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ID263 - Identification of safety critical scenarios of Hydrogen Refuelling Stations in a multifuel context

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Clean Hydrogen Partnership

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Safety and Permitting for Hydrogen at Multifuel Retail

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"(…) lack of guidelines and instructions for local authorities can cause **delays**, **extra costs** and **divergent interpretations** from case-to-case, further complicating the obligations of H2 Refuelling Station operators." 2018, https://www.hylaw.eu/

Goals of the project :

Definition of **commonly applicable, effective, and evidence-based guidelines** to facilitate the construction of HRS in multi-fuel refuelling stations through:

- Identification of relevant gaps in the current legal and administrative framework;
- Acquisition of experimental data from engineering research;
- Active engagement with a community of stakeholders in the overall process.

ENGIE Lab CRIGEN · Air Liquide creative oxygen · Bespoke Research and Consultancy from HSE · INERIS maîtriser le risque pour un développement durable · Hydrogen Europe · ITM Power Energy Storage | Clean Fuel · kiwa · snam · Shell Hydrogen · ZSW

Main objective : To develop good practice guidelines that can be used as a common approach to risk assessment and addressing the safe design for gaseous hydrogen refueling stations in a multifuel context

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1. WP structure

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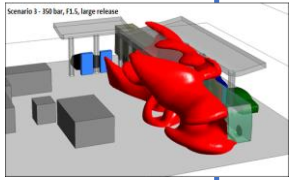
WP6 – Project management

WP1 - Detailed investigation of current status

- T1.1 Definition of scope for regulatory analysis (Cross-country research framework)
- T1.2 Research into permitting requirements and public guidance on required risk assessments
- T1.3 Comparative assessment and gap analysis

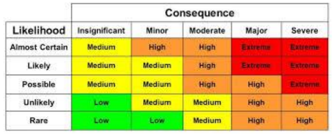


WP2 - Practical research to address gaps in current understanding

- T2.1 Leakage characterisation of H2 dispensers
  - Task 2.1.1 Leakage characteristics
  - Task 2.1.2 Dispersion characteristics
  - Task 2.1.3 Ignition probabilities
  - Task 2.1.4 Efficiency of safety barrier
- T2.2 Fire and explosion hazards
  - Task 2.2.1: Defining a zoning threshold
  - Task 2.2.2 Domino effect arising from faults on hydrogen dispensers
  - Task 2.2.3 Vulnerability of hydrogen dispensers to incidents involving other fuel dispensers

WP3 - Generate best practice guidance

- T3.1 State of the art of technology
- T3.2 State of the art on risk assessment methodologies
- T3.3 Preliminary risk analysis
- T3.4 Detailed risk assessment
- T3.5 Identification of critical scenarios
- T3.6 Risk assessment review of critical scenarios & hazardous areas
- T3.7 Best practice guidelines redaction



Likelihood	Consequence: Insignificant	Minor	Moderate	Major	Severe
Almost Certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	Extreme	Extreme
Possible	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Rare	Low	Low	Medium	High	High

WP4 – Engagement

- T4.1 Establishment of the Network
- T4.2 Inception phase
- T4.3 Workshop on state of the art and case study models
- T4.4 Workshop on refined case study models and WP2 methodology
- T4.5 Workshop on results of WP2 and WP3
- T4.6 Workshop on development of best practice guidance
- T4.7 Meeting on adoption of best practice guidance (WP3)

WP5 - Dissemination, Communication and exploitation

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2. Scope

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

Table 1: Main equipment on each configuration

	Hydrogen supply				Process steps				Refuelling	
	Trailers	Bundle	PEM Electrolyser	Stationary liquid storage	Cryopump	Vaporizer	Compressor	Buffer storage	Heat exchanger or Cooling system	Dispenser
Config. 1	X	X					X	X	X	X
Config. 2	X		X				X	X	X	X
Config. 3*				X	X	X	X	X	X	X

