MultHyFuel
Mid-project update webinar

04/10/2023

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101006794. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research

Content

Time	Subject		Speaker
11:00-11:05	**Welcoming words**		**Hydrogen Europe (Dinko Durdevic)**
11:05-11:15	**Introduction to MultHyFuel**		**Hydrogen Europe (Dinko Durdevic)**
11:15-11:30	WP1 - Regulatory analysis on permitting requirements in the EU		Hydrogen Europe (Joana Fonseca)
11:30-11:50	WP3 - Risk assessment and development of guidelines (WP 3)		ENGIE (Sebastien Quesnel)
	Break		
12:00-12:20	WP 2 – Testing results	Leakages, clouds and ignition	INERIS (Christophe Proust)
12:20-12:40		Fire and Explosion	HSE (Louise O'Sullivan)
12:40-12:50	Future events and engagement with industry stakeholders		Hydrogen Europe (Dinko Durdevic)
12:50-13:00	Q&A		

Background and context

With increasing demand for FCEV, Hydrogen Refueling Stations are required to be upscaled and co-located alonsige conventional fuels in commercial and residential areas.

The problem:

- In some countries, specific regulations for HRS don't exist
- Co-location of hydrogen with conventional fuels is not seen in most safety regulations
- Different approaches are taken by different countries

HyLAW

"(…) lack of guidelines and instructions for local authorities can cause **delays** and **extra costs** and may lead to **divergent interpretations** from case-to-case, further complicating the obligations of HRS operators."

2018, https://www.hylaw.eu/

Goals

Goal

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

- Identification of relevant gaps in the current legal and administrative framework;
- Acquisition of experimental data from engineering research on hydrogen leaks, their effects and the effects of mitigation measures;
- Actively engage a community of stakeholders in the overall process, from gap identification to review and validation of the solutions proposed, to facilitate evidence-based policy-making;
- Successfully disseminate the project's results.

Consortium

Air Liquide creative oxygen

ENGIE Lab CRIGEN

BESPOKE RESEARCH AND CONSULTANCY FROM HSE

Hydrogen Europe

ITM POWER Energy Storage | Clean Fuel

INERIS maîtriser le risque pour un développement durable

kiwa

Shell Hydrogen

snam

ZSW

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WP structure

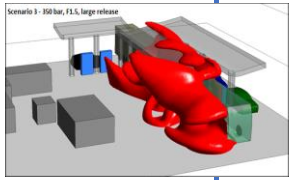
WP6 – Project management

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

	Consequence				
Likelihood	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

Website

Launched July 2021

Includes:

- Summary of project
- Public deliverables
- Slides / recordings from launch event & workshops
- News from project
- Communication, dissemination and exploitation plan

Contact email: info@multhyfuel.eu

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Research into permitting requirements

Preliminary extensive diagnosis of the existing rules, standards and best practices in the domain.

Goal

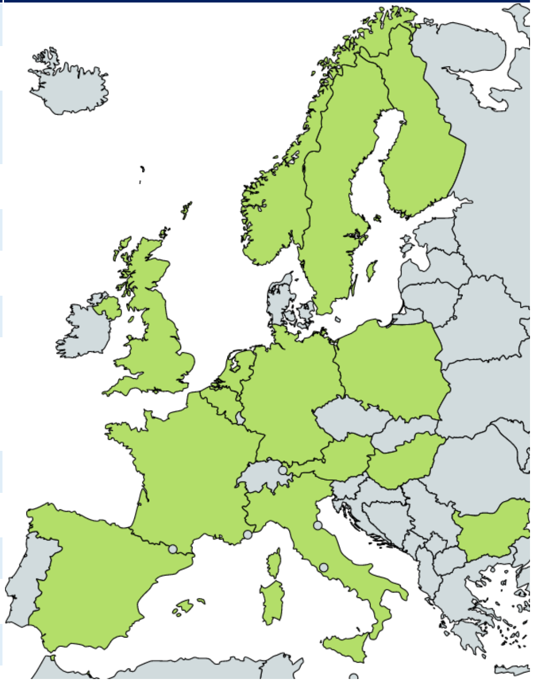
- Collect specific information on requirements, rules, conditions, standards applicable at national level in 14 European countries (Network of National Experts);
- Comparative assessment and gap analysis.

Scope of research

- Existing permitting requirements for HRS;
- Risk Assessment regulations/methodologies;
- Safety or separation distances;
- Intervals and content of equipment maintenance.

Network of National Experts

COUNTRY	ORGANIZATION	EU COVERAGE & REPRESENTATIVENESS
AT	Austrian Energy Agency	
BE	WaterstofNet vzw	
BG	Bulgarian Hydrogen, Fuel Cell and Energy Storage Association	
FI	VTT Technical Research Centre of Finland LTD	
FR	France Hydrogéne	
DE	ZSW	
HU	Hungarian Hydrogen & Fuel Cell Association	
IT	Italian National Agency for new technologies, energy and sustainable economic development and H2 Italy	
NL	NEN	
PL	NEXUS Consultants	
ES	Aragon Hydrogen Foundation	
SE	Hydrogen Sweden	
UK	ITM Power	
NO	Greenstat	



- D1.2 – Permitting requirements and risk assessment methodologies for HRS in the EU (first version)

Divided set of countries

Different countries find themselves in different situation concerning HRS regulation and deployment levels.

Group 1 – No deployment of HRS yet

- Hungary, Poland, Bulgaria

Group 2 – HRS deployed with no HRS-specific guidelines

- Austria, Belgium, Finland, Norway, Sweden, Spain, United Kingdom

Group 3 – HRS deployed and HRS-specific guidelines

- Italy, Germany, France, the Netherlands

Group 1

No deployment of HRS yet (Poland, Bulgaria, Hungary)

- What would happen if an operators wanted to deploy an HRS in these countries?
- Existent HRS-specific guidelines reliant on EU-wide regulation and conventional fuels regulation
- Unexperienced authorities
- Innacurate requirements
- Different resulting safety distances – they are not hydrogen specific, they come from interpreting conventional fuel regulation into what would happen with hydrogen

	PO	BG	HU
Are there HRS-specific guidelines?	No	Yes	Yes
If yes, what are they based on?	Conventional	CNG	LPG/CNG
Safety distance between the H2 dispenser and other fuels	10 m	20-55 m	5 m
Safety distance between H2 dispenser and other equipment	10 m	2.35 m	5 m

Group 2

HRS deployed with no HRS-specific guidelines (AT, BE, FI, NO, SE, ES, UK)

Different rules according to size

2 countries required HAZOP study
4 countries leave it up to the engineer (with some guidelines)

Belgium case: electrolyser would be represented as a combination of standardised components and guidelines are based on industrial data which is not hydrogen-specific

Country	Range where new rules apply	Rules that apply
United Kingdom.1	> 2 tonnes	Assessment is now required from the Hazardous Sustances Agency
United Kingdom.2	> 5 tonnes tonnes (or less when there is the storage of other dangerous substances, such as LPG)	Comes within scope of COMAH regulation and more stringent rules
Finland	> 2 tonnes	Permitting is now required and is in the scope of Tukes
Norway	> 5 tonnes	Permitting is now required

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Group 3

HRS deployed and HRS-specific guidelines (France, Germany, Italy, the Netherlands)

- Safety distances are prescribed but flexible
- Authorities may request more restrictive measures in some countries (France), in others the operator may opt for less restrictive measures at their own risk (Germany, Italy)

The Netherlands: HAZOP is required before HRS starts operation

France: According to different sizes, different regulation will apply. Safety distances depend on the dispenser flowrate.

Germany: Different procedure according to size (3 tonnes). Depending on which ordinance is relevant for the HRS, different aspects must be examined within the framework of the risk assessmentHAZOP is normally asked but not mandatory.

Italy: Guidelines are quite strict unless the operator decides to go for the “engineering approach” and does their own study.

