure 67 : Areva backup System (pressure release devices) ©AREVA/ENSOSP 2015

Figure 68 : Areva backup System (pressure release device detail) ©AREVA/ENSOSP 2015

Figure 69 : Figure 35Areva backup System (H2 and O2 network detail with valves) ©AREVA/ENSOSP 2015

Figure 70 : Emergency shutdown and h2/o2 valves on an AREVA green box ©AREVA/ENSOSP 2015

APPENDICES (UU)

Appendix 1. Informative hazard distances for non-reacting hydrogen jets

The nomogram for graphical evaluation of hydrogen concentration decay in a momentum-dominated hydrogen jet based on the similarity law and the under-expanded jet theory without losses is shown in Figure A1.1 [5]. The nomogram consists of four main graphs entitled: “Volumetric to mass fraction”, “The similarity law”, “Choose leak diameter”, and “Choose density in the nozzle exit”, and one additional graph “Calculate density in the nozzle exit by storage tank pressure and temperature” (based on calculations by the under-expanded jet theory without losses).

The use of the nomogram for the calculation of the distance from the nozzle (for example 1 mm in diameter) to the 4 vol. % of hydrogen in air (blue-coloured dash line) along the axis of the release from a storage tank at a pressure of 70 MPa and temperature 300 K is demonstrated below.

1. Draw the vertical line downward from the point on the horizontal axis “Hydrogen volumetric fraction”, corresponding to the concentration of interest (4 vol. % or 0.04), until the intersection with the line of the graph “Volumetric to mass fraction” (left-hand, top corner on Figure A1.1).
2. Draw the horizontal line from this intersection point to the intersection with the similarity law line on the right-hand top corner graph “The similarity law” (Figure A1.1).
3. Draw the vertical line downward from the intersection point obtained on “The similarity law” graph until the intersection with line corresponding to 1 mm diameter on the graph “Choose leak diameter” (Figure 1). Please note that there are eight lines on the “Choose leak diameter” graph, which correspond to the following leak diameters (from top to bottom): 15 mm, 10 mm, 5 mm, 3 mm, 2 mm, 1 mm, 0.5 mm, 0.1 mm). These figures are shown at the right side of the graph.
4. Calculate the density using the additional graph “Calculate density in the nozzle exit by storage tank pressure and temperature” located at the bottom of the nomogram using given pressure (70 MPa) on the ordinate axis and a line corresponding to the chosen temperature (300 K). This is shown by two thick grey arrows on the “Calculate density in the nozzle exit by storage tank pressure and temperature” graph. The density calculated graphically at the nozzle exit for 70 MPa and 300 K is about 23 kg/m^3.
5. Draw the horizontal line from the intersection point on “1 mm” line obtained of the “Choose leak diameter” graph to the left-hand graph entitled “Choose density in the nozzle exit” until the intersection with an imaginary line corresponding to 23 kg/m^3 (located between two lines, 20 kg/m^3 and 50 kg/m^3, shown on the graph). Please note that there are five lines at the graph corresponding to the densities of 1 kg/m^3, 3 kg/m^3, 10 kg/m^3, 20 kg/m^3, and 50 kg/m^3 from top to bottom, respectively. These values are shown at the left side of the graph.

6. Draw the vertical line downward from the intersection point with the imaginary line corresponding to 23 kg/m^3 to the intersection with the abscissa axis ‘Distance to concentration of interest’ on the “Choose density in the nozzle exit” graph. Thus, the calculated graphically distance from the nozzle exit to hydrogen concentration of 4% by volume is about 7.7 m.