* The production, liquefaction and delivery process have not been included in configuration 3. Liquid hydrogen stored in a stationary vessel was considered, refilled by a liquid hydrogen trailer by bunkering

Exemplar **Gaseous hydrogen** refuelling in **different configurations** (supply, flowrate, light and heavy-duty vehicles) :

●#1 – Small capacity, ready-to-deploy multifuel station *(« simple » and already used technologies, situated in urban/ suburban locations with cars/ trucks/buses*)

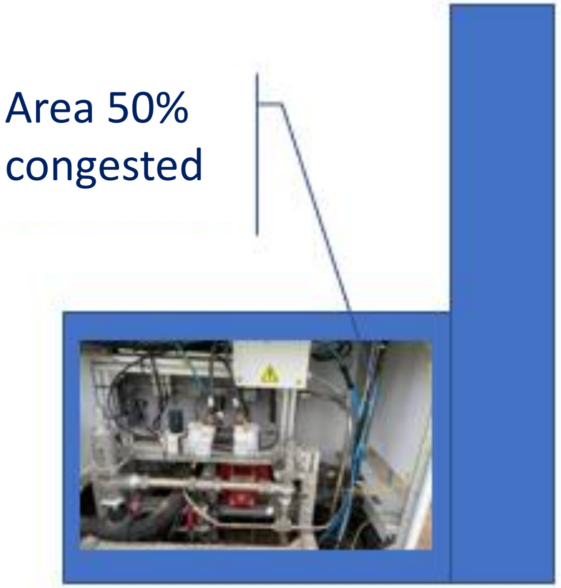
●#2 – Onsite H2 production multifuel station (*on-site hydrogen production, situated in suburban location with car and trucks/buses*)

●#3 – High capacity multifuel station (*considering future large needs of hydrogen for mobility, situated in an industrial location with dispensers 300 g/s*)

2. Scope – H2 dispensers studied

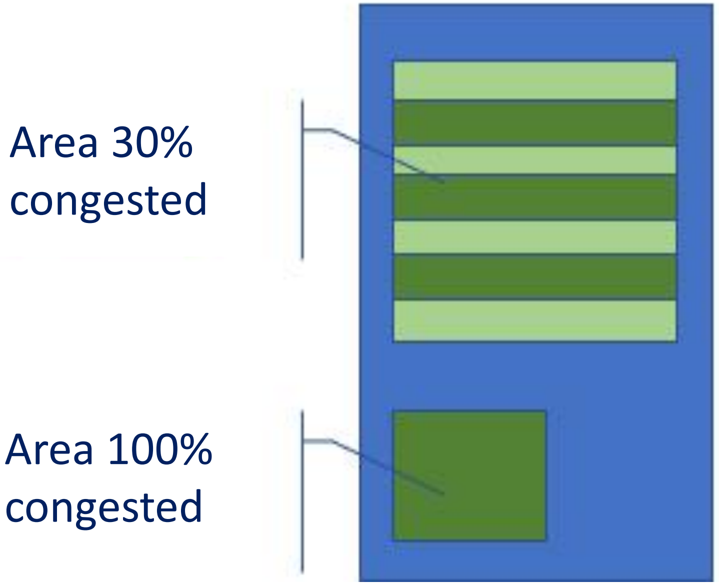
Dispenser (A)

- Size : H 1 m x L 0.80 x W 0.4 m
- Congestion : 50% at the bottom
- Ventilation : Natural



Dispenser (B)

- Size : H 1.9 m x L 0.75 x W 0.6 m
- Congestion : 30% In the whole enclosure
- Ventilation : Natural & Forced



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3. Preliminary results : lessons learnt

