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Deliverable 1.3
Account of scenarios and operational emergency planning and response strategies and tactics

Lead authors: ENSOSP (Laurent LECOMTE)
Contributing authors: ENSOSP (Franck VERRIEST and Wilfried STÉFIC), AL (Deborah HOUSSIN), UU (Sile BRENNAN)

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FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

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FUEL CELLS AND HYDROGEN
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Summary

This deliverable outlines the scenarios and intervention strategies relevant to responders dealing with hydrogen safety incidents.

Scenarios were identified for vehicles, refuelling stations and storage installations, and stationary fuel cell installations. The emphasis within HyResponse where loss of containment is considered has been on gaseous hydrogen. These previously identified scenarios, intervention tactics and strategies were updated where appropriate, based on the outputs of tasks 1.1 (cf. D1.1 HyResponder document) and 1.2 and the experience gained at ENSOSP through the use and promotion of the existing operational training platform since 2016. Update of the existing scenarios, intervention tactics and strategies was carried out by ENSOSP with input from UU and AL.

In addition, new emergency scenarios involving LH_2 have been introduced, and intervention tactics and strategies identified. AL and UU worked with ENSOSP to define potential LH_2 accident scenarios. AL provided input from an industrial perspective on the potential technologies and incidents and both UU and AL provided technical input on the likely consequences. ENSOSP led the risk and hazard analysis, assisted with identification of potential hazards, and proposed intervention tactics and strategies.

Keywords

Gaseous and liquid hydrogen, risk, accidental scenarios, feared events, dangerous effects, hazardous distances, release, burst, deflagration, thermal effects, overpressure effects, spillage, flammable cloud, ignition, harm criteria, thresholds, intervention strategies

Table des matières

1. Methodology

Each Fuel Cell and Hydrogen application is considered in one chapter and each chapter is structured in the same way as described in the following subchapters below.

Projects are still underway, in particular on LH2, this deliverable will potentially have to be updated at the end of the HyResponder project.

1.1 Identification of hazardous phenomena

For each FCH application, the potential hazards that could have an impact on life, property or environment have been synthetized in a table. As showed in the Table 1, the hazardous equipment i.e. pipes, pressure storage and their related potential hazards are identified.

Table 1: Example of hazardous phenomena for gaseous stationary storages

Substance	Equipment of hazards	Potential of Hazard
Hydrogen	Tanks	Burst of a pressurized tank
Hydrogen	Pipes	UVCE (Unconfined Vapor Cloud Explosion) Jet Fire Flash Fire

1.2 Potential consequences

The severity of a hazardous phenomenon is characterized by its potential effects, themselves characterized by several threshold distances e.g. explosion overpressure threshold of 20 mbar reached at a distance of 5 m from the FCH application. Depending on the regulation in place locally, each country may use different values of thresholds or even parameters to characterize the potential effects of a hazardous phenomenon.

NOTE: it is not the intent of HyResponder project to provide harmonized harm criteria or thresholds to characterize the potential effects of a hazardous phenomenon (even though this is not explicitly foreseen by the DoA, one of the main targets of trainings is however harmonization and the project is in an ideal position to provide a decisive contribution to such harmonisation process. The project will make the best use of SAB members expertise to consider this opportunity and provide advice in this regard).

1.2.1 Blowdown time of pressurized tanks

The blow down time can be calculated using an engineering tool available within the HyResponder eLaboratory: https://hyresponder.eu/e-platform/e-laboratory/

1.2.2 Leak from FCH system

The envelops of the flammable limits from hydrogen jet release can be calculated using engineering tool available within the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/).

1.2.3 Thermal effects

The flame length and separation distances from jet fires can be calculated using engineering tools available within the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/)

Two examples are provided to characterize the potential effects of a hydrogen jet fire on a human. As shown in Table 2, the harm criteria for jet fire may be characterized as a function of the temperature degrees of the flame for a given exposure period (LaChance, 2010), while, as shown in Table 3, it may also be described as a function of the thermal flux per square meter (kW/m^2) or with a notion of time $(kW/m^2)^{4/3}s$.

Table 2: Harm criteria and corresponding separation distances for jet fire (LaChance, 2010)

Harm levels	"No harm" limit	"Pain" threshold	"Death" limit
Criteria	70℃ for any duration	115℃ for 5 min exposure	309℃ for 20 s exposure, causing third degree burn
Separation distances	3.5× F_L	3× F_L	2× F_L

Note: FL stands for Flame Length (m)

Table 3: Example of threshold effect values on humans

	Thresholds of thermal effects	
	kW/m^2	$(kW/m^2)^{4/3}s$
Irreversible effects	3	600
Lethal effects	5	1000
Significant lethal effects	8	1800

1.2.4 Overpressure effects

The overpressure effects from an explosion can be characterized by several thresholds depending on the target i.e. human or structures. The Table 4 and 5 provide an example of threshold effect values for human and constructions respectively.

- Effects on humans

Table 4: Example of threshold effect values on humans

	Thresholds of overpressure effects	
	mbar	kPa
Irreversible effects by indirect effects (glass breakage)	20	2
Irreversible effects	50	5
Lethal effects	140	14
Significant lethal effects	200	20

- Effects on construction

Table 5: Example of threshold effect values on structures

	Thresholds of overpressure effects	
	mbar	kPa
Significant destruction of windows	20	2
Light damage of structures	50	5
Important damage of structures	140	14
Domino effects	200	20
Prolonged exposition and very important damage of structures, except concrete	300	30

Several tools are provided in order to calculate overpressure effects from a pressurized tank burst.

2. Hydrogen dangers in emergency situations

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 liquid phase by cryogenically liquefaction. Its dangers are associated to its chemical and physical properties.

- **Asphyxiation**

Hydrogen can replace oxygen in the atmosphere and then cause asphyxiation by anoxia. The effects begin if oxygen rate is under 18% in the air (normal oxygen rate in the air is 20-21%)

- **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.

- **Noise**

Due to the high pressure needed for storage (350-700b), a gaseous hydrogen leak produces a noise that can reach 130-140 dB (first ear damages occur above 90dB and pain limit starts at 120 dB)

- **Embrittlement**

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

- **Cryogenics**

At ambient pressure, liquid hydrogen must be kept a 20.3°K (-252.85°C/-423.13ºF)

Direct skin contact with liquid or cold gaseous hydrogen causes instantaneous cold burns.

- **Combustion**

Hydrogen is highly flammable and explosive. Ignition range in air is 4-75% [% v/v] and the minimum ignition energy is 0.02 mJ.

In the air, the Hydrogen flame is only visible on 30% of its length.

3. TYPICAL SCENARIOS

3.1 FC H_2 CARS

3.1.1 Hazardous phenomena

At the time of writing there are no commercialized cars with on-board liquid hydrogen storage tanks.

Fuel cell electric vehicles are:

- purely fuel cell car with a 700-bar storage tank
- or electric vehicle with a H_2 range extender and a 350-bar storage tank

On-board tanks have a volume around 80 L (2 tanks) or 140 L, allowing to provide from 5 to 7 kg of H_2.