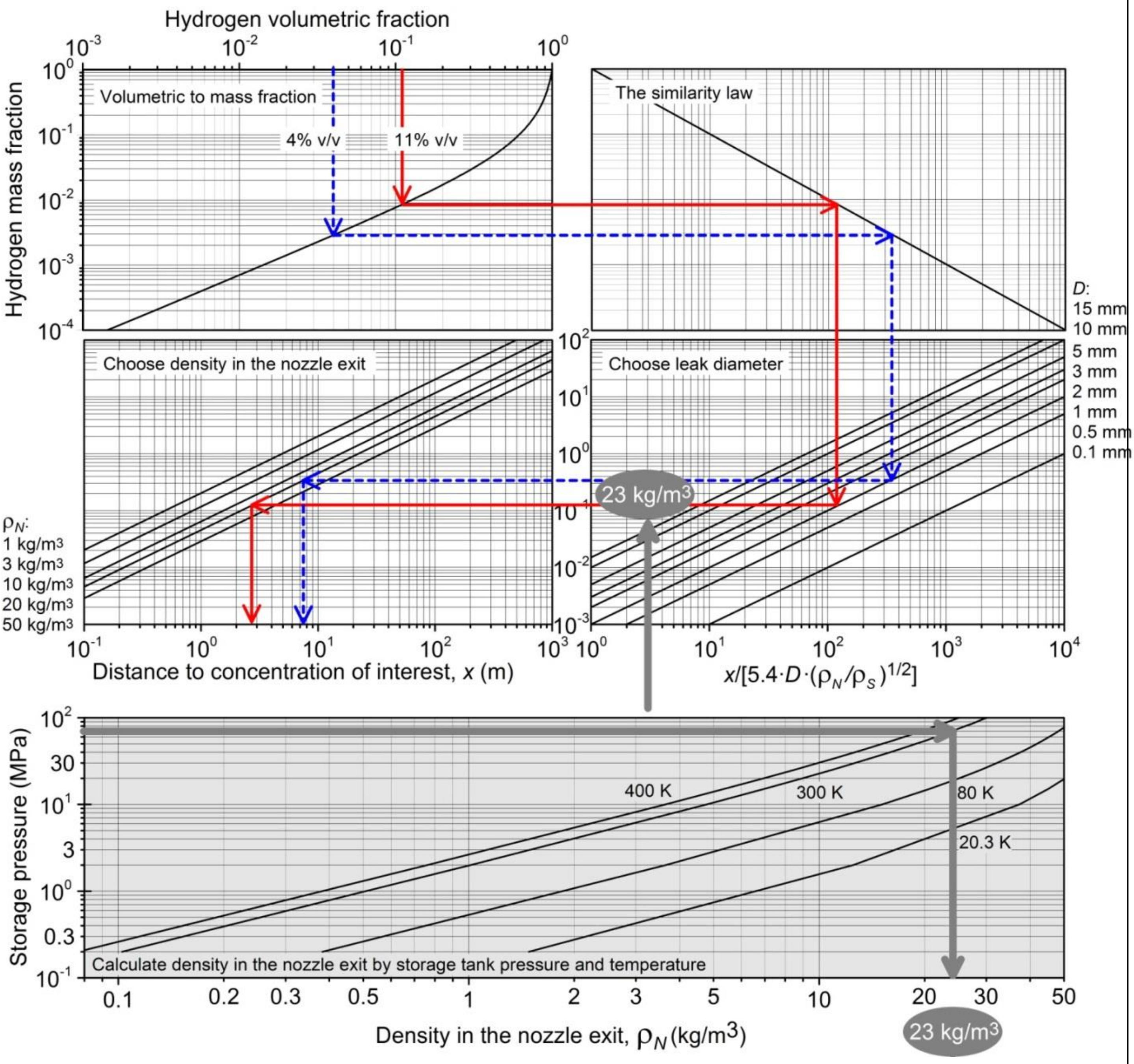


Figure A1.1. The nomogram for concentration decay calculation in unignited jets [5].

The use of the equation (2) for the similarity law with more accurate value of hydrogen density at the nozzle calculated by the under-expanded jet theory (23.95 kg/m^3) and air density of 1.205 kg/m^3 (NTP) gives 8.36 m for 4 vol. % of hydrogen in air. The error of graphical calculations is at the acceptable level and below 10%.

Appendix 2. Informative hazard distances for hydrogen jet fires

The parameters needed to predict the flame length using the nomogram in Figure A2.1 [5] are those at the actual nozzle exit only. This means that calculation of flow parameters at the notional nozzle exit is not required.