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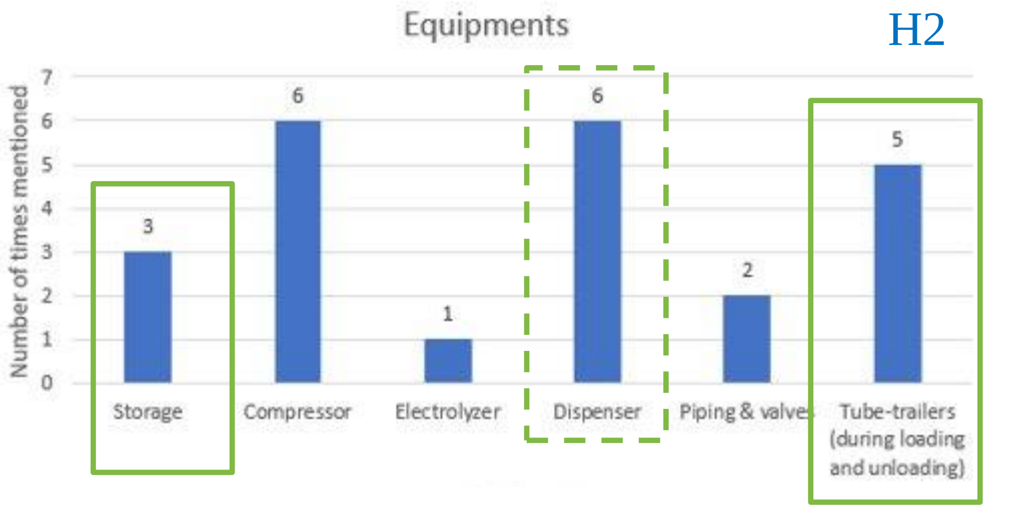