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

- Release from 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

Concerning pressure peaking, this phenomenon is observed for gases which are significantly lighter than air, which can result in overpressure exceeding enclosure or building structural strength limit in case of sufficiently high hydrogen release rate.
The enclosure can be strongly damaged up to its total destruction. Even if foreseeable, this phenomenon will be not assessed in this document, because it is considered as an

instantaneous phenomenon and thus not the main feared event for first responders. Actually, this event have already occurred when first responders intervene.

3.1.2 Potential consequences

3.1.2.1 Release without ignition

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

0.1- and 1-mm diameter releases can characterize an accidental leak due to a default of tightness on connections, equipment… and 2- and 4-mm diameter releases are more representative of a TPRD release.

These values are interesting in order 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.

E-laboratory tool was used to assess these blowdown duration from storage pressure to atmospheric pressure, considering the adiabatic approach and ambient temperature at 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

0.1- and 1-mm diameter releases can characterize an accidental leak due to a default of tightness on connections, equipment… and 2- and 4-mm diameter releases are more representative of a TPRD release.

3.1.2.2 Release with immediate ignition

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

Release flowrates were calculated with e-laboratory tool, (https://hyresponder.eu/e-platform/e-laboratory/) and horizontal jet fire characteristics and consequences are based on the Schefer approach.

Decrease of the flowrate is not taken into account; the maximal pressure is used. Thus hazardous 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	1.5·10^{-4} kg.s^{-1}	0.2 m	0.2 m	< 0.2 m	< 0.2 m
1 mm	350 bar	1.5·10^{-2} kg.s^{-1}	2.3 m	2.9 m	2.6 m	< 2.3 m
2 mm	350 bar	6.0·10^{-2} kg.s^{-1}	4.5 m	6.4 m	5.6 m	5 m
4 mm	350 bar	2.4·10^{-1} kg.s^{-1}	9.1 m	14 m	12 m	11 m
0.1 mm	700 bar	2.7·10^{-4} kg.s^{-1}	0.3 m	0.3 m	< 0.3 m	< 0.3 m
1 mm	700 bar	2.7·10^{-2} kg.s^{-1}	3 m	4 m	3.5 m	3.2 m
2 mm	700 bar	1.1·10^{-1} kg.s^{-1}	6.1 m	9 m	8 m	7 m
4 mm	700 bar	4.3·10^{-1} kg.s^{-1}	12 m	19 m	17 m	15 m

Another approach should be to use "harm criteria" for people described by LaChance (2010), proposed in e-laboratory tool and presented in Table 2. Corresponding values are given Table 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

3.1.2.3 Release with delayed ignition

For release with delayed ignition, an unconfined vapour 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 ignition point.

Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5; choice is done regarding hydrogen flowrate and considering the phenomenon in 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

3.1.2.4 Mechanical rupture of the storage tank

In order 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: 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

Hazardous distances are very close for a type-III storage tank.

3.2 FC GASEOUS H_2 BUSES, TRAINS AND TRUCKS

In this section buses, trains and trucks are treated together because very close in terms of design (e.g. storage pressure and volume, TPRD size and location etc.).

Up to now, existing fuel cell buses and trains have only gaseous hydrogen on-board tanks.

A recent communication of Daimler AG announced a LH_2 truck prototype - Mercedes Benz GenH2 Truck - for 2023. This case will be treated in the LH_2 plane and ship section.

3.2.1 Hazardous phenomena

As for FCEV, the main feared events are:

- Release from 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

Concerning TPRD, for FCEV the TPRD outlet is very close to the ground, compared to train and bus where TPRD outlet is - up to now - located on the roof. TPRD location is not completely clear for FC gaseous H_2 truck; it depends on the OEM.

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

Storage pressure is 350 bar with storage tanks of higher volume compared to FCEV. An evolution should be to increase the storage pressure up 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 it can be found from 5 to 10 cylinders for one bus or one train coach.

On-board H_2 is from 30 to 45 kg for buses, and can reach 180 kg for trains.

On-board LH_2 possibility is not actually under-development for buses and trains; that is the reason why only gaseous hydrogen risk is treated in this document. The risk associated with LH_2 trucks will be treated in a dedicated section with planes and ships.

3.2.2 Potential consequences

3.2.2.1 Release without ignition

The Table hereafter gives the blowdown duration for several tank volumes and different release diameters.

These values are interesting in order to assess the time required to totally empty the tank and evaluate the risk of tank burst in case of fire.

E-laboratory tool was used to assess these blowdown duration from storage pressure to atmospheric pressure, considering the adiabatic approach and ambient temperature at 15°C.

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

3.2.2.2 Release with immediate ignition

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

Pressures and diameters being the same as FCEV, distances corresponding to thermal effects for jet fires are given in Tables 7 and 8.

3.2.2.3 Release with delayed ignition

For release with delayed ignition, an unconfined vapour 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 ignition point.

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

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

3.2.2.4 Mechanical rupture of the storage tank

In order 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 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

Hazardous distances are very close for a type-III storage tank.

3.3 FC LH_2 TRUCKS, SHIPS AND PLANES

- **LH_2 trucks**

As previously said, existing fuel cell trucks have 350-bar gaseous hydrogen on-board tanks. In order to increase autonomy, development are led to integrate 700-bar gaseous hydrogen on-board tanks (e.g. Nikola). Autonomy is around 500-600 km.

However, recently (September 2020) Daimler truck AG announced the fuel-cell concept truck Mercedes-Benz GenH2 Truck using "subcooled" liquid hydrogen (at -243°C). In collaboration with Linde they plan for the first refuelling of a prototype vehicle at a pilot station in Germany in 2023. The targeted autonomy for such a truck is 1000 km.

Characteristics of LH_2 trucks are not clearly defined. That is the reason why the assumption of a 1-m^3 storage tank will be done, at 1-bar of storage pressure. It appears consistent regarding communicated targeted autonomy and assessed truck H_2 consumption.

- **LH_2 ships**

Liquid hydrogen provides more energy on board in the same space, when compared to compressed hydrogen or batteries.

Norled constructed the world's first ship to be powered by liquid hydrogen, with liquid on-board storage of 1-t H_2 (lower than 15 m^3 storage volume at 1 bar), and to be in operation in 2021.

Several projects are on-going considering liquid hydrogen on-board storage.

- **LH_2 planes**

As for ships, several projects are on-going considering liquid hydrogen on-board storage for planes, but still under-development.

Volumes of on-board liquid storage investigated are less than 500 L for this application (e.g. 289 L and 400 L for some on-going research projects).

3.3.1 Hazardous phenomena

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

- Liquid cryogenic release
  - unignited release: with cryogenic burns and/or 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 vaporization
- Mechanical rupture of the tank inducing a blast wave

3.3.2 Potential consequences

3.3.2.1 Release without ignition

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

Appropriate individual protection can protect the first responders against these damages.

3.3.2.2 Release with immediate ignition

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

Release flowrates were calculated with e-laboratory tool (the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/) applying Helmholtz free energy based equation of state, and horizontal jet fire characteristics and consequences are based on Schefer approach.

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

3.3.2.3 Release with delayed ignition

For release with delayed ignition, an unconfined vapour 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 ignition point.

Overpressure distances were calculated with the TNO Multi-Energy approach, considering a level 5; choice is done regarding hydrogen flowrate and considering the phenomenon in 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 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

3.3.2.4 Mechanical rupture of the storage tank

In order to evaluate maximum hazardous distances, an engulfing fire is considered on a stand-alone cryogenic tank (type I) at maximum working pressure.