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Agenda

MultHyFuel

1) Introduction

2) Objectives and scope

3) WP3 Preliminary results

4) WP3 tasks in progress

5) Conclusions and next steps

1. Introduction

Achieved
In progress
Not started

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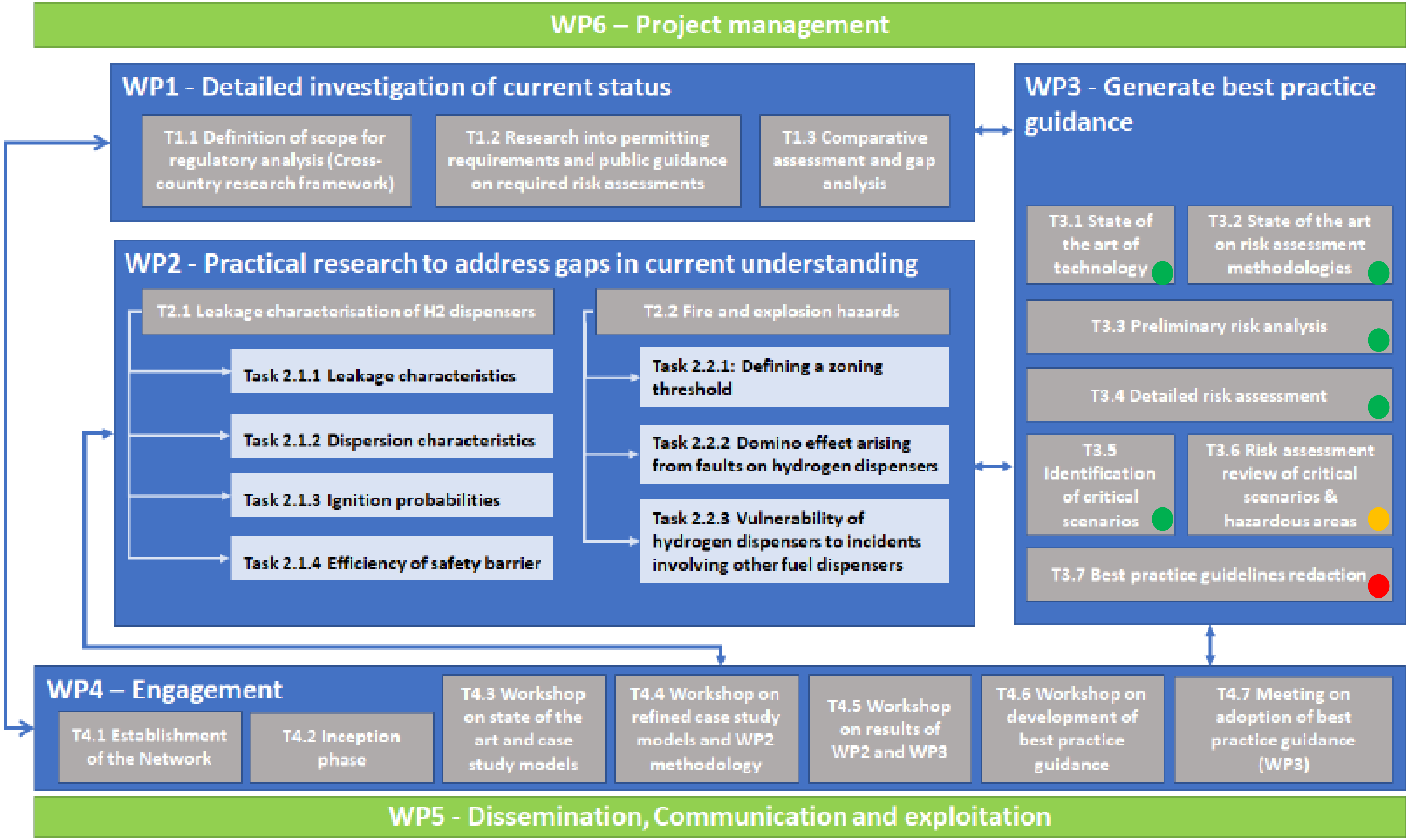

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1. Introduction

Work Package 1: Detailed investigation of current status

Work Package 2: Practical research to address gaps in current understanding

Work Package 3: Generate best practice guidance

- **Task 1:** State of the art about refueling station technologies to define case study models
- **Task 2:** Benchmark of risk assessments on H2 & conventional stations to recommend tools/methods for risk assessment in Multiple fuels context
- **Task 3 & 4:** Preliminary and detailed risk assessments on 3 case study configurations
- **Task 5:** Identification of critical scenarios and safety barriers to be studied in WP2 (experimentation)
- **Task 6:** Review of critical scenarios with inputs from WP2 to define separation, safety distances, hazardous areas
- **Task 7:** Writing best practices guidelines for multi fuels stations based on findings of WP3

Work Package 4: Engagement

Work Package 5: Dissemination, communication and exploitation

2. Objectives

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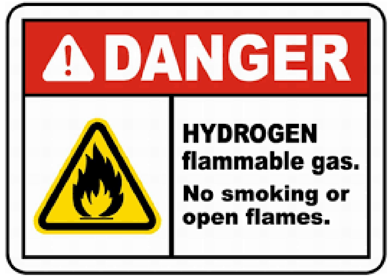
- to develop best practice guidelines that can be used as a common approach to **risk assessments** (e.g. suggested methods/tools for risk modelling, Atex, safety distances)
- to determine recommendations for the safe **implementation of H2 dispensers in multi-fuel stations** (separation distances, safety barriers) to be used in standards and regulation relative to HRS
- to confirm risk **assessment assumptions by experimentations** (severity, likelihood, failure) on dispenser accessories



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2. Task 3.1 – definitions of configurations

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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

Figure 1: Example of the studied configuration (configuration 1)

Hydrogen refuelling with **different configurations** (supply, flowrate, light and heavy vehicles) :

- #1 – Ready-to-deploy multi-fuel station (*« simple » and already used technologies, situated in sub- or urban location with car and trucks/buses*)
- #2 – On-site H2 production multi-fuel station (*on-site hydrogen production, situated in suburban location with car and trucks/buses*)
- #3 – High capacity & High filling multi-fuel station (*future large needs of hydrogen for mobility, situated in industrial location with dispensers 300 g/s*)

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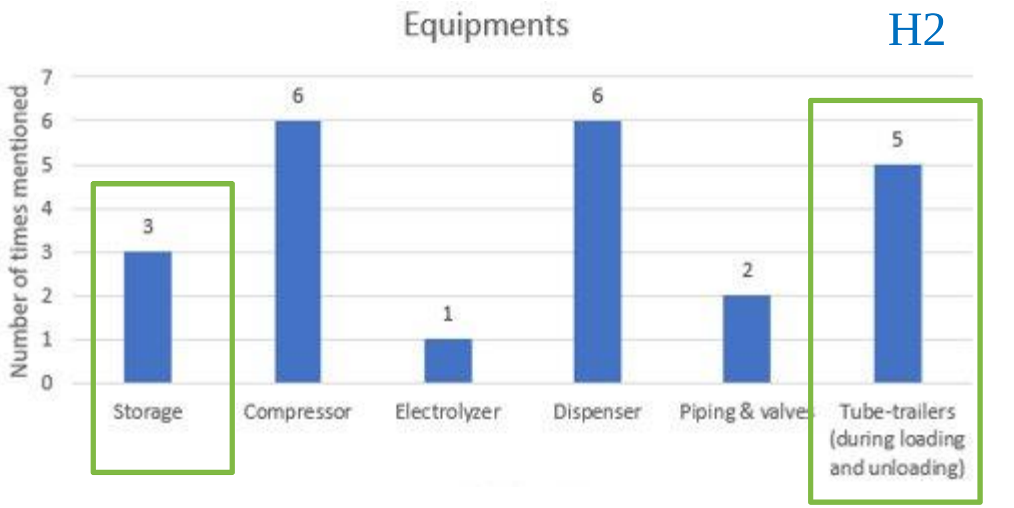
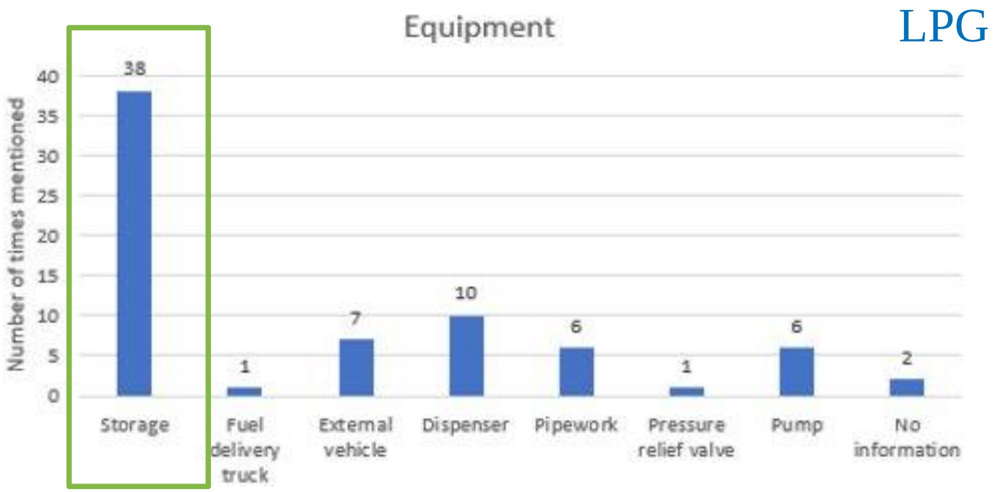
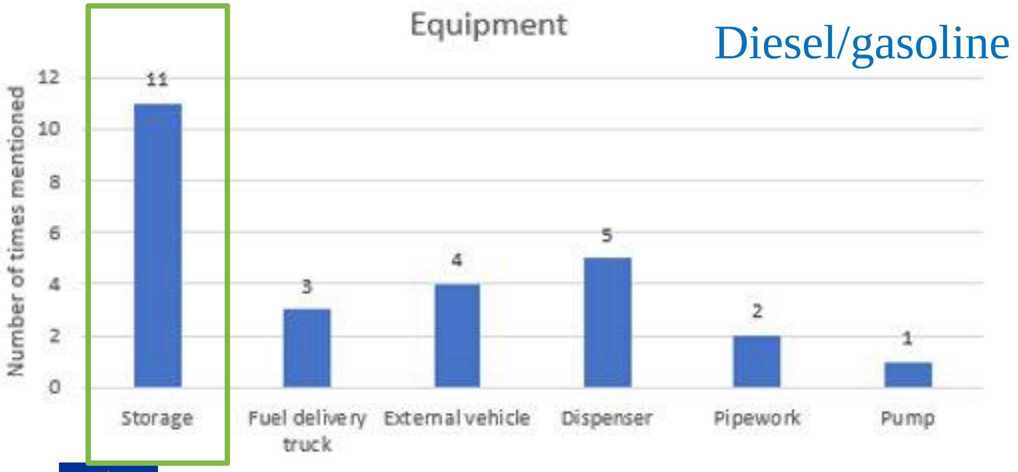
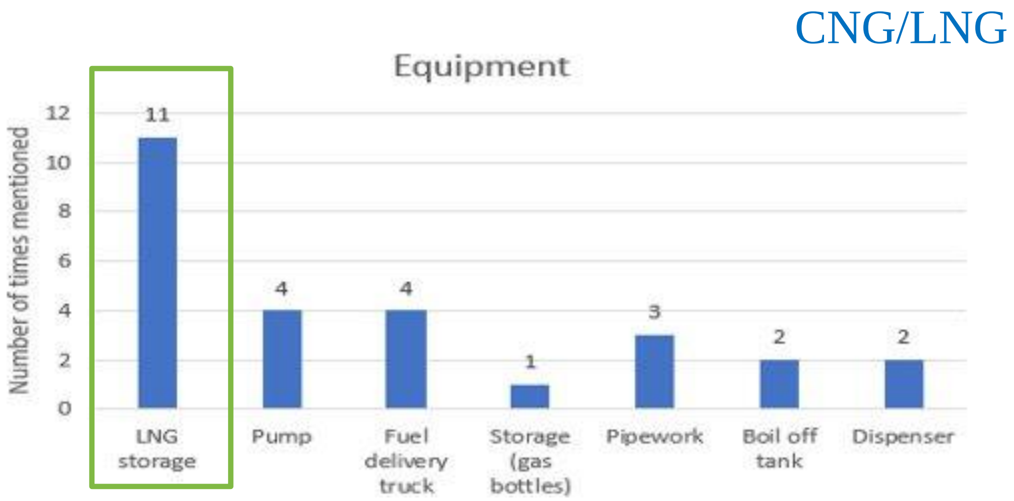
3. Task 3.2 – lessons learned