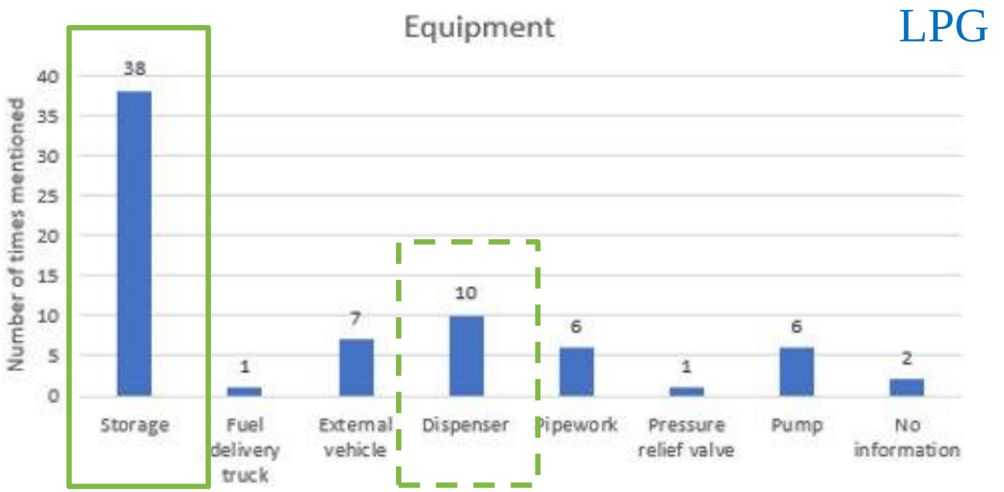

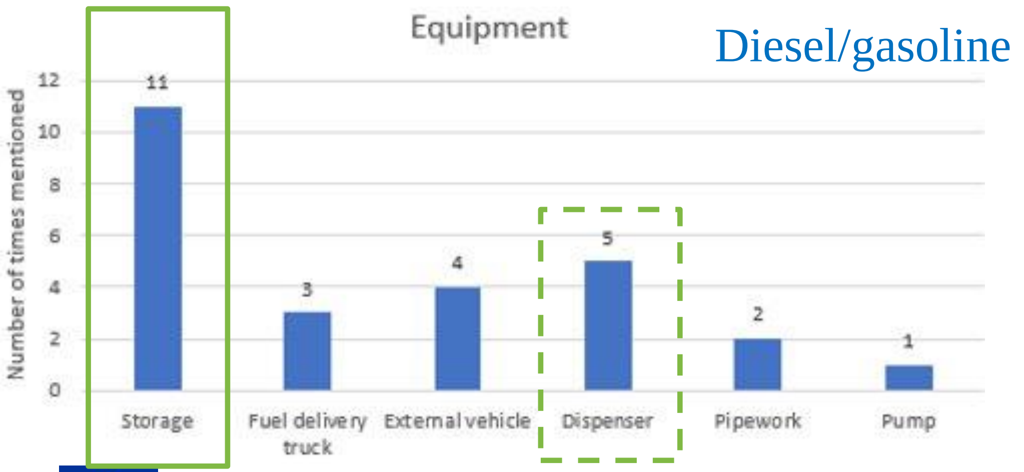

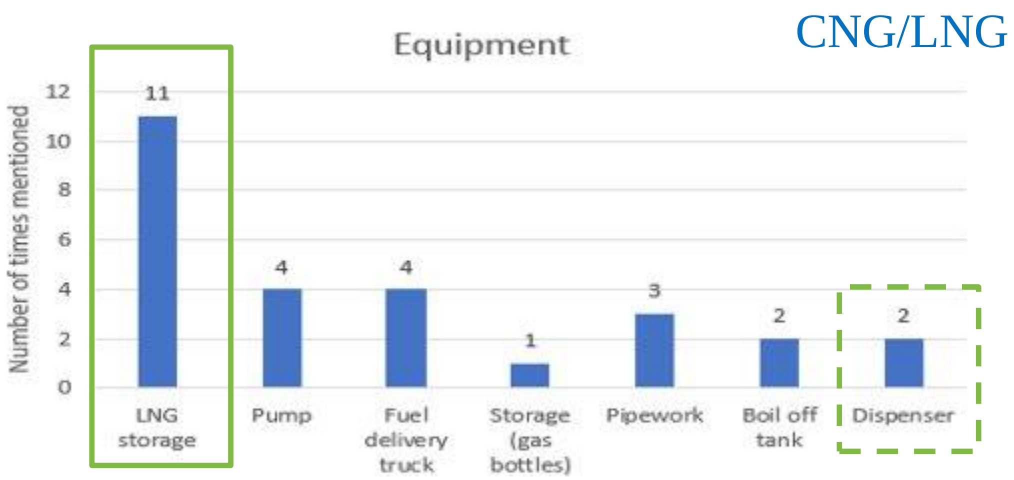

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3. Preliminary results : Example safety barriers

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Topics	Example safety barriers
Design	Design of canopy roof to limit degree of confinement
	Choice of materials : H2-compatible materials (e.g. for fittings, piping, seals, *etc*.)
	Safe location of outlet for vent lines and layout review
	Pressure safety valves
Operation	Hazardous Area Classification with management of ignition sources
	Concentration sensors, pressure and temperature sensors
	Vibration alarm on compressor with emergency shutdown
	Periodic control for the integrity of HRS and dispenser equipment (i.e. hoses)
Detection	H2 flame and gas detection with appropriate emergency protocols (e.g. alarms, shutdown, *etc*.)
Isolation	Shut-off valves to isolate equipment
	Flowrate restriction orifices, break-aways, quick couplings

4. Likelihoods

- **Example :** focus on H2 hose dispenser

Probability interval	E	D	C	B	A
Frequency (per year)	$E < 10^{-5}$	$10^{-5} < D < 10^{-4}$	$10^{-4} < C < 10^{-3}$	$10^{-3} < B < 10^{-2}$	$10^{-2} < A$

- **Semi quantitative approach** : evaluating the probability of occurrence from the Central Feared Event / top hazardous event. It is a simplified approach to classify the different major accident events.