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

3.4 FC H_2 FORKLIFTS

Forklift applications and infrastructures used gaseous hydrogen:

- at 200 bar for storage
- up to 1000 bar for intermediary storage in buffers
- at 350 bar in forklift on-board storage

Risks and hazardous distances were treated and presented in the HyReponse project and documents.

3.5 H_2 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.

Gaseous and liquid hydrogen will be treated in this section in separate sub-sections.

3.5.1 Gaseous hydrogen trailers and refuelling stations

For refuelling stations based on a gaseous hydrogen storage, in main cases the trailer is the storage of the station. "Swap" is operated; i.e. "full for empty" exchange.

The main trailers are composed of 200-bar steel tubes (i.e. type I vessels) of 2-m^3 each.

In order to increase capacity, new trailers are designed with type IV vessels of 350-L each, allowing to reach up to 700 bar of storage pressure.

3.5.1.1 Hazardous phenomena

Schemes hereafter present the main feared events for gaseous trailers and refuelling stations.

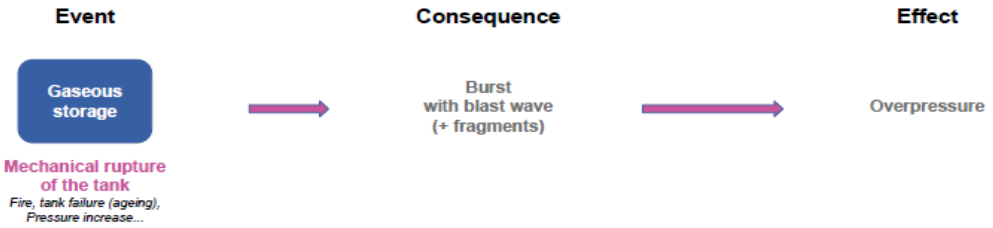

Figure 1: Feared events on storage or high pressure capacities

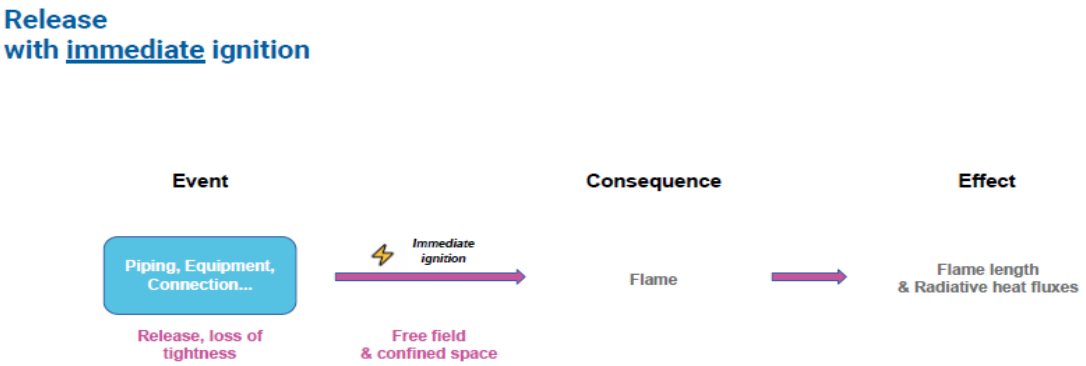

Figure 2: Feared events on connections or other leaking equipment with immediate ignition

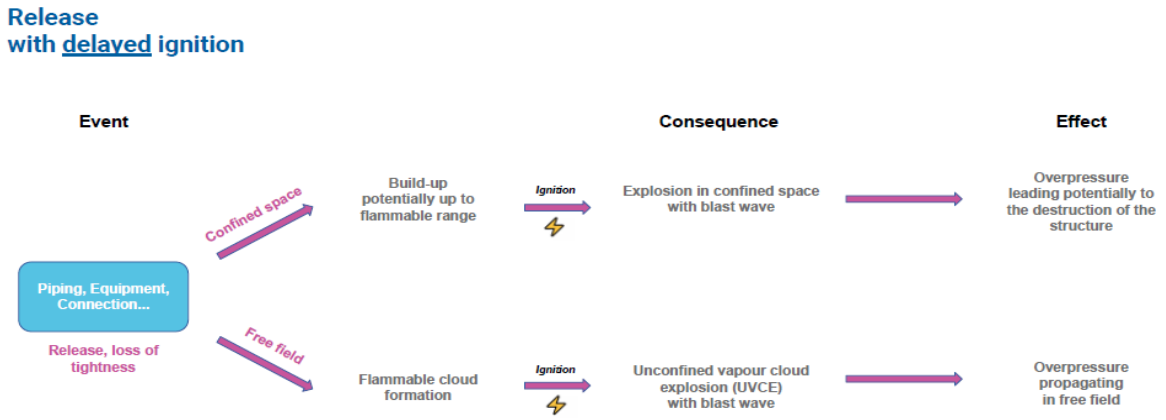

Figure 3: Feared events on connections or other leaking equipment with delayed ignition

3.5.1.2 Potential consequences

3.5.1.2.1 Release without ignition

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

An E-laboratory tool (the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/) was used to assess these blowdown durations from storage pressure to atmospheric pressure, considering the adiabatic approach and ambient temperature at 15°C.

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

1-mm diameter release can characterize an accidental leak due to a default of tightness on connections, equipment… and 2-, 4- and 6-mm diameter releases are more representative of a TPRD release.

3.5.1.2.2 Release with immediate ignition

Reference flowrate considered to carry out calculations is 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.

Thermal effects were calculated with Schefer approach.

Hazardous distances due to thermal effects of the jet fire are presented in the Table hereafter.

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

3.5.1.2.3 Release with delayed ignition

Reference flowrate considered to carry out calculations is 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.

Hazardous distances due to UVCE are presented in the Table hereafter.

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

3.5.1.2.4 Mechanical rupture of the storage

Two cases are investigated:

- type I vessels at 200 bar of working pressure,
- and type IV vessels at 700 bar of working pressure.

Hazardous distances are given in the Table hereafter.

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

3.5.2 Liquid hydrogen trailers and refuelling stations

3.5.2.1 Hazardous phenomena

Schemes hereafter present the main feared events for liquid trailers and refuelling stations.