The dimensionless flame length, L_F/d increases for laminar and transitional to turbulent regime flames (traditional buoyancy-controlled jet flame regime), then it is practically constant for transitional and fully developed turbulent expanded flames (traditional momentum-dominated jet flame regime) and finally it increases again for under-expanded jets (under-expanded momentum-dominated jet flame regime). To use the last part of the curve, the application of the under-expanded jet model is required.

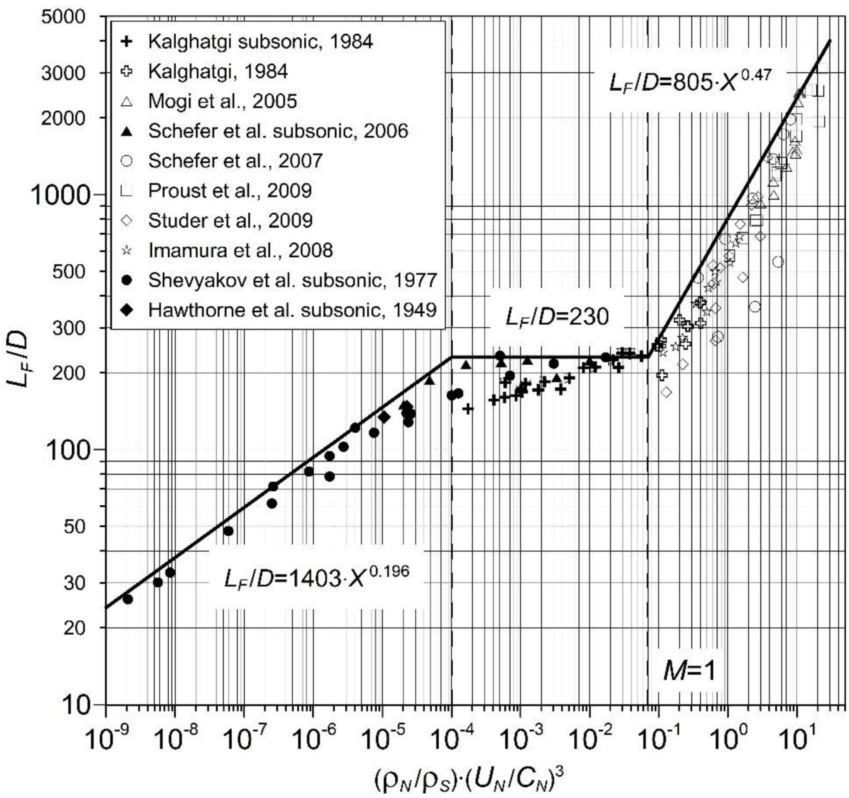


Figure A2.1. The dimensionless correlation for the flame length [5].

In Figure A2.1:

Y-axis: L_f/d_n where L_f - flame length, m; d_n – real nozzle diameter, m.

X-axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ where

- ρ_N - the density at the nozzle exit, can be found for under-expanded jets using the under-expanded-jet theory [5] or lower graph in the nomogram in Figure A1.1; and for expanded jets is equal to 0.0838 kg/m^3 at NTP,
- lρ_S – the density of the surrounding air, equal to 1.205 kg/m^3 for air at NTP,

- C_N - the speed of sound in hydrogen at the nozzle exit parameters, U_N - the velocity of the hydrogen at the jet exit, $U_N = C_N$ for sonic and supersonic jets. For subsonic jets:

$$U_N = \sqrt{2\frac{\Delta P}{\rho}}$$

The three hazard distances for jet fire are defined as follows (:

- "no harm": 70 °C for any duration (this hazard distance equal to 3.5 times the flame length $x=3.5\ L_f$);
- "pain" limit: 115 °C for 5 min exposure (this hazard distance equal to 3 times the flame length; $x=3L_f$);
- "fatality" limit: 309 °C, third degree burns for 20 seconds exposure (this hazard distance equal to 2 times the flame length $x=2L_f$).

Appendix 3. Informative hazard distances for catastrophic rupture of high-pressure hydrogen tank in a fire.