- **Sources of leak frequencies:**
  - ***SANDIA Database*** (hydrogen-specific data)
  - ***BEVI*** (RIVM Netherlands)
  - ***Norskeolje&gass PLOFAM*** "Process Leak for Offshore Installations Frequency Assessment Model" Offshore & Onshore Reliability Data

- **Ignition likelihood** :
  - assumed to be equal to 1, in consideration of the low ignition energy required to ignite a flammable cloud of hydrogen (immediate/delayed ignition).
  - the 2023 MultHyFuel WP2 experimental programme results, and the consideration of safety barriers, could help refine the evaluation of likelihoods.

4. Likelihoods

- **Comparison :**

Probability interval	E	D	C	B	A
Frequency (per year)	$E < 10^{-5}$	$10^{-5} < D < 10^{-4}$	$10^{-4} < C < 10^{-3}$	$10^{-3} < B < 10^{-2}$	$10^{-2} < A$

Table 3. Result of likelihood assessment for loss of containment from the dispenser hose.

Config.	Central Feared Event (CFE)/ Top Event	Pressure	Time maximum filling (h/day)	DATABASE BEVI	Sandia	Norskeolje&gass PLOFAM	DPh/ major accident event
1	Loss of H_2 containment (medium leak 10%) on hose	350 bar	3.33	A	D	E	(U)VCE Flashfire Jet fire
2			5	A	D	E	
3			21.7	A	C	D	
1		700 bar	3.33	A	D	E	
2			5	A	D	D	
3			21.7	A	C	D	
1		1000 bar	3.33	A	D	D	
2			5	A	D	D	
3			21.7	A	C	D	

Sandia database data was chosen as the source of failure frequencies for the risk assessment.

Further work :

- Validation of the occurrence of leakage using experimental data or lessons learned from new installations;
- Estimation of the likelihoods to take into account the mitigation and protective barriers; and
- Consideration of the ignition likelihood in the event of loss of containment.

5. Consequences

- **Thresholds (French regulations)**

	Radiative heat fluxes	Overpressures
Significant Lethal Effects (5%)	8 kW.m^{-2}	200 mbar
First Lethal Effects (1%)	5 kW.m^{-2} or 100% LFL	140 mbar
Irreversible Effects	3 kW.m^{-2} or 110% LFL	50 mbar
Indirect Effects (glass break)	-	20 mbar

LFL: Lower Flammability Limit

- **Example of scenario** : H2 build up and VCE in dispenser casing

- **Assumptions :**
  - natural ventilation with 2-openings (top and bottom)
  - GH2 concentration is homogeneous in the whole dispenser volume (conservative approach)
  - if the calculated concentration is higher than 30% in the dispenser, then 30% is taken into account for a deflagration consequences calculation (30%-H2, stoichiometry or the worst case)
  - If 100 mbar internal overpressure is reached, then the dispenser is considered to be destroyed and the overpressure decay is a function of the distance from the dispenser.

5. Consequences

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- **Results for dispenser :**

Table 5. Consequences of the ignition of a 30% H2-air mixture inside dispensers A & B.

	Dispenser A	Dispenser B
Volume	0.32 m^3	0.855 m^3
Initial H_2 concentration	30%*	30%*
Internal effects		
Overpressure	284 mbar	195 mbar
Consequence on structure*	Destruction	Destruction
External effects – Overpressure decay with the distance		
200 mbar	1 m	1 m
140 mbar	1 m	2 m
50 mbar	3 m	4 m
20 mbar	6 m	8 m

* *For lower H_2 concentrations, internal overpressure is lower than 100 mbar; thus, consequences are limited to inside the dispenser, which is not destroyed*

- Results for the **full-bore rupture of the hose :**
  - **jet fire** reaching more than 80 m for 700 bar, but safety barriers to be considered (limitation of duration by automatic shut-off valve; and limitation of release flow by a restriction orifice);
  - **flash fire** (delayed ignition) with maximum effects at 15 m from the dispenser, the flowrate will be limited by the restriction orifice, and ignition likelihood could be reduced by the shut-off valve.
  - **whipping** of the hose (no domino effects / irreversible effects around dispenser)