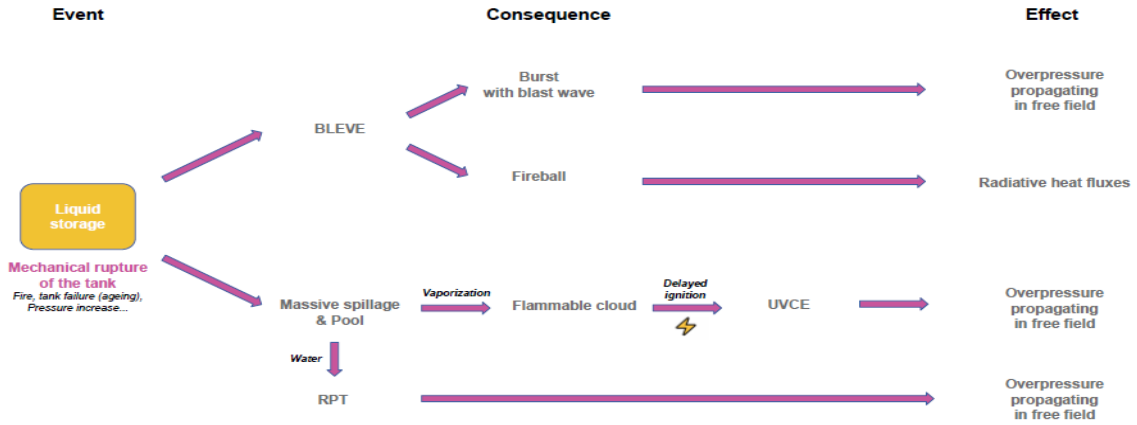

Figure 4: Feared events on storage or high pressure capacities

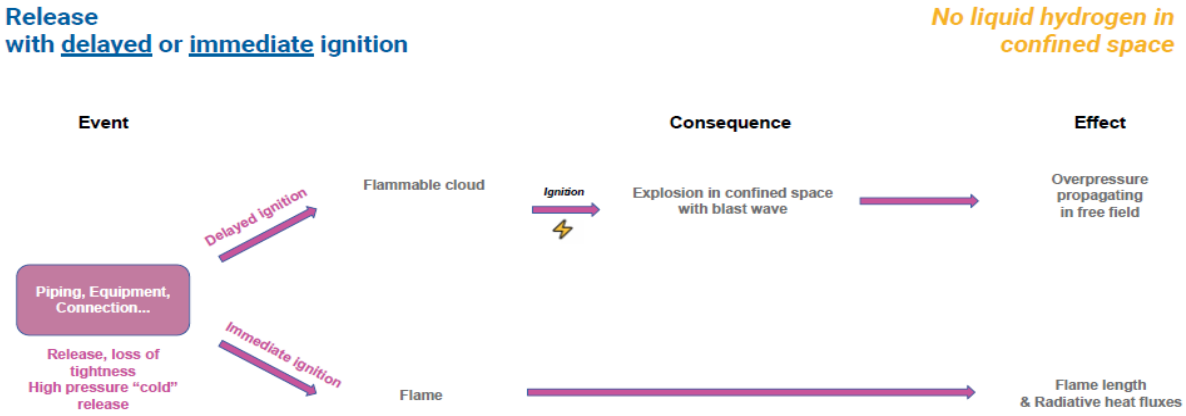

Figure 5: Feared events on connections or other leaking equipment

3.5.2.2 Potential consequences

3.5.2.2.1 Release without ignition

Liquid trailers and liquid storage of liquid refuelling storage 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 vaporize and induce a flammable cloud.

For 20-m^3 storage, based on numerical simulation the size of the pool could be 17 m x 17 m with a thickness of 5 cm.

Size and characteristics of corresponding to flammable vapour cloud are given in the Table hereafter.

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

Values given can vary with weather conditions (temperature, wind…) and environment (obstacles, congestions, nature of the ground, building…).

Dispersion of this flammable cloud is relatively quick. According to simulations it is assessed to be less than 2 min, but further studies are required to confirm this figure.

3.5.2.2.2 Release with immediate ignition

Reference diameter considered to carry out calculations is 45 mm. The initial pressure is 10 bar.

Three cases were evaluated:

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

Flowrates were calculated with e-laboratory dedicated tool (the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/) and thermal effects with Schefer approach.

Hazardous distances due to thermal effects of the jet fire are presented in the Table hereafter.

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

3.5.2.2.3 Release with delayed ignition

- **Storage**

In case of massive spillage, characteristics of flammable cloud were given in a previous section.

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

Consequences of ignition of this flammable cloud are given in the Table hereafter.

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**

Reference diameter considered to carry out calculations is 45 mm. The initial pressure is 10 bar.

Three cases were evaluated:

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

Hazardous distances due to UVCE are presented in the Table hereafter.

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

3.5.2.2.4 Mechanical rupture of the storage

Two cases are investigated:

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

Hazardous distances are given in the Tables hereafter.

Table 25: Overpressure effects due to tank burst considering 100% of 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

4. STRATEGY

4.1 Strategy Definition

Building an incident settlement strategy is answering the question:

"Which goal does the organization want to reach?"

Answering this question define 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

Inside a 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.

4.1.1 Stakes assessment

The three mains 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 but personal safety considerations.

So strategies can be divided in two main orientations:

High stake 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.

4.2 The emergency call management

The incident begins when the emergency call arrives at 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…)
- Location of the incident
- are any persons killed, injured or threatened by the incident?

With that information, the emergency answering service can select the nearest available emergency appliance and provide useful advice to the person who called:
As an example, if the emergency call concerns a Fuel Cell vehicle catching fire in the street:

- Make sure all the passengers escape from the vehicle
- If safe, shut down the contact key
- Provide first aid to the casualties in a safe area
- If you are trained and able to use a fire extinguisher use it if the fire is small
- Evacuate the area and keep anybody from approaching the vehicle before the fire services arrive

Before leaving the fire station, the incident commander must choose a safe way to arrive at the incident ground, preventing the fire appliances to cross a flammable gas cloud, and make sure to arrive upwind and have adequate and suitable resources mobilised to the incident including specialised Hazmat support and significant water resources (if the resource is not sustainable, two water trucks must be requested at the start, one of which is to carry out norias).

4.3 Fire and Rescue operational sequence

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

1. RECOGNITION and SIZE UP
2. RESCUE
3. PREPAREDNESS
4. INCIDENT SETTLEMENT
5. PROTECTION
6. CLEAR OUT
7. OVERHAUL

4.3.1 RECOGNITION and SIZE UP:

This step aims at collecting every available information on the incident field in order to size up the scene.
The incident commander will search for information such as:
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?
Do I need additional resources?

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

During the 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.

- **Thermal Imaging Equipment**

The first responders can use a thermal imaging device to make the hydrogen flame in the air visible as shown on picture

Car H_2 on fire

Figure 6: H_2 tank fire (700 bar) - *ENSOSP 2014*

A Laser thermometer can also be used to find safely high or low temperature items

Hydrogen leak and liquid spreading:

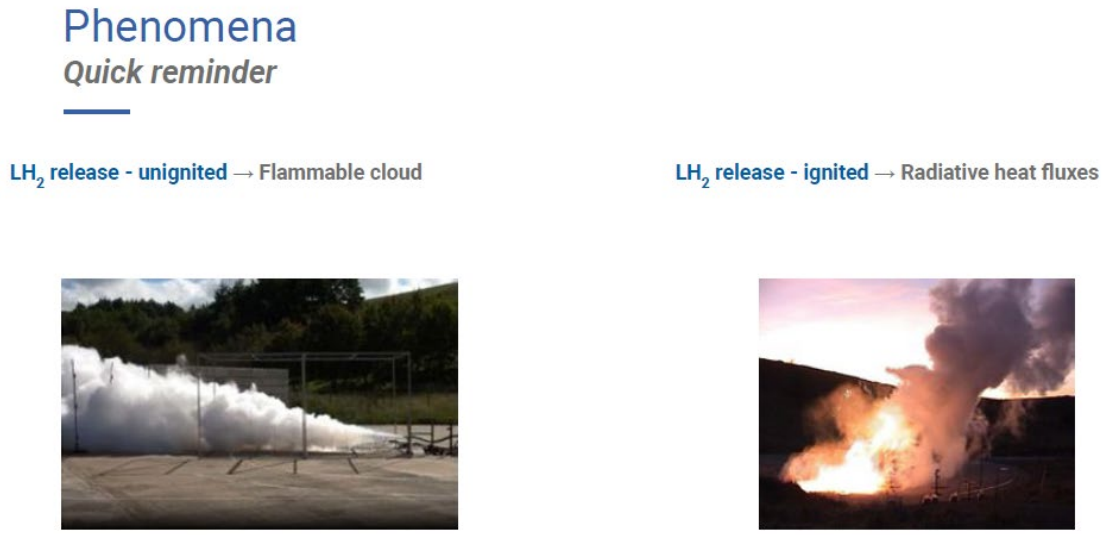

Figure 7: HSE experiments - *PRESLHy FCHJU project 2020*

- **Single-gas monitor**

Single-gas or multi gas monitor continuously displays gas concentrations in the atmosphere. It can be used to monitor O_2 rate and H_2 rate. Such an equipment is useful for First responders to assess the threat zone and create or refine the danger area.

4.3.2 RESCUE

If a casualty is identified and located, rescue operations will need to be launched immediately but not before recognition is complete. Casualties are taken out of the danger area and led to the first aid paramedics teams. As said before: rescue of human lives overrides all but personal safety considerations.

4.3.3 PREPAREDNESS

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

4.3.4 INCIDENT SETTLEMENT

Considering the available information and the sustainability of water resources, the incident commander will at this step decide to use an offensive or a defensive tactic.

1st example:

A FCH Car is burning on a little 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 open, 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 on both directions, wait for the blowdown of the tank while preparing the hoses lines and then extinguish the car fire, using the electrical car fire procedures.

2nd example:

A FCH car is burning in a crowded street, close to a 10 floor building, no sound is heard, the fire began 2 minutes ago.
Tactical choice if sustainable water resources:
Use an offensive tactic: close the road on both directions, prevent anybody from approaching less than 100 meters from the car, stretch two hoses 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.

4.3.5 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 busses 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.

4.3.6 CLEAR OUT

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

4.3.7 OVERHAUL

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.
An overhaul of the fire ground must be steadily done, until any risk still exists.

4.4 INTERVENTION STRATEGIES for FCH applications

4.4.1 RESCUE

Situations covered by this sequence are:

- Injured person in a nearby FCH.
- Asphyxiation caused by an H2 leak in a confined space.
- Electrocution
- Burns caused by a H2 leak

The indicative step by step sequence are 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 and obtain site plan; - Take into account the risk of explosion of hydrogen in confined spaces; - Take into account the risk of anoxia in confined spaces.
	Prohibit	- Prohibit the progress downwind. It is imperative to establish an exclusion zone of 50 m = evacuation; - 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	**-In case of hydrogen leak in confined spaces:** Wear a self-contained breathing apparatus Remove the affected casualty 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		Confirm or refine exclusion zone (50 m) Conduct surveys using an explosimeter (from top to bottom of the installation or storage facility)
PROTECTION		**- Actions to prevent a risk of anoxia:** • Close the hydrogen supply valves • Ventilate the area by promoting the natural drawing (do not use electrical and thermal fans **Action on the electrical risk:** Press the emergency shutdown device of the installation (delay of 20 minutes with the presence of residual current)
CLEAR OUT OVERHAUL		- The monitoring phase ceases as soon as: the oxygen level in the room is normal (about 20 vol. %) Repeatedly check H2 presence in the atmosphere • the electrical system is secure and supported by a technician

4.4.2 Electrical Fire

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, obtain site plan; - Take into account the "low voltage" hazards
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m = evacuation; - 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 outside the exclusion zone • Administer medical support - 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 • Request specialist support
PREPAREDNESS/INCIDENT SETTLEMENT		Confirm or refine exclusion zone (50 m) (based on the sound of a leak under pressure, readings of explosimetry, 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		Press the emergency shutdown device 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 OVERHAUL		Look for high temperature points on hydrogen storage using thermal imaging device on Hydrogen storage (UAV for example if available); - The monitoring phase ends when it is found that the actions aimed at extinguishing measures proved effective.

4.4.3 External Fire

The situation covered by this sequence is a Fire threatening a FCH application or a H2 storage

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

steps	actions	Goals
RECOGNITION	Identify	Contact the safety manager of the installation for the details of the incident, obtain site plan; - Take into account the risk of explosion of a hydrogen tanks under fire, with projections (several tens of meters for bottles to several hundred for trailers).
	Prohibit	- Prohibit the progress downwind and imperative to establish an exclusion zone of 50 m = evacuation; - 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 • Administer medical support - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim • Avoid contact with electrical stakeholder bodies • Request specialist support
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 250l/min minimum (avoid directing the jets on pipes) • establishment of spread water jet for the protection of sensitive point (power Bay ....)
PROTECTION		Press the emergency shutdown device (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 OVERHAUL		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage (UAV for example if available); ; -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

4.4.4 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, obtain site plan; - 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 50 m = evacuation; - 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 ghost and its length using thermal camera (hardly visible flame in its entirety, in the day light); - Pay attention to the significant sound of an ignite gas leak.
RESCUE	act Isolate	**- In case of hydrogen in confined spaces:** • Wear a breathing apparatus • Remove the affected person(s) outside the exclusion zone • Administer medical assistance **- If risk of electrified or electrocuted victim** • Use the electro-rescue equipment to remove the victim • Avoid contact with electrical stakeholder bodies • Seek specialist support
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 OVERHAUL		- Look for high temperature points on hydrogen storage using thermal imaging device on Hydrogen storage (UAV for example if available); - Conduct surveys of explosimeter in confined spaces prioritizing high points; - Press the emergency shutdown device of the installation (delay of 20 minutes with the presence of a residual current).

4.4.5 Unignited H2 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, obtain site plan; - Take into account the risk of explosion
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m = evacuation; - 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 • Administer medical assistance - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim • Avoid contact with electrical stakeholder bodies • Seek specialist support
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 OVERHAUL		- 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 shutdown device during the overhaul phase, clears electric ignition sources, intrinsic with the installation.

5. Tactics

Given the existing knowledge on fires involving hydrogen applications in the gas phase, the HyResponder project makes it possible to complete the following "tactical sheets" by including operational situations in the presence of liquefied hydrogen.

So, for each selected application (in addition to cars, buses, forklifts, trailers, refuelling stations, stationary generator (SPGS), hydrogen-based energy storage system (H2ESS), we offer trucks, trains, ships, application, storage and distribution facilities for gaseous and liquefied hydrogen.

A tactical approach is proposed for 4 incidents in the presence of H2 or LH2:

• No leak, no fire,

• Leak,

• Fire in the application,

• External fire threatening the application

For each situation, we offer a step-by-step sequence, information on safety points and indicative safety distances in the event of failure of the decompression devices and to prevent the public from experiencing the effects of the explosion of the tanks.

Important notice: Remember that the distances are INDICATIVE.