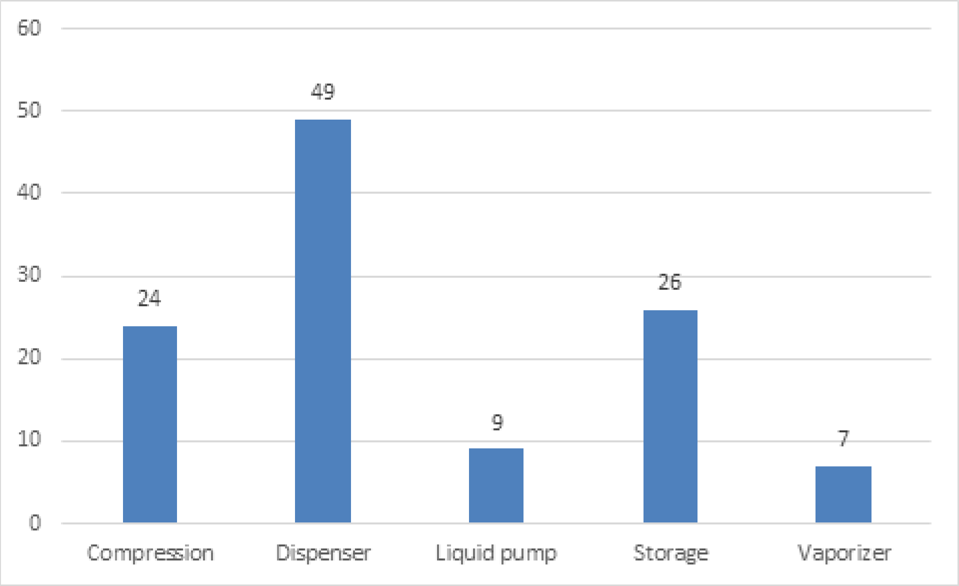


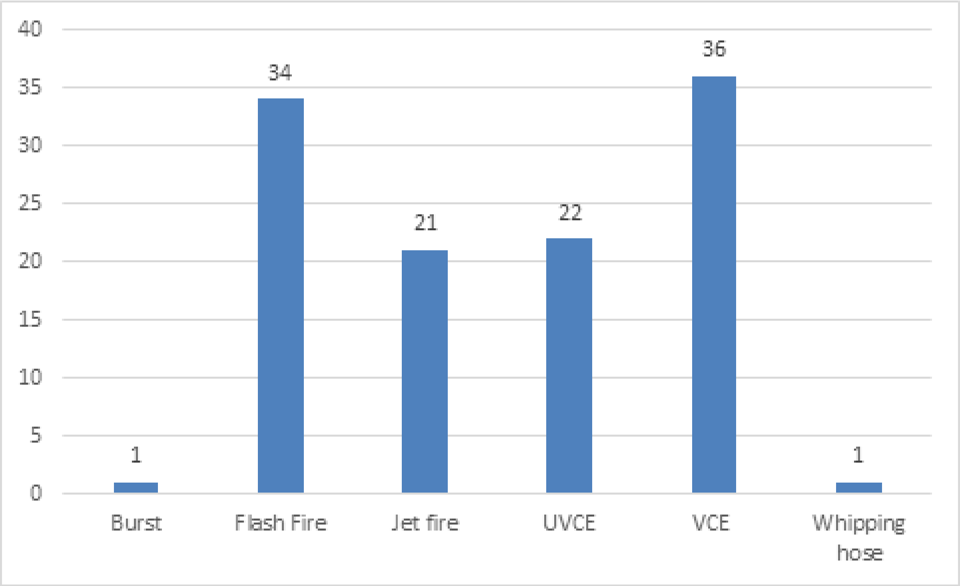


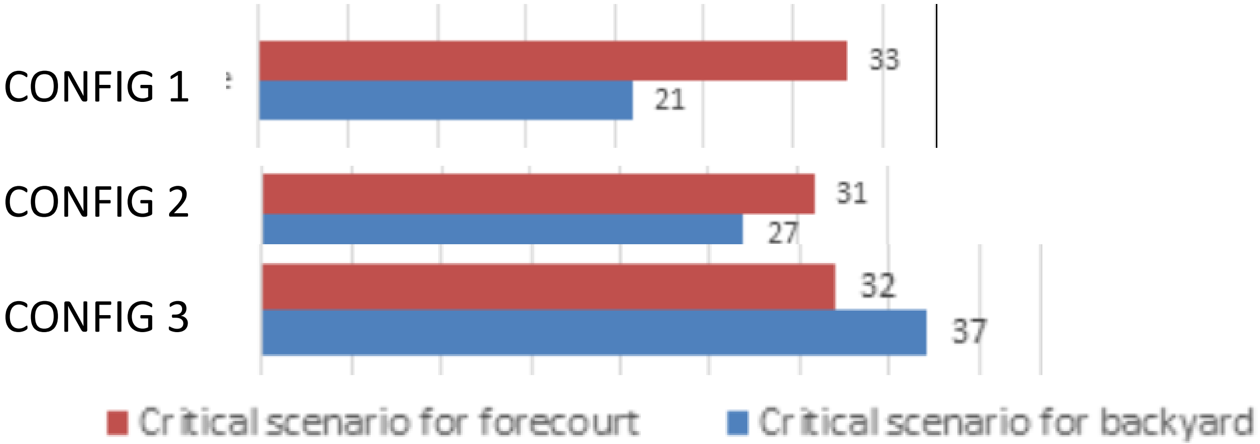




3. Task 3.3 : preliminar risk assessment







3. T3.3 – PRA : safety barriers examples

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Topics	Example of recommendations
Design	Canopy roof to limit degree of confinement
	Choice of materials : H2 compatible materials (e.g. for fittings, pipings, seals…)
	Safe location of outlet for vent lines
	Pressure safety valves, bursting discs, explosion panels
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 (i.e hoses, liquid tank or tube trailer, dispenser, piping, buffer storage)
Detection	H2 flame and gas detection with associated emergency protocols (e.g. alarms, shutdown…)
Isolation	Shut-off valves to isolate equipment
	Flowrate restriction orifices, break-aways, quick couplings

3. T3.4 – detailled risk assessment

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- **Likelihood example :**

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	DATABASE Sandia	DATABASE 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.