The methodology [13] allows hazard distances for humans and buildings from a rupture of high-pressure hydrogen tank in a fire (either stand-alone tank or onboard tank) to be determined. The methodology was applied to build the nomograms to graphically find hazard distances from stand-alone (Figure A3.1) and under-vehicle (Figure A3.2) tank rupture in a fire.

The temporary loss of hearing described by Baker et Al. [14] that occurs at overpressure above 1.35 kPa and impulses above 1 Pa·s will be considered as a threshold for “No harm” to humans. The thresholds for “injury” and “fatality” for humans and the thresholds for buildings were adopted from Mannan [15] are represented in Table 6 and 2.

Table 6. Thresholds of overpressures for humans harm (outdoors)

Effect	Overpressure, kPa
1% probability of eardrum rupture (chosen as “injury”)	16.5
1% probability of fatality-lung haemorrhage (chosen as “fatality”)	100

Table 7. Thresholds of overpressure for buildings damage

Damage	Overpressure, kPa
Minor damage of the house [3] (chosen as “minor damage”)	4.8
Partial demolition of the house-remains inhabitable [3](chosen as “partial demolition”)	6.9
Almost total destruction of the house [3] (chosen as “almost total destruction”)	34.5-48.3

The harm criteria for humans and buildings described above are used further in the nomograms for determination of the hazard distances from a rupture of stand-alone and under-vehicle high-pressure hydrogen tanks of different volume with different pressure.

RUPTURE OF A STAND-ALONE TANK IN A FIRE

Figure A3.71 represents two nomograms allowing to find the hazard distances from a stand-alone tank rupture in a fire to humans (of different severity, i.e., “no harm”, “injury” and “fatality”) and to

[13] V. Molkov and S. Kashkarov, “Blast wave from a high-pressure gas tank rupture in a fire: stand-alone and under-vehicle hydrogen tanks,” vol. 40, no. 36, pp. 12581–12603, 2015

[14] W. E. Baker, P. A. Cox, P. S. Westine, J. J. Kulesz, and R. A. Strehlow, Explosion hazards and evaluation. Elsevier Scientific Publishing Company, 1983

[15] S. Mannan, Lees’ Loss Prevention in the Process Industries, 3rd ed., vol. 1. Elsevier Butterworth-Heinemann, 2005

buildings (of different damage, i.e., “minor damage”, “partial demolition” and “almost total destruction”).

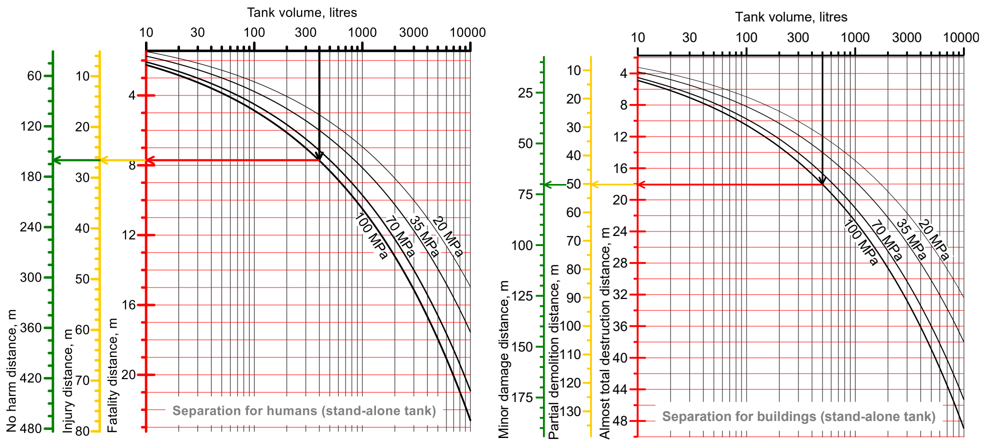


Figure A3.71. Nomograms for determination of hazard distances from stand-alone tank rupture: distances to humans (left) and distances to buildings (right).