The incident commander must enlarge or reduce the safety perimeter, taking into account the reality of the situation and in particular the capacity of the H_2, LH_2 (or O_2) tank concerned.

5.1 Tactic n°1 - FC app - No leak, no fire

	FC CAR / FC FORKLIFT / FC BUS / FC TRUCKS / FC TRAINS / FC SHIP	
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 (may include using vehicle tracking)
- Are there any person involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not come from the rear of the vehicle
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression distance
- Switch on the pump and connect the fire truck to a fire hydrant or water truck

SAFETY AREA

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

SIZE UP THE SCENE

BY QUESTIONNING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- What type of vehicle is affected?
- What happened?
- Vehicle gas tank size and content in litres
- Is someone injured? Threatened?

- Has a leak occured? Is a leak still occuring?
- Is a part of the vehicle damaged?

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

RESCUE

Rescue of humans override all but personal safety considerations

Engage rescue as a conventional accident with hazmat support

EXPOSURE PROTECTION

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 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 (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"

OVERHAUL

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

5.2 Tactic n°2 - FC app - H2 leak without fire

	FC CAR / FC FORKLIFT / FC BUS / FC TRUCKS / FC TRAINS / FC SHIP	
Tactic n° 2	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 person involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not come from the rear of the vehicle
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck

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 eared before the FR arrive?

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 (more than 150°C/302°F)

RESCUE

Rescue of humans override all but personal safety considerations
Engage rescue as a conventional accident with hazmat support, 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 the passengers in the opposite direction of the 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
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 (more than 150°C/302°F) => refine safety area

INCIDENT TREATMENT

If H2 Leak still exist after "exposure protection step "anf if it exists, 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

OVERHAUL

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

5.3 Tactic n°3 - FC app - Fire

	FC CAR / FC FORKLIFT / FC BUS / FC TRUCKS / FC TRAINS / FC SHIP	
Tactic n° 3	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 happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION
- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary
- Do not cross an eventual explosive gas cloud
- Do not come from the rear of the vehicle
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)
- 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 cloud of flammable gas, and make sure to arrive upwind
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck

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 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 eared before the FR arrive?

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

RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support, 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
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 => refine safety area
INCIDENT TREATMENT
In case of High stake level situation and if sustainable water resources, operate an offensive fire attack, each team prepare 80 m of hoselines directly connected to the fire appliance 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 **=> defensive attack until water resources are sustainable** The teams avoid passing through danger angles 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 In there is no identified stake, evaluate the opportunity to let the vehicle burn safely
OVERHAUL
• 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 authorized personnels (idealy manufacturer)

5.4 Tactic n°4 - FC app - External fire threatening the application

	FC CAR / FC FORKLIFT / FC BUS / FC TRUCKS / FC TRAINS / FC SHIP	
Tactic n° 4	EXTERNAL FIRE THREATENING THE APPLICATION	

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 happend? TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION • Wind direction • Wind speed ITINERARY, choose a safe itinerary • Do not cross an eventual explosive gas cloud • Do not come from the rear of the vehicle • Anticipate the need of a hydrant TAKE FOLLOWING TOOLS (if availble use drone UAV) • 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 cloud of flammable gas, and make sure to arrive upwind • Stop the fire appliance 50 meters before the incident • Away from a possible ignited flammable liquid leak progression • Switch on the pump and connect the fire truck to a fire hydrant or water truck 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
Answer the following questions • What is burning?

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

RESCUE

Rescue of humans override all but personal safety considerations

Engage rescue as a conventional accident with hazmat support.

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

EXPOSURE PROTECTION

Team 1: attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle.

INCIDENT TREATMENT

Operate an defensive fire attack (and sustain water resources), each team prepare 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

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

OVERHAUL

Check temperature on the FCH vehicle with thermal imaging device

5.5 Tactic n°5 - H2 (LH2) trailer - No leak no fire

	H2 (LH2) trailer	
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) • Are there any person involved in the incident? • Type of vehicle concerned with manufacturer's emergency response guidance • What happend? TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION • Wind direction • Wind speed ITINERARY, choose a safe itinerary • Do not cross an eventual explosive gas cloud • Do not come from the rear of the trailer Anticipate the need of a hydrant TAKE FOLLOWING TOOLS (if availble use drone UAV) • 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 cloud of flammable gas, and make sure to arrive upwind • Stop the fire appliance 50 meters before the incident • Away from a possible ignited flammable liquid leak progression • Switch on the pump and connect the fire truck to a fire hydrant or water truck SAFETY AREA • Set up a safety area for the public beyond a radius of 50 meters • Ensure that unauthorized/untrained personnel do not enter the hazardous area
SIZE UP THE SCENE
BY QUESTIONNING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS • Which Type is the involved vehicle? • What has happened? • Is someone injured? Threatened? • Has a leak occured? Is a leak still occuring? • Is a part of the truck damaged?

- Is the trailer dismanteled?

Check energies present in the involved vehicle (tank type, refuelling hole type, vehicle registration papers...)
Does a flammable liquid leak exists?
Operate H2 detector

RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support
EXPOSURE PROTECTION
Use only necessary personnel Set parking brake Wedge the vehicle Turn off the ignition key check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic 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
INCIDENT TREATMENT
Check and close every H2 valve on the trailer If no H2 leak and no sign of fire is detected, engage incident settlement following usual road trafic accident and extrication guidelines DO NOT • cut or crush H2 lines • damage H2 tanks If the trailer is dimanteled, inspect individualy each cylinder, contact the transport company hotline to evacuate safely the cylinders
OVERHAUL
After a last H2 atmospheric control, make sure that the vehicle or the wreckage and the cargo is evacuated by authorized personnels (idealy transport company)

5.6 Tactic n°6 - H2 trailer - H2 leak without fire

	H2 trailer	
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 person involved in the incident?
- Type of vehicle concerned with manufacturer's emergency response guidance
- What happend?
- Type of trailer concerned? Size, full or empty?
- Is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not come from the rear of the trailer Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 100 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, BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- Which Type is the involved vehicle?

- What happened?
- Is the trailer dismanteled?
- Has a loud hissing sound been eared before the FR arrive?

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 (more than 150°C/302°F)

RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support 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
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
INCIDENT TREATMENT
Listen to abnormal noises Repeatedly check H2 presence in the atmosphere => refine safety area Check and close every H2 valve on the trailer If there is no means for preventing H2 leak, and no identified stake, evaluate the opportunity to let the vehicle leak safely
OVERHAUL
After a last H2 atmospheric control, Make sure that the vehicle or the wreckage and the cargo is evacuated by authorized personnels (idealy transport company)

5.7 Tactic n°7 - H2 trailer - Fire

	H2 trailer	
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 happend? • Type of trailer concerned? Size, full or empty? • Is the cargo dismanteled? TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION • Wind direction • Wind speed ITINERARY, choose a safe itinerary • Do not cross an eventual explosive gas cloud • Do not come from the rear of the trailer Anticipate the need of a hydrant TAKE FOLLOWING TOOLS (if availble use drone UAV) • 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 cloud of flammable gas, and make sure to arrive upwind. • Stop the fire appliance 50 meters before the incident • Away from a possible ignited flammable liquid leak progression • Switch on the pump and connect the fire truck to a fire hydrant or water truck. SAFETY AREA • Set up a safety area for the public beyond a radius of 500 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, BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- Which Type is the involved vehicle?
- What happened?
- Is the trailer dismanteled?
- Is a cylinder involved in fire?