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3. T3.4 – detailled risk assessment

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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)

4. T3.5 – identification of 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

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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5. T3.6 – review of critical scenarios RA

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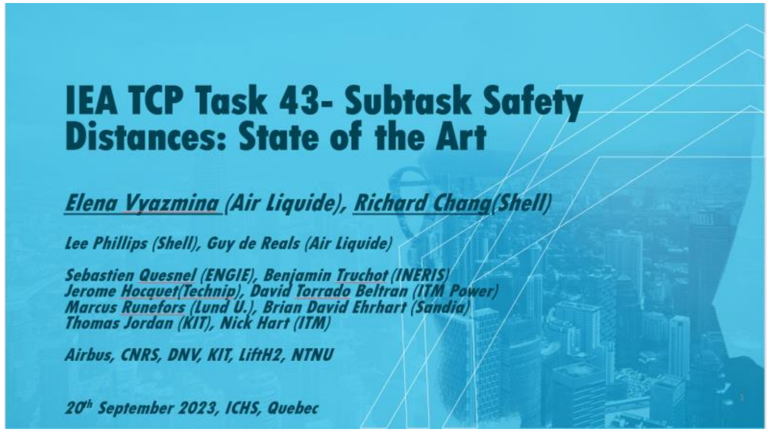
I N P R O G R E S S

Sub tasks of 3.6	Status
3.6.1 **Benchmarking** on Hazardous Area Classification & separation distances	In progress
3.6.2 **Review of severity** of critical scenarios : comparison of experimentation T2.1 with T3.4 calc on dispensers scenarios	Not started
3.6.3 **Review of likelihood** of critical scenarios	Not started
3.6.4 Comparison of **leak size** from test on H2 equipment (WP2) with leak size used in 3.3/3.4 (Hazardous classification)	In progress
3.6.5 Complementary calculations if needed (i.e., explosion inside dispenser) simple models only	Not started
3.6.6 Definition of approach for HAC & separation distances	In progress
3.6.7 Case study on a dispenser to apply approach (a and b) defined in 3.6.6	Not started
3.6.8 Taking in consideration experimentation results on safety barriers for likelihood evaluation	Not started
3.6.9 Taking in consideration experimentation results on dominos effect between dispensers for separation distances	Not started
3.6.10 Revised matrix of critical scenarios	Not started
3.6.11 Recommendations of separation distance between dispensers	Not started
3.6.12 Recommendation of hazardous are classification around H2 dispenser	Not started

- Achieved
- In progress
- Not started



GAPS:

Harm criteria

- Radiation vs. temperature
- **People**: Overpressure criteria varies from 50mbar – 140mbar to not considered
- **Equipment:** Thermal radiation criteria varies from 10kW/m2 – 40kW/m2. Some consider overpressure

Leak scenarios

- Range of hole sizes for consequence & risk based approaches
- Explosion severity limits to be considered (LFL vs 8% vs 10% in air)

E. Vyazmina, G. de Reals, R. Chang, L. Phillips, S. Quesnel, B. Truchot, J. Hocquet, D. Torrado Beltran, M. Runefors, B. D. Ehrhart, "IEA TCP Task 43- subtask Safety Distances: state on the art", ICHS, Québec City, Canada, September 19-21, 2023.

Participant	Participant A	Participant B	Participant C	Participant D	Participant E
Use Case	HRS, Electrolysers, Storage	HRS, Electrolysers, Storage	HRS	HRS	Any H2 installations
Country	France	Sweden	Netherlands, Germany, UK	France	USA
Regulation	ICPE 4715/1416	MSBFS 2020	PGS 35 TRBS-3151 APEA/BCGA/EI Guidance – UK 'Blue Book'	national regulation, standards are used to evaluate the failure probability	NFPA-2
Company Methodology For Safety Distances	Consequence based at feasibility stage Risk based at detailed design stage	Follow MSBFS 2020 approach which is consequence based	Follow safety distances in relevant standards	Safety distance objective is to prevent any consequences on target (human beings). The evaluation is risked based, consequences and probabilities are taken into account.	Consequence-based distances using a risk-informed leak size
Leak Scenarios	Feasibility: Full bore (external safety distance) 10% diameter leak (internal safety distance) Detailed design: Same approach but further refinements	3% leak - asset damage 10% leak - single fatality 100% leak - multiple fatalities	Safety distances based on 10% leaks of typical pipe diameters at HRS for PGS 35 Unknown for Germany & UK	Full bore rupture and 10% of the diameter leak, thermal aggression on storage	Multiple leak sizes (from 0.01%-100% of flow area) for the risk-informed analysis, but then setback distances themselves use a constant 3% (now 1%) fractional leak size for gaseous hydrogen and 5% for liquid hydrogen
Harm Criteria	French Regulations used in France only Company specific harm criteria based on NFPA 2020 used in other regions **People**: 4.7kW/m2 & 50mbar **Buildings**: 25kW/m2 & 140mbar **Equipment**: 25-40kW/m2 & 200mbar	**People**: 309degC for individuals, 115degC for areas with groups of people **Buildings**: Flame impingement Equipment: 10 - 30kW/m2 depending on equipment size and pressure	Dutch standards (PGS 35) **People**: 3kW/m2 (public), 10kW/m2 (1% lethality) **Buildings**: 10-35kW/m2 **Equipment**: 10-35kW/m2	French regulation (29/09/2005) **Thermal radiation** : 3 kW/m², 5 and 8 kW/m² **Overpressure** : 50 mbar for non-reversible effect, 140 and 200mbar for 1 to 5% of lethality	**Thermal Radiation**: 4.732 kW/m2 exposure of employee for 3 minutes 9 kW/2 for LH2, 4.732 kW/m2 for GH2 for cars and exposed persons not servicing the system and combustible buildings 20 kW/m2 for non-combustible buildings and other hazardous materials **Overpressure** (only considered for LH2): 70mbar, 137mbar, 170mbar

5. 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).

5. Next steps

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- Review of risk assessment on critical scenarios with experimental results : **theory vs exp (Task 3.6)**

- Establishment of **guidelines** for implementing Hydrogen Refuelling Stations (HRS) in a multifuel environment (2024-1) : **safety barriers, separation distances, hazardous area classification…**

- **Targeted engagement with standardisation bodies** (e.g. CEN/CLC JTC 6: Hydrogen in Energy Systems, CEN/CLC Sector Forum Gas Infrastructure: Mobility, …)

- **Workshops** : European Hydrogen Week on November 21st

Content

Time	Subject		Speaker
11:00-11:05	Welcoming words		Hydrogen Europe (Dinko Durdevic)
11:05-11:15	Introduction to MultHyFuel		Hydrogen Europe (Dinko Durdevic)
11:15-11:30	WP1 - Regulatory analysis on permitting requirements in the EU		Hydrogen Europe (Joana Fonseca)
11:30-11:50	WP3 - Risk assessment and development of guidelines (WP 3)		ENGIE (Sebastien Quesnel)
	Break		
12:00-12:20	WP 2 – Testing results	Leakages, clouds and ignition	INERIS (Christophe Proust)
12:20-12:40		Fire and Explosion	HSE (Louise O'Sullivan)
12:40-12:50	Future events and engagement with industry stakeholders		Hydrogen Europe (Dinko Durdevic)
12:50-13:00	Q&A		

Break

Content

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11:00-11:05	Welcoming words		Hydrogen Europe (Dinko Durdevic)
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	Break		
12:00-12:20	**WP 2 – Testing results**	**Leakages, clouds and ignition**	**INERIS (Christophe Proust)**
12:20-12:40		Fire and Explosion	HSE (Louise O'Sullivan)
12:40-12:50	Future events and engagement with industry stakeholders		Hydrogen Europe (Dinko Durdevic)
12:50-13:00	Q&A		

Safety and Permitting for Hydrogen at Multifuel Retail

MultHyFuel

Public Webinar

Public Webinar – WP 2.1

04th October 2023

MultHyfuel @ INERIS

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MultHyFuel

MultHyFuel Project – Work Package 2 Overview

MultHyFuel

Work Package 1: Detailed investigation of current status

Work Package 2: Practical research to address gaps in current understanding

- Determine leakage frequencies, flow rates, extent of hazardous zones and ignition probabilities for faults on HRS (hydrogen refuelling station) plant;
- Reproduce the key fire and explosion scenarios which cannot be investigated sufficiently using simpler modelling tools, studying these both experimentally and using Computational Fluid Dynamics (CFD);
- Test the performance and reliability of key safety barriers, identified in WP3, under realistic conditions;
- Conduct experiments to demonstrate the effect of hazardous occurrences on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt, and vice-versa.

WP2.1

Work Package 3: Generate good practice guidance

Work Package 4: Engagement

Work Package 5: Dissemination, communication and exploitation

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WP2.1.1 – leakage frequencies and flowrates

Using existing databases ?

Config.	CFE	Pressure	DATABASE (leak/year) BEVI (purple book)	Sandia (HyRAM)	Norskeolje&gas PLOAFM	PhD
1	Loss of H2 containment (medium leak 10%) on hose	350 bar	10^{-3}	10^{-4}	10^{-5}	(U)VCE Flashfire Jet fire
2			10^{-3}	10^{-4}	10^{-5}	
3			10^{-3}	10^{-3}	10^{-4}	
1		700 bar	10^{-3}	10^{-4}	10^{-5}	
2			10^{-3}	10^{-4}	10^{-4}	
3			10^{-3}	10^{-3}	10^{-4}	
1		1000 bar	10^{-3}	10^{-4}	10^{-4}	
2			10^{-3}	10^{-4}	10^{-4}	
3			10^{-3}	10^{-3}	10^{-4}	
1	Full bore rupture (1'' = 2.54 mm) on hose	350 bar	10^{-3}	10^{-4}	10^{-5}	
2			10^{-3}	10^{-4}	10^{-5}	
3			10^{-3}	10^{-3}	10^{-4}	
1		700 bar	10^{-3}	10^{-4}	10^{-4}	
2			10^{-3}	10^{-4}	10^{-5}	
3			10^{-3}	10^{-3}	10^{-5}	
1		1000 bar	10^{-3}	10^{-4}	10^{-5}	
2			10^{-3}	10^{-4}	10^{-5}	
3			10^{-3}	10^{-3}	10^{-5}	