One may use the nomogram as follows. For instance, in Figure A3.71 (left) let us choose the hydrogen tank volume of 500 L and internal tank pressure (see the curves) of 100 MPa (shown with black arrow). Then, for finding the “fatality” distance, the horizontal line is simply drawn towards the axes on the left (shown with red arrow). The first red axis gives the “fatality” distance (7.7 m). To find “injury” and “no harm” distances, the line should be simply extended to the yellow and green axes, respectively. For the case under consideration the injury distance is 26.5 m, and no harm distance is 160 m.

RUPTURE OF AN UNDER-VEHICLE TANK IN A FIRE

Figure A3.72 depicts two nomograms used for determination of hazard distances for under-vehicle tank rupture in a fire.

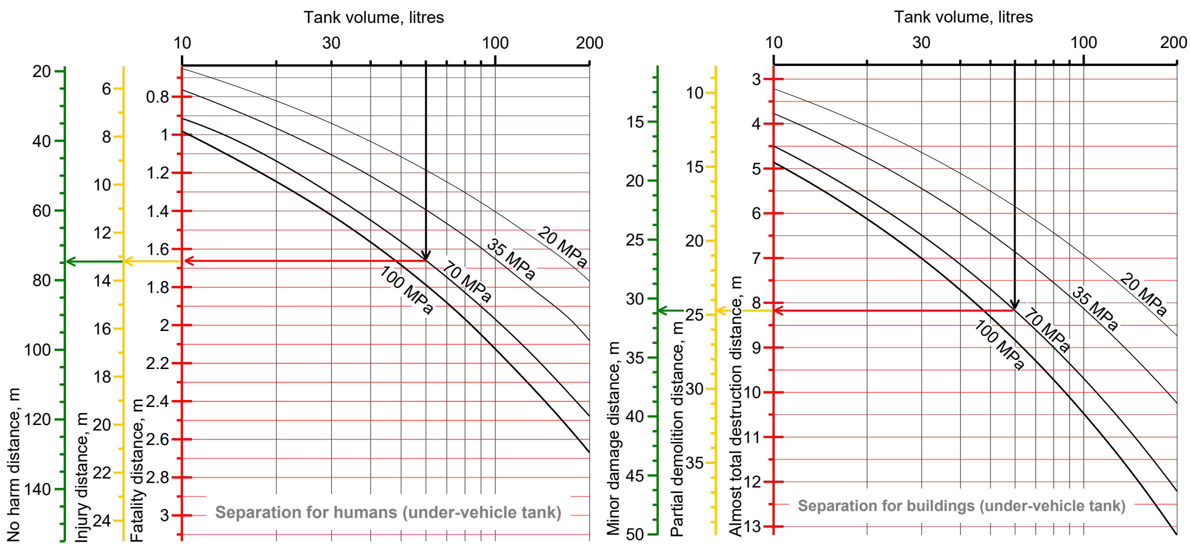


Figure A3.72. Nomograms for determination of hazard distances from under-vehicle tank rupture: distances to humans (left) and distances to buildings (right).

GLOSSARY

Accident is an unforeseen and unplanned event or circumstance

Acceptance criteria are terms of reference against which the performance of a design is assessed.

Blowdown is a process where the storage pressure decreases with time during a leak.

Consequences are expected effects from the realisation of the hazard and severity, usually measured in terms of life safety exposure, property damage and environmental impact.

Deflagration and **detonation** are propagation of a combustion zone at a velocity that is respectively less than and greater than the speed of sound in the unreacted mixture**.**

Deterministic study is a methodology, based on physical relationships derived from scientific theories and empirical results that, for a given set of initial conditions, will always produce the same outcome**.**

Emergency shutdown are control system actions, based on process parameters, taken to stop the fuel cell power system and all its reactions immediately to avoid equipment damage and/or personnel hazards [16].

First responder is an employee of an emergency service (e.g., fire-fighters, police, medical personnel), who is likely to arrive first to/assess a scene of an accident/incident.

Forced ventilation is a movement of air and its replacement with fresh air by mechanical means.

Flammability range is the range of concentrations between the lower and the upper flammability limits.