Check the fire scene with the thermal imaging camera

- Is there an ignited H2 leak from a cylinder?
- Is a cylinder impinged by a flame dart?

RESCUE

Rescue of humans override all but personal safety considerations

Engage rescue as a conventional accident with hazmat support, 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

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…)

INCIDENT TREATMENT

In case of high stake level situation and if sustainable water resources, operate an offensive fire attack, each team prepare 80 m of hoselines directly connected to the fire appliance pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the 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 **=> defensive attack until water resources are sustainable**

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
Previosly, the incident commander must have took 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
Mind that water will be polluted during extinction , operate its containement
If there is no identified stake, evaluate the opportunity to let the vehicle burn safely
Remember that a cylinder is not equipped with a pressure release device and will explode if subjected to a pressure increase

OVERHAUL

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 authorized personnels idealy transport company

5.8 Tactic n°8 - H2 trailer - External fire threatening the application

	H2 trailer	
Tactic n° 8	EXTERNAL FIRE THREATENING THE APPLICATION	

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 happend?
- Type of trailer concerned? Size, full or empty?
- Is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Do not come from the rear of the trailer Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

Answer the following questions

- What is burning?
- What's the fire strength?

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

RESCUE

Rescue of humans override all but personal safety considerations

Engage rescue as a conventional accident with hazmat support, 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

EXPOSURE PROTECTION

Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the H2 trailer

INCIDENT TREATMENT

Operate an defensive fire attack (and sustain water resources), each team prepare 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 H2 trailer.
- Team 2 : Put out the fire with water, foam or powder depending what is burning.

If putting fire out is not possible, move the H2 trailer by any way possible (driving, towing...) away from the radiant effect of the fire
Remember that a cylinder is not equipped with a pressure release device and will explode if subjected to a pressure increase

OVERHAUL

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 authorized personnels idealy transport company)

5.9 Tactic n°9 - Refuelling station H2 and LH2 - No leak no fire

	REFUELLING STATION	
Tactic n° 9	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) • Are there any person involved in the incident? • Are there any vehicle involved in the incident? • What happend? TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION • Wind direction • Wind speed ITINERARY, choose a safe itinerary • Do not cross an eventual explosive gas cloud • Anticipate the need of a hydrant TAKE FOLLOWING TOOLS (if availble use drone UAV) • 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 cloud of flammable gas, and make sure to arrive upwind. • Stop the fire appliance 50 meters before the incident • Away from a possible ignited flammable liquid leak progression • Switch on the pump and connect the fire truck to a fire hydrant or water truck. SAFETY AREA • Set up a safety area for the public beyond a radius of 50 meters • Ensure that unauthorized/untrained personnel do not enter the hazardous area
SIZE UP THE SCENE
BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS • What has happened?

- Is someone injured? Threatened?
- Has a leak occured? Is a leak still occuring?
- Is a vehicle connected to the refuelling sation? (if yes, apply FCH vehicle related tactic)

Check energies present in the involved vehicle (tank type, refuelling hole type, vehicle registration papers...)
Operate H2 detector
Where emergency shutdown devices of the refuelling station activated?

RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support
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 if physcaly 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 simultaneaously the tactic related to trailers DO NOT • cut or crush H2 lines • cut or crush High Voltage Lines (orange) • damage H2 tank
OVERHAUL
After a last H2 atmospheric control, make sure that the refuelling station will be checked be authorized personnels before restart

5.10 Tactic n°10 - Refuelling station – H2 or LH2 leak without fire

	REFUELLING STATION	
Tactic n° 10	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 person involved in the incident?
- Are there any vehicle involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 100 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, BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- What has happened?

- Is someone injured? Threatened?
- Has a leak occured? Is a leak still occuring?
- Has a loud hissing sound been eared before the FR arrive?
- Is a vehicle connected to the refuelling sation? (if yes, apply related tactic)

Check energies present in the involved vehicle (tank type, refuelling hole type, vehicle registration papers...)
Operate H2 detector
Where emergency shutdown devices of the refuelling station activated?

RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support, 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 the persons in the opposite direction of the 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 hose line to protect the action of teams Push Emergency shutdown devices If the dispenser if physically damaged, close the valves between the storage area and the dispenser
INCIDENT TREATMENT
Close the valves between the dispenser and 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 simultaneously 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
OVERHAUL
After a last H2 atmospheric control, make sure that before restart, the refuelling station will be checked be authorized personnels and the malfuction and damages repaired

5.11 Tactic n°11 - Refuelling station H2 or LH2- Fire

	REFUELLING STATION	
Tactic n° 11	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?
- Are there any vehicle involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 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, BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS

- What has happened?
- Is someone injured? Threatened?
- Has a leak occured? Is a leak still occuring?
- Has a loud hissing sound been eared before the FR arrive?
- Is a vehicle connected to the refuelling sation? (if yes, apply related tactic)

Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers...)
Operate H2 detector
Where emergency shutdown devices of the refuelling station activated?

RESCUE

Rescue of humans override all but personal safety considerations
Engage rescue as a conventional accident with hazmat support, 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

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

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 stake 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 took appropriate actions to prevent pressure increase in the tanks and checked the efficiency.
If sustainable water resources, operate an offensive fire attack each team prepare 80 m of hoselines directly connected to the fire appliance pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire **=> defensive attack until water resources are sustainable**

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
In there is no identified stake, evaluate the opportunity to let the vehicle burn safely

OVERHAUL

Cool the wreckage as soon as no heat point is detected by the thermal imaging device
Repeatedly check H2 presence in the atmosphere => refine safety area

5.12 Tactic n°12 - Refuelling station H2 or LH2 - External fire threatening the application

	REFUELLING STATION	
Tactic n° 12	EXTERNAL FIRE THREATENING THE APPLICATION	

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?
- Are there any vehicle involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters before the incident
- Away from a possible ignited flammable liquid leak progression
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- Set up a safety area for the public beyond a radius of 500 meters
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

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

- What has happened?

- Which part of the application is concerned by the incident? (dispenser, storage, electrical equipment...)
- Is someone injured? Threatened?
- 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 is able to provide accurate informations

RESCUE

Rescue of humans override all but personal safety considerations
Engage rescue as a conventional accident with hazmat support, 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

EXPOSURE PROTECTION

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

INCIDENT TREATMENT

Operate an defensive fire attack (and sustain water resources), each team prepare 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 therefuelling station
- Team 2: put out the fire with water, foam or powder depending what is burning

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

OVERHAUL

Cool the wreckage as soon as no heat point is detected by the thermal imaging device
Repeatedly check H2 presence in the atmosphere => refine safety area

5.13 Tactic n°13 – Stationary app H2 or LH2 – No leak no fire

	Stationary power generation unit (SPGU) / Hydrogen-based energy storage system (H2ESS)	
Tactic n° 13	NO LEAK NO FIRE (technical alarm)	

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 kwown by the fire service?
- Does a firefighting plan exists? Take it in the fire appliance and read it on the road.
- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Are there any person involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters 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
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- If H2/O2 storage is concerned, set up a safety area for the public beyond a radius of 500 meters
- 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 beyond a radius of 50 meters
- 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 • What has happened? • Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...) • Is someone injured? Threatened? • Has a leak occured? Is a leak still occuring?Which ones? • Is the system delivering electricity? • Is a technician present on the plant area? Look for the emergency fire and rescue plan Locate precisely dangerous areas, Emergency shutdown devices, valves Evaluate the amount of compressed gases present in the tanks
RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support To reach safely a casualty, it is necessary sure that he's not already submited to an electrical current. Push Emergency shutdown devices, take fallen cables away with appropriate elctrical gloves...
EXPOSURE PROTECTION
Push Emergency shutdown devices of the concerned aera As it is possible, 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, engage incident settlement 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
OVERHAUL
After a last H2 atmospheric control, make sure that the application will be checked be authorized personnels before restart.