Multhyfuel – deliverable 3.4

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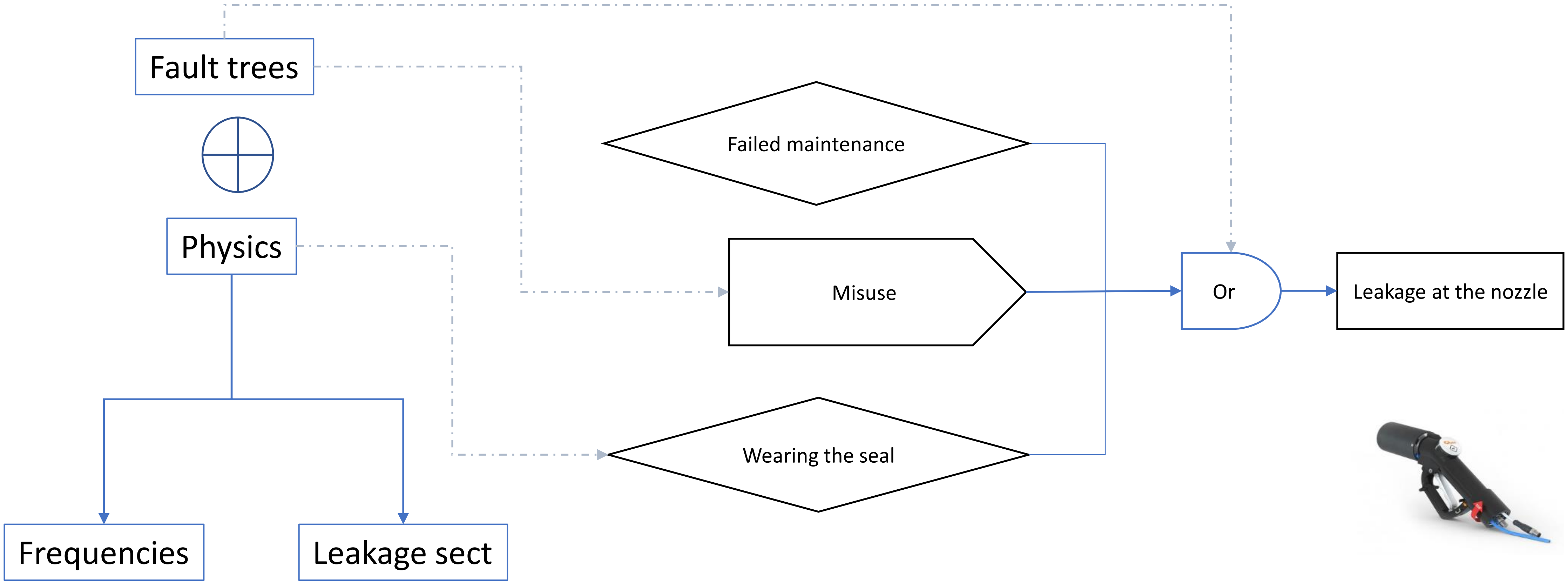
WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : principles



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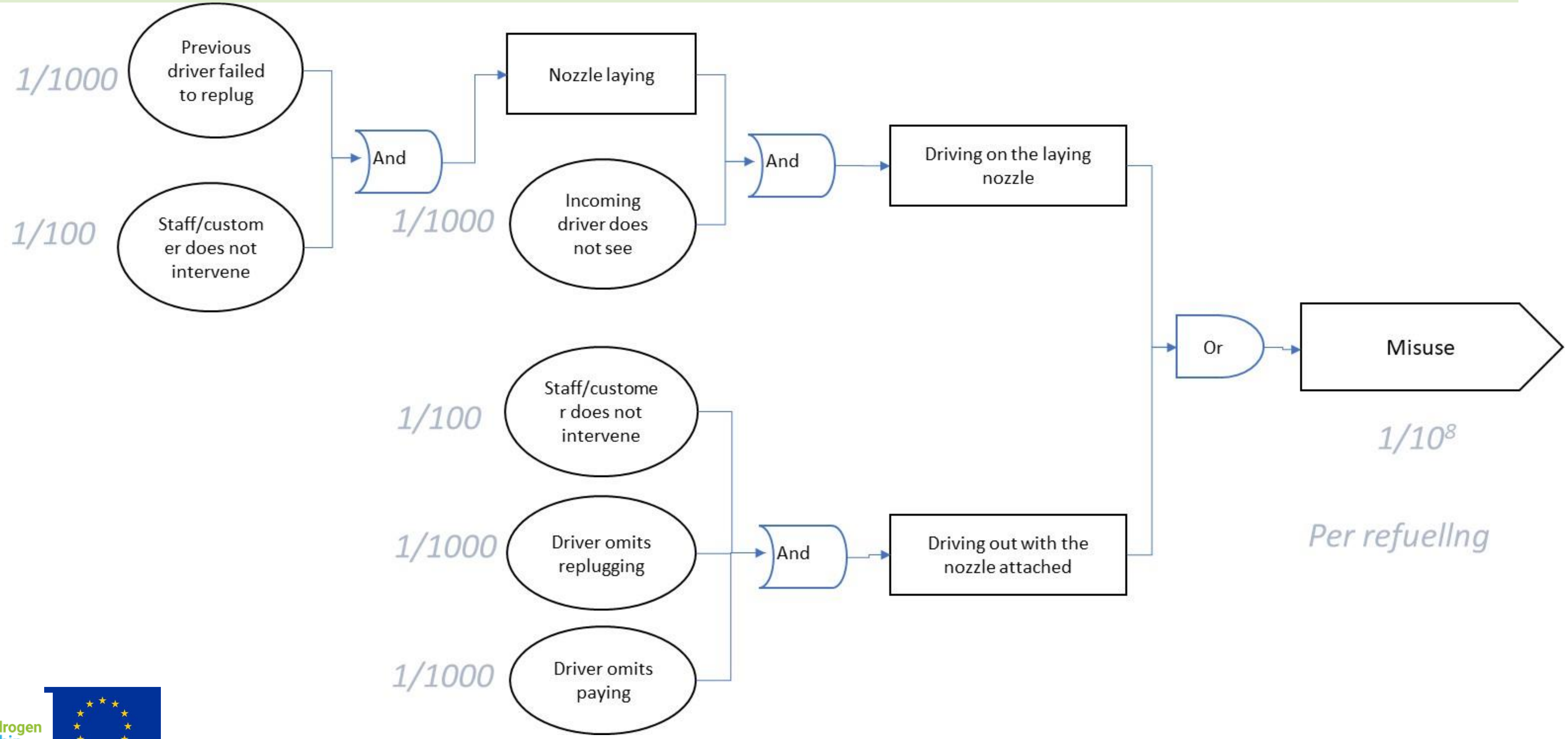
WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : principles



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WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : principles

Physical modeling => wear :

- Moving part like valve stems and the closing part of a check valve (in the breakaway and in the nozzle) are concerned. Steel dry rubbing over steel is assumed.
- The steel/steel wear rate is between 10^8 and 10^9 µm³/(km.N). In km the length of the sliding zone and in N the normal force.
- The steel/polymer wear rate is between 10^9 and 10^{10} µm³/(km.N)
- It is assumed that the tightness is lost after having abraded 10% of the thickness of the sealing piece

Component name	nozzle
comment	abrasion of the O ring
diameter of the O ring (m)	0,012
thickness (m)	0,002
sliding ditance at each cycle (m)	0,01
wearing rate (micro m³/kmN)	10000000000
sliding force (N) assumed 10 kgf max	100
reduction of thickness at each cycle (mm)	2,65258E-10
leaking criterion abrasion of x% thickness	10
number of cycles before leakage	**753982,2369**
Maximum feeding diameter (m)	0,004
outer leakage diameter m	0,0102
inner leakage diameter m	0,01
leakage path length m	0,02
Hydraulic diameter m	0,0002
Physical leakage cross section m2	3,17301E-06
Area reduction due to head losses	0,377964473
% of feeding area	**9**