Fuel Cell (FC) is an electrochemical generator that produces electricity by the conversion of chemical energy into electrical. In the case of a hydrogen-fed FC, oxygen and hydrogen are combined to produce electricity, heat, and water. FC is made of two electrodes (positive (cathode) and negative (anode)) immersed in an electrolyte solution, which provides a transfer of the ions in both directions, while a corresponding flow of electrons in an external circuit provides electricity

Incident is something that occurs casually in connection with something else**.**

Lower flammability limit (LFL) is the lowest concentration and the **upper flammability limit** (UFL) is the highest concentration of a combustible substance in a gaseous oxidizer that will propagate a flame**.**

Natural ventilation is a movement of air and its replacement with fresh air because of wind and/or temperature gradients [17].

Minimum Ignition Energy (MIE) of flammable gases and vapours is the minimum value of the electric energy, stored in the discharge circuit with as small a loss in the leads as possible, which (upon discharge across a spark gap) just ignites the quiescent mixture in the most ignitable composition**.**

---

[16] IEC/TS 62282-1. International Electrotechnical Commission. Technical Specifications. Fuel cell technologies. Part 1: Terminology (2010). Edition 2. Geneva, Switzerland

[17]- IEC/TS 62282-1. International Electrotechnical Commission. Technical Specifications. Fuel cell technologies. Part 1: Terminology (2010). Edition 2. Geneva, Switzerland

Normal Temperature and Pressure (NTP) conditions are temperature 293.15 K and pressure 101.325 kPa.

Pressure Relief Device (PRD) is a safety device that protects against a failure of a storage vessel by releasing some or the entire tank content in the event of high temperatures, high pressures or a combination of both.

Probabilistic study is a systematic development of numerical estimates of the expected frequency and/or consequence of potential accidents**.**

Reforming is a process of producing a hydrogen-rich gas mixture from a raw fuel for eventual use in a fuel cell [18].

Risk is a combination of the probability of an event and its consequence**.**

Scenario is a set of circumstances, chosen as an example that defines the development of accident**.**

Hazard distance is a distance from the (source of) hazard to a determined (by physical or numerical modelling, or by a regulation) physical effect value (normally, thermal or pressure) that may lead to a harm condition (ranging from "no harm" to "max harm") to people, equipment, or environment [ISO19880-1].

Strategy is a stable notion decided at a political level, according to the risk sociological acceptance. Choosing a strategy to deal with a type of incident is tightly linked with the "Stakes assessment" notion [19] .

Tactic is a variable concept decided at an operational level, according to the situation available at the present moment and in a near future.

Thermally Activated Pressure Relief Device (TPRD) provides a controlled release of the GH_2 from a high-pressure storage container before its walls are weakened by high temperatures, leading to a catastrophic rupture.

Under-expanded jet is a jet with a pressure at the nozzle exit which is above atmospheric pressure**.**

---

[18] IEC/TS 62282-1. International Electrotechnical Commission. Technical Specifications. Fuel cell technologies. Part 1: Terminology (2010). Edition 2. Geneva, Switzerland

[19] TRETSIAKOVA-Mc NALLY, D. MAKAROV "Introduction to FCH applications and hydrogen safety" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Hydrogen properties relevant to safety" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Hydrogen fires" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Safety of hydrogen storage" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Harm criteria for people and environment, damage criteria for structures and equipment" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Unignited hydrogen releases, their prevention and mitigation" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Hazards of hydrogen use indoors" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Dealing with hydrogen explosions" Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV "Sources of hydrogen ignition and prevention measures" Ulster University Hyresponse Project 2015;A.ZANOTO et al. "Description of selected FCH systems and infrastructure, relevant safety features and concepts" AIR LIQUIDE, Hyresponse Project 2015;F.VERBECKE et al., "Detailed scenarios of typical accident for selected FCH systems and infrastructures" AREVA, Hyresponse Project 2015;S. BERTAU et al., "Operational emergency response strategies and tactic "Emergency Response approach" ENSOSP, Hyresponse Project 2015;S. BERTAU et al., "Elaboration of multi-level operational exercises" ENSOSP, Hyresponse Project 2015;E. MARANNE et al. "Virtual reality educational exercises" ENSOSP, Hyresponse Project 2015;M. GENTILLEAU et al. "Guide opérationnel départemental de référence d'intervention sur véhicules. " SDIS 86, 2015.