5.14 Tactic n°14 – Stationary app – H2 or LH2 leak without fire

	Stationary power generation unit (SPGU) / Hydrogen-based energy storage system (H2ESS)	
Tactic n° 14	H2 LEAK WITHOUT FIRE	

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 kwown by the fire service?
- Does a firefighting plan exists? Take it in the fire appliance and read it on the road.
- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Are there any person involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind
- Stop the fire appliance 50 meters 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
- Switch on the pump and connect the fire truck to a fire hydrant or water truck

SAFETY AREA

- If H2/O2 storage is concerned, set up a safety area for the public beyond a radius of 500 meters
- 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 beyond a radius of 50 meters
- 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 • What has happened? • Which part of the application is concerned by the incident? (FC, H2/O2 storage, ...) • Is someone injured? Threatened? • Has a leak occured? Is a leak still occuring? • Is the system delivering electricity? • Is a technician present on the plant area? Look for the emergency fire and rescue plan Locate precisely dangerous areas, Emergency shutdown devices, valves, Evaluate the amount of compressed gases present in the tanks
RESCUE
Rescue of humans override all but personal safety considerations Engage rescue as a conventional accident with hazmat support, 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
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 As it is possible, 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 => refine safety area
INCIDENT TREATMENT
If no H2 leak and no sign of fire is detected, engage incident settlement DO NOT : cut or crush H2/O2 lines, cut or crush High Voltage Lines (orange), damage H2/O2 tank Fire services are not supposed to open the Fuel Cell comparment Locate precisely the H2 leak, if located in an building, operate a wide ventilation of all concerned premises According to information provided by the emegency plans and the validation of the technicians (if available), close appropriate valves, ESD... Repeatedly check H2 presence in the atmosphere => refine safety area Mind that photovoltaic panels still produce high voltage electricity when exposed to daylight Mind that H2 and O2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank
OVERHAUL
After a last H2 atmospheric control, make sure that the application will be checked be authorized personnels before restart

5.15 Tactic n°15 – Stationary app - Fire

	Stationary power generation unit (SPGU) / Hydrogen-based energy storage system (H2ESS)	
Tactic n° 15	FIRE	

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 kwown by the fire service?
- Does a firefighting plan exists? Take it in the fire appliance and read it on the road.
- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Are there any person involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters 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
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- if H2/O2 storage is concerned, set up a safety area for the public beyond a radius of 500 meters
- 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 beyond a radius of 50 meters
- 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

- What happened?

- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Is someone injured? Threatened?
- Has a leak occured? Is a leak still occuring?Which ones?
- Is the system delivering electricity?
- Is a technician present on the plant area?

Look for the emergency fire and rescue plan
Locate precisely dangerous areas, Emergency shutdown devices, valves,
Evaluate the amount of compressed gases present in the tanks

RESCUE

Rescue of humans override all but personal safety considerations
Engage rescue as a conventional accident with hazmat support, 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

EXPOSURE PROTECTION

Evacuate adjacent buildings
Prevent the fire from spreading to uninvolved buildings
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
As it is possible, 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 => refine safety area

INCIDENT TREATMENT

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 comparment

The fire concerns the storage area.(High stake level situation)

- Push Emergency shutdown devices
- Prevent the fire to spread to a uninvolved part of the plant with water spray curtains

If sustainable water resources, put the fire out with an offensive fire attack, each team prepare 80 m of hoselines directly connected to the fire appliance pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire **=> defensive attack until water resources are sustainable**

If the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve
Previosly, the incident commander must have took appropriate actions to prevent pressure increase in the tanks and checked the efficiency
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
In there is no identified stake, evaluate the opportunity to let the fire burn safely

OVERHAUL

Cool the wreckage as soon as no heat point is detected by the thermal imaging device
Repeatedly check H2 presence in the atmosphere => refine safety area

5.16 Tactic n°16 – Stationary app - External fire threatening the application

	Stationary power generation unit (SPGU) / Hydrogen-based energy storage system (H2ESS)	
Tactic n° 16	EXTERNAL FIRE THREATENING THE APPLICATION	

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 kwown by the fire service?
- Does a firefighting plan exists? Take it in the fire appliance and read it on the road.
- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Are there any person involved in the incident?
- What happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION

- Wind direction
- Wind speed

ITINERARY, choose a safe itinerary

- Do not cross an eventual explosive gas cloud
- Anticipate the need of a hydrant

TAKE FOLLOWING TOOLS (if availble use drone UAV)

- 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 cloud of flammable gas, and make sure to arrive upwind.
- Stop the fire appliance 50 meters 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
- Switch on the pump and connect the fire truck to a fire hydrant or water truck.

SAFETY AREA

- If H2/O2 storage is concerned, set up a safety area for the public beyond a radius of 500 meters
- 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 beyond a radius of 50 meters
- 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

- What has happened?
- Which part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)
- Is someone injured? Threatened?
- Has a leak occured? Is a leak still occuring?
- Is the system delivering electricity?
- Is a technician present on the plant area?

Look for the emergency fire and rescue plan
Locate precisely dangerous areas, Emergency shutdown devices, valves
Evaluate the amount of compressed gases present in the tanks

RESCUE

Rescue of humans override all but personal safety considerations
Engage rescue as a conventional accident with hazmat support, 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

EXPOSURE PROTECTION

Evacuate adjacent buildings
Prevent the fire from spreading to uninvolved buildings
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
As it is possible, 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 => refine safety area

INCIDENT TREATMENT

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 stake level situation)

- Push Emergency shutdown devices
- Prevent the fire to spread to a uninvolved part of the plant with water spray curtains

If sustainable water resources, put the fire out with an offensive fire attack, each team prepare 80 m of hoselines directly connected to the fire appliance pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire **=> defensive attack until water resources are sustainable**

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 took appropriate actions to prevent pressure increase in the tank an checked the efficiency
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
In there is no identified stake, evaluate the opportunity to let the fire burn safely

OVERHAUL

Cool the wreckage as soon as no heat point is detected by the thermal imaging device
Repeatedly check H2 presence in the atmosphere => refine safety area

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Appendix

Tools for consequences assessment.

e-laboratory on the HyResponder e-Platform (https://hyresponder.eu/e-platform/e-laboratory/)

More information will be available in HyResponder D2.3 and D2.8 documents.