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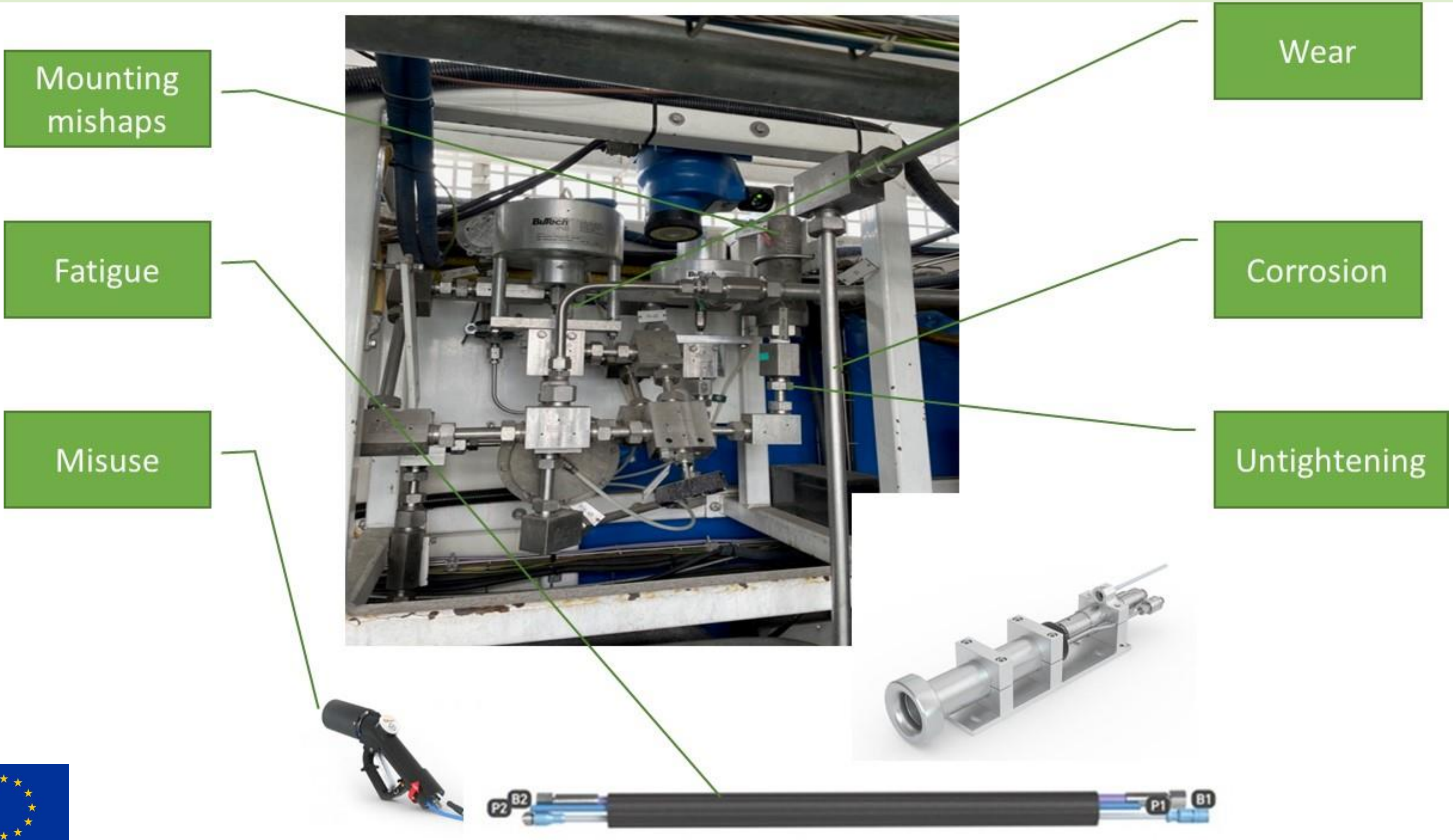
WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : practise



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WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : practise

Components
- 1000 b Nozzle ID4mm (3/8'')

Solicitations
- Deficient mounting procedure
- Misuse
- Wear (seals, seats)

For one manipulation

Component name	nozzle
comment	leakage through sealing system
nber of critical operations to assemble the component	10
nber of assembly/disassembly of the component/year	1
nber of such component in the dispenser	1
Leakage frequency nber/year	**0,01**
Maximum feeding diameter (m)	0,004
outer leakage diameter m	0,0102
inner leakage diameter m	0,01
leakage path length m	0,02
Hydraulic diameter m	0,0002
Physical leakage cross section m2	3,17301E-06
Area reduction due to head losses	0,377964473
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sliding ditance at each cycle (m)	0,01
wearing rate (micro m^3/kmN)	10000000000
sliding force (N) assumed 10 kgf max	100
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leakage path length m	0,02
Hydraulic diameter m	0,0002
Physical leakage cross section m2	3,17301E-06
Area reduction due to head losses	0,377964473
% of feeding area	**9**

- Conclusions :
  - Deficient mounting :
    - Failed maintenance procedure of the nozzle (fault tree : 10^{-2}/proc)
    - Bad plugging by the user (damaged or dirty receptacle : not properly maintained) => as above
    - 9% of full bore cross section
  - Wear :
    - Failure of the compression seal after 10^5 cycles or refuelling ($N_{end\text{-}cycles}$)
    - Note : abrasion of the seal of the vehicle after 7 10^5 cycles whereas only about 10^3 refuelling during vehicle lifetime
    - 9% of full bore cross section
  - Misuse : tearing off the nozzle:
    - slide 8 : 10^{-8}/refuelling
    - Full bore rupturing (ID 4 mm)
- Comments :
  - Breakaway assumed not functional
  - Fatigue of the clamping system ?

WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : verification & validation => failure rate (frequency) by **KIWA**

Component name	ckeck valve 3/8
comment	internal leakage
inner diameter of the seal (m)	0,005
thickness of the seal (m)	0,001
sliding distance at each cycle (m)	0,001
sliding force (N) assumed 10 kgf	1374,446786
wearing rate (micro m^3/kmN)	10000000000
abraded thickness at each cycle	8,75E-10
leackage criterion by decreasing in % Din	10
number of cycles before blockage	**114285,7143**

Component name	flow valve 3/8 -KIWA stem
comment	blockage of the stem in the screw
inner diameter of the screws (m)	0,005
thickness of the thread (cross section m)	0,0005
sliding distance at each cycle (m)	0,157079633
sliding force (N)	137,4446786
wearing rate (micro m^3/kmN)	1000000000
abraded thickness at each cycle	1,37445E-09
blockage criterion by accumulation in % Din (0,0002 mm)	4
number of cycles before blockage	**14551,30908**

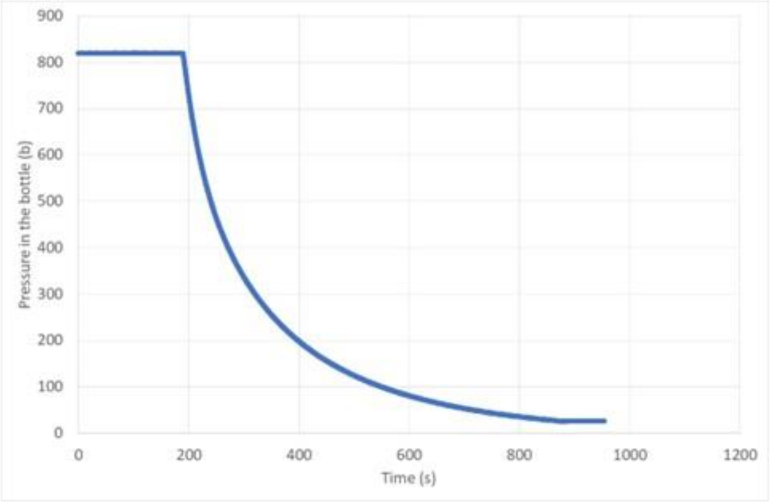
situation	size	failure (cycles)
manual valve rotation 0-360°	3/8''	10 000 - 60 000
check valve cycling 0->70 MPa	3/8''	order 100 000
hose pressure cycling 0->70MPa	3/8''	75 000
fittings pressure cycling 0->70MPa	9/16''	above 250 000

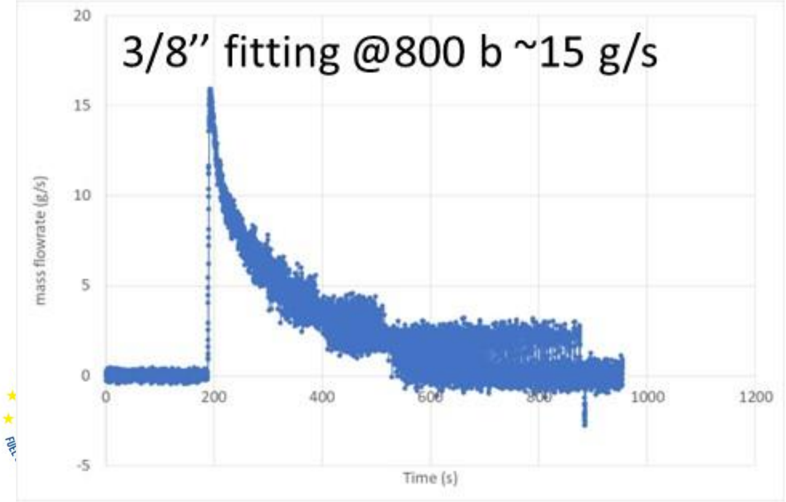
Component	fitting 9/16
Pressure amplitude (Mpa)	70
Temperature amplitude	0
nber of identical fittings	1
nber of Pcycles/y	1
unscrewing by axial loading	
Friction coefficient x dissipation factor	0,001
Thermal dilatation coef (1/°C)	0,000017
Poisson coefficient	0,3
Young modulus (Mpa)	200000
Yield stress (Mpa)	600
screw core diameter (m)	0,022
inner diameter of the screw (m)	0,014
thread size (m)	0,001
screwing force (% of yield)	80
length of the stressed zone	0,011
Tightening stress (Mpa)	480
Tightening angle (rad)	0,165876092
extra stress due to pressure cycle (Mpa)	14,7875
maximum internal temperature difference °C	0
extra stress due to temperature cycle (Mpa)	0
Sliding angle due to extra stress by overpressure	3,84475E-07
nber of pressure cycles to unscrewing	**431435,3134**