6. Critical scenario determination

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- **Severity scale**

(French Order of 20/09/2005) :

Severity level of consequence	Area defined by the thresholds of significant lethal effects (in French “Seuil des effets léthaux significatifs” SELS)	Area bounded by lethal effects thresholds (in French “Seuil des effets léthaux” SEL)	Area defined by the thresholds of irreversible effects (in French “Seuil des effets irréversibles” SEI)
V. Disastrous	More than 10 people exposed	More than 100 people exposed	More than 1000 people exposed
IV. Catastrophic	Less than 10 people exposed	Between 10 and 100 people exposed	Between 100 and 1000 people exposed
III. Major	At most 1 person exposed	Between 1 and 10 people exposed	Between 10 and 100 people exposed
II. Serious	No person exposed	At most 1 person exposed	Less than 10 people exposed
I. Moderate	No lethality zone outside the establishment		Less than 1 person exposed

- **Risk Matrix :**

NO	High risk zone
MMR 1	Medium risk zone
MMR 2	Low risk zone
-	Acceptable risk zone

Severity of the consequences on the people exposed to the risk	Likelihood (increasing direction from E to A)				
	E	D	C	B	A
V. Disastrous	NO partiel (new site) / MMR rank 2 (existing site)	NO rank 1	NO rank 2	NO rank 3	NO rank 4
IV. Catastrophic	MMR rank 1	MMR rank 2	NO rank 1	NO rank 2	NO rank 3
III. Major	MMR rank 1	MMR rank 1	MMR rank 2	NO rank 1	NO rank 2
II. Serious			MMR rank 1	MMR rank 2	NO rank 1
I. Moderate					MMR rank 1

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6. Critical scenarios

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- According to risk assessment, the equipment that registers the highest number of critical hazardous events is the **dispenser and its accessories**, but the storage, compression and liquid equipment in the station backyard also present a significant number of scenarios.

- This study shows that the hydrogen dispenser is a safety-critical piece of equipment in a refueling station. The central feared event is a loss of containment which can lead to **explosions in the open air (UVCE) or in a confined environment (VCE inside the dispenser) or to jet fires or flashfires.**

- The risk assessment also highlights that the large number of leaks are related to the **high numbers of fittings** in the different dispensers, potential failure of equipment due to **hydrogen embrittlement, human error** during maintenance, bad connections with hose or nozzle, impact events such as **crash, vehicle driveaway** or domino effects due to the LOC of other fuels.

Number of events	High-risk zone	Intermediate risk zone	Lower-risk zone
Config.1	13	28	2
Config. 2	13	27	3
Config. 3	24	26	4

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Conclusions

Risk assessment :

- For HRS, the most **foreseeable leaks are the small ones** with likelihoods in the range of 10^{-6}/year,
- Focus on forecourt, the **most foreseeable hazardous events occur on the hose** (about 10^{-4}/year).
- The highest number of safety critical scenarios are on the dispenser : 10% diameter of pipe and full-bore rupture of the hose leading to **UVCE or VCE inside the dispenser or jet/flash fires**

The following could be considered to manage the risks :

- Reducing the risk with **safety barriers** : breakaway couplings, crash protection around the dispenser island, gas detection with emergency shutdown, as well as adequate inspection and maintenance of equipment.
- **Reducing the number of connections** as well as the use of **alternative fitting types** should be investigated to reduce the likelihood of release.
- Reducing severity of events by **minimizing the number of people in the vicinity of the dispensers** during any refueling operation (e.g. passengers in coaches).

Next steps : **Refining the risk assessment** of the scenarios and events by considering results of experiments from WP2 of the MultHyFuel project, e.g. leak frequency and size, safety barriers efficiency, domino effects, ignition likelihoods.

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Thank you for your attention

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next MultHyFuel webinar taking place on the **4th of October** between **11 am – 1 pm CEST**.

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