Water electrolysis is a process, in which water is split into hydrogen and oxygen using electrical energy [20].

[20] HyResponse Deliverable 2.1 Description of selected FCH systems and infrastructure, relevant safety features and concepts, 2015

REFERENCES

[1]V. Molkov and S. Kashkarov, “Blast wave from a high-pressure gas tank rupture in a fire: stand-alone and under-vehicle hydrogen tanks,” vol. 40, no. 36, pp. 12581–12603, 2015

[1]W. E. Baker, P. A. Cox, P. S. Westine, J. J. Kulesz, and R. A. Strehlow, Explosion hazards and evaluation. Elsevier Scientific Publishing Company, 1983

[1]S. Mannan, Lees’ Loss Prevention in the Process Industries, 3rd ed., vol. 1. Elsevier Butterworth-Heinemann, 2005

[1] IEC/TS 62282-1. International Electrotechnical Commission. Technical Specifications. Fuel cell technologies. Part 1: Terminology (2010). Edition 2. Geneva, Switzerland

[1] HyResponse Deliverable 2.1 Description of selected FCH systems and infrastructure, relevant safety features and concepts, 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Introduction to FCH applications and hydrogen safety” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hydrogen properties relevant to safety” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hydrogen fires” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Safety of hydrogen storage” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Harm criteria for people and environment, damage criteria for structures and equipment” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Unignited hydrogen releases, their prevention and mitigation” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hazards of hydrogen use indoors” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Dealing with hydrogen explosions” Ulster University Hyresponse Project 2015;TRETSIAKOVA-Mc NALLY, D. MAKAROV “Sources of hydrogen ignition and prevention measures” Ulster University Hyresponse Project 2015;A.ZANOTO *et al.* “Description of selected FCH systems and infrastructure, relevant safety features and concepts” AIR LIQUIDE, Hyresponse Project 2015;F.VERBECKE *et al.,* “Detailed scenarios of typical accident for selected FCH systems and infrastructures” AREVA, Hyresponse Project 2015;S. BERTAU *et al.*, “Operational emergency response strategies and tactic “Emergency Response approach” ENSOSP, Hyresponse Project 2015;S. BERTAU *et al.,* “Elaboration of multi-level operational exercises” ENSOSP, Hyresponse Project 2015;E. MARANNE *et al.* “Virtual reality educational exercises” ENSOSP, Hyresponse Project 2015;M. GENTILLEAU et al. “Guide opérationnel départemental de référence d'intervention sur véhicules. “ SDIS 86, 2015.

TABLE OF ILLUSTRATIONS

TABLE OF CONTENTS

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Introduction to FCH applications and hydrogen safety” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hydrogen properties relevant to safety” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hydrogen fires” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Safety of hydrogen storage” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Harm criteria for people and environment, damage criteria for structures and equipment” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Unignited hydrogen releases, their prevention and mitigation” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Hazards of hydrogen use indoors” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Dealing with hydrogen explosions” Ulster University Hyresponse Project 2015

TRETSIAKOVA-Mc NALLY, D. MAKAROV “Sources of hydrogen ignition and prevention measures” Ulster University Hyresponse Project 2015

A.ZANOTO *et al.* “Description of selected FCH systems and infrastructure, relevant safety features and concepts” AIR LIQUIDE, Hyresponse Project 2015

F.VERBECKE *et al.,* “Detailed scenarios of typical accident for selected FCH systems and infrastructures” AREVA, Hyresponse Project 2015

S. BERTAU *et al.*, “Operational emergency response strategies and tactic “Emergency Response approach” ENSOSP, Hyresponse Project 2015

S. BERTAU *et al.,* “Elaboration of multi-level operational exercises” ENSOSP, Hyresponse Project 2015

E. MARANNE *et al.* “Virtual reality educational exercises” ENSOSP, Hyresponse Project 2015

M. GENTILLEAU et al. “Guide opérationnel départemental de référence d'intervention sur véhicules. “ SDIS 86, 2015.