Component	POM hose
3 mm POM thick (75 Mpa) + 0.5 mm steel wires (800 MPa)	
Temperature amplitude (int/ext)	0
mean working pressure (Mpa)	70
Thermal dilatation coef (1/°C)	0,00008
Poisson coefficient	0,35
Young modulus (MPa axial)	3000
Radial Ultimate strength (MPa axial 100 MPa)	192,481203
Radial yield stress (MPa axial 100 MPa)	141,3533835
Pipe outer diameter (m)	0,013
Pipe inner diameter (m) -feeding	0,006
length (m)	1
min bend (m)	0,18
Sollicitation mode	***radial stress***
Maximum internal temp gradient (°C)	0
Maximum stress due to temperature cycles (M	0
Maximum stress due to pressure cycles (Mpa)	95
number of cycles to rupture	**111418,1718**

WP2.1.1 – leakage frequencies and flowrates

A new approach : verification & validation => maximum “realistic” flowrate cross section





P (b)	component	event	mass flowrate (g/s)	meas % full cross section	Predicted %
800	full bore 0.5 mm	reference	10	100	
800	full bore 2 mm	reference	160	100	
800	full bore 2.6 mm (1/4")	estimated	270	100	
800	full bore 5 mm (3/8")	estimated	1000	100	
800	full bore 7.8 mm (9/16"")	estimated	2434	100	
800	Maximator U fitting 9/16"	Unscrewing/bad mounting	30-50	1,6	**5**
800	Maximator U fitting 3/8"	Unscrewing/bad mounting	15-30	2,0	**8**
800	Maximator U fitting 1/4"	Unscrewing/bad mounting	10	3,7	**19**
800	Maximator valve 9/16"	Bad mounting	1-3	0	**4**
800	Maximator valve 3/8"	Bad mounting	20-30	3	**9**
800	Maximator valve 1/4"	Bad mounting	10-12	4	**24**

WP2.1.1 – leakage frequencies and flowrates

MultHyFuel

A new approach : outcome

Equipement	sollicitation	nbre/cycle or year to failure	%fullbore	nber/components	nber/cycle/year	unit failure rate /year	failure rate /year
pipe 9/16 (ID=7.8 mm)	Fatigue due to P and T cycling (elongation mode)	2E+11	100	10	10000	0,00000005	5,00E-07
pipe 9/16 (ID=7.8 mm)	Corrosion	5000	100	1	1	0,0002	2,00E-04
pipe 3/8 (ID=5 mm)	Fatigue due to P and T cycling (elongation mode)	3000000000	100	10	10000	3,33333E-06	3,33E-05
pipe 3/8 (ID=5 mm)	Corrosion	3000	100	1	1	0,000333333	3,33E-04
Hose (3/8)	Fatigue due to P and T cycling (radial mode)	100000	100	1	10000	0,1	1,00E-01
Hose (3/8)	Misuse (tearing off, driving on)	100000000	100	1	10000	0,0001	1,00E-04
Nozzle (3/8)	Deficient mounting (plugging, maintenance)	100	9	1	10000	100	1,00E+02
Nozzle (3/8)	Wear (seals)	100000	9	1	10000	0,1	1,00E-01
Nozzle (3/8)	Misuse (tearing off, driving on)	100000000	100	1	10000	0,0001	1,00E-04
Breakaway (3/8)	Fatigue due to P and T cycling (elongation mode)	10000000	9	1	10000	0,001	1,00E-03
Breakaway (3/8)	Deficient mounting (plugging, maintenance)	100	9	1	1	0,01	1,00E-02
Flow valves (9/16)	Deficient mounting (maintenance)	100	4	5	1	0,01	5,00E-02
Flow valves (9/16)	Wear (seals)	20000000	2	5	10000	0,0005	2,50E-03
Flow valves (1/4)	Deficient mounting (maintenance)	100	24	1	1	0,01	1,00E-02
Flow valves (1/4)	Wear (seals)	20000000	15	1	10000	0,0005	5,00E-04
Pressure control valve (9/16)	Deficient mounting (maintenance)	100	1	1	1	0,01	1,00E-02
Pressure control valve (9/16)	Wear (seals)	1000000000	1	1	10000	0,00001	1,00E-05
Pressure safety valve (3/8)	Deficient mounting (maintenance)	100	1	1	1	0,01	1,00E-02
9/16'' union couplings	Deficient mounting (maintenance)	100	5	20	1	0,01	2,00E-01
9/16'' union couplings	Untightening due to pressure cycling	400000	5	20	10000	0,025	5,00E-01
3/8'' union couplings	Deficient mounting (maintenance)	100	8	20	1	0,01	2,00E-01
3/8'' union couplings	Untightening due to pressure cycling	300000	8	20	10000	0,033333333	6,67E-01
1/4'' union couplings	Deficient mounting (maintenance)	100	19	20	1	0,01	2,00E-01
1/4'' union couplings	Untightening due to pressure cycling	200000	19	20	10000	0,05	1,00E+00

Eq typically 1-2 mm

- No « small » leaks…
- Full bore from databases 10^{-5} to 10^{-3}/y)

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WP2.1.2 – hazardous zones

MultHyFuel

Complex geometries = > CFD simulations / choice and validation

Tools :

- CFX (HSE), FLACS (AL), OpenFOAM 1812 and KFX (Shell), OpenFOAM1912 (INERIS)
- Mosly RANS k-epsilon
- Notional nozzle "source terms" to avoid simulating the expansion zone

Validation tests:

- underexpanded H2 releases (40 b, 12 mm) in the open atmosphere and inside an array of cylindrical obstacles,
- Small vertical jet in a box (stratification)
- Cm sized cells

Remarks :

- The choice of the "source term" model might be the most impacting parameter
- The dimensions of the cloud seem overestimated (on average) with a scattering of about +/-25%

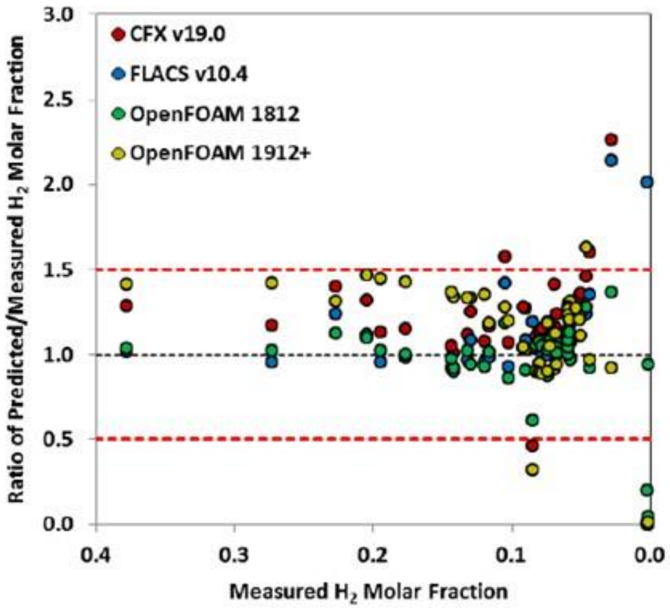


Figure 8 – Ratio of predicted-to-measured concentration as a function of H_2 molar concentration for the unobstructed free jet scenario. Figure includes both centreline and radial data from Figure 6 and Figure 7

Clean Hydrogen Partnership

WP2.1.2 – hazardous zones

Complex geometries = > CFD simulations / results

Scenarios :

- 3 configurations
- 2 atmospheric conditions
- Several leakages

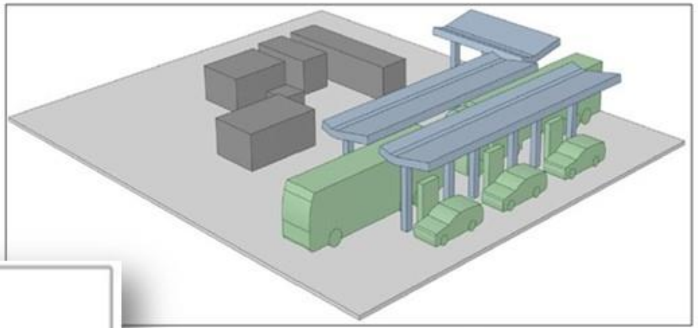


Figure 32 – Perspective view of the 3D geometry for Configuration 1

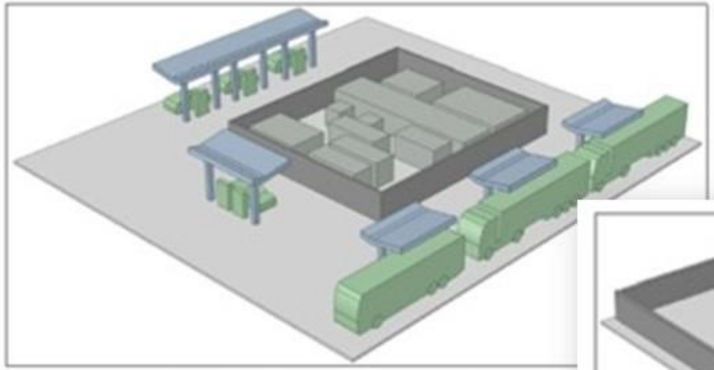


Figure 33 – Perspective view of the 3D geometry for Configuratio

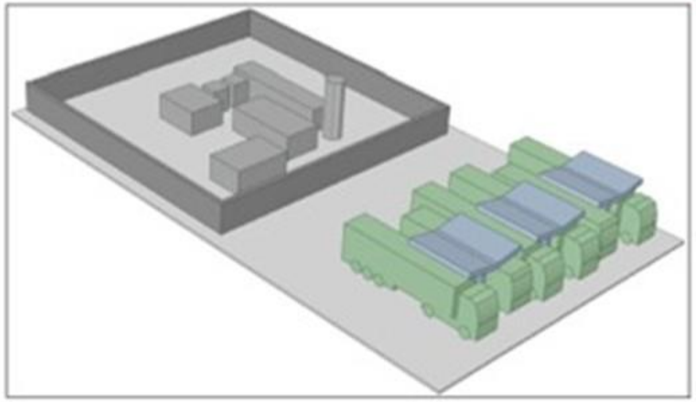


Figure 34 – Perspective view of the 3D geometry for Configuration 3

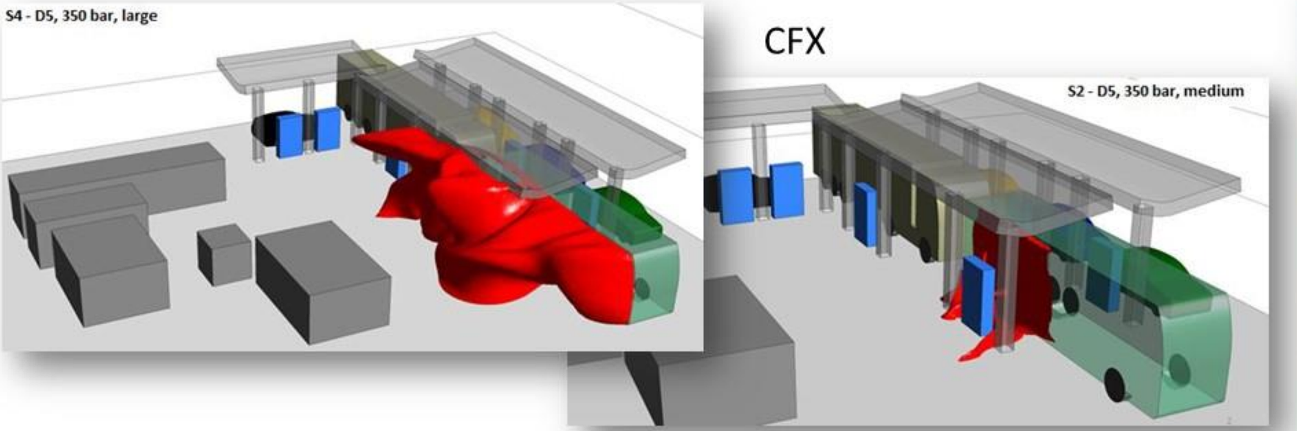
Scenario No.	Release Type	Release Location	Leak Size	Pressure (barg)	Mass Flow Rate (g/s)	Wind Condition	Configuration
1	External	Hose	Medium	350	14.8	F1.5	1
2						D5	
3			Large		120.0*	F1.5	
4						D5	
5			Medium	700	25.9	F1.5	
6						D5	
7			Large		60.0*	F1.5	
8						D5	
9	External	Hose	Medium	350	14.8	F1.5	2
10						D5	
11			Large		120.0*	F1.5	
12						D5	
13			Medium	700	25.9	F1.5	
14						D5	
15			Large		60.0*	F1.5	
16						D5	
17	Internal	Pipe/Valve	Small	1000	1.5	F1.5	3
18						D5	
19			Medium	350	14.8	F1.5	
20						D5	
21	External	Hose	Small	350	0.7	F1.5	
22						D5	
23			Medium		14.8	F1.5	
24						D5	
25			Large		120.0*	F1.5	
26						D5	
27			Large	700	300.0*	F1.5	
28						D5	

Table 14 – List of realistic release scenarios to be modelled using CFD tools. Cases marked with (*) indicate that the mass flow rate is restricted to the dispenser H2 delivery flow rate. All other mass flow rates have been estimated using the FCH2 e-Laboratory *Jet Parameters* tool

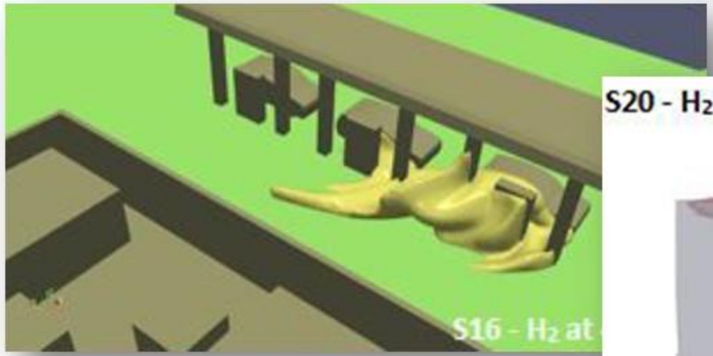
WP2.1.2 – hazardous zones

MultHyFuel

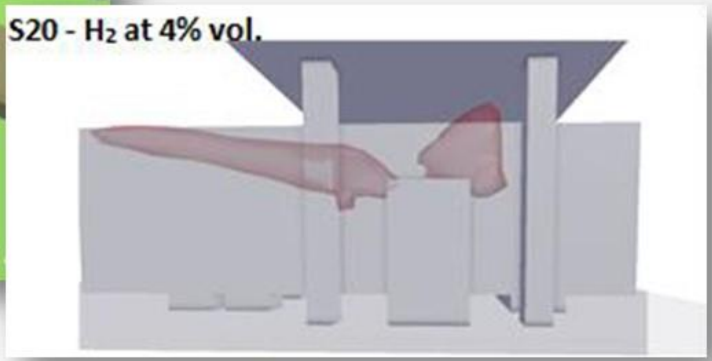
Complex geometries = > CFD simulations / results



CFX



OPENFOAM



FLACS

Scenario No.	Release Type	Release Location	Leak Size	Pressure (barg)	Mass Flow Rate (g/s)	Wind Condition	Configuration
1	External	Hose	Medium	350	14.8	F1.5	1
2						D5	
3			Large		120.0*	F1.5	
4						D5	
5			Medium	700	25.9	F1.5	
6						D5	
7			Large		60.0*	F1.5	
8						D5	
9	External	Hose	Medium	350	14.8	F1.5	2
10						D5	
11			Large		120.0*	F1.5	
12						D5	
13			Medium	700	25.9	F1.5	
14						D5	
15			Large		60.0*	F1.5	
16						D5	
17	Internal	Pipe/Valve	Small	1000	1.5	F1.5	3
18						D5	
19			Medium	350	14.8	F1.5	
20						D5	
21	External	Hose	Small	350	0.7	F1.5	
22						D5	
23			Medium		14.8	F1.5	
24						D5	
25			Large		120.0*	F1.5	
26						D5	
27			Large	700	300.0*	F1.5	
28						D5	

Table 14 – List of realistic release scenarios to be modelled using CFD tools. Cases marked with (*) indicate that the mass flow rate is restricted to the dispenser H2 delivery flow rate. All other mass flow rates have been estimated using the FCH2 e-Laboratory *Jet Parameters* tool

Clean Hydrogen Partnership

WP2.1.2 – hazardous zones

MultHyFuel

Complex geometries = > CFD simulations / results

Results :

- Larger influence of the modelling (as compared to the validation exercise) despite the same source term
- Large influence of the leakage scenario and possible influence of the canopy and other obstacles
- Turbulence intensity is not given but was measured in the validation tests (5-10 m/s in the flammable zone)

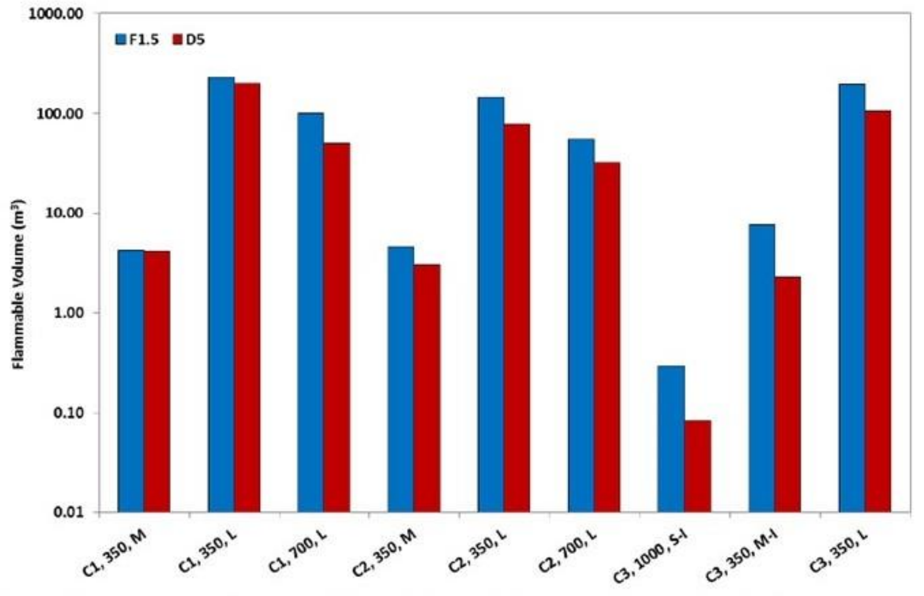


Figure 65 – Comparison of the predicted flammable cloud volume across the range of realistic release scenarios modelled. Here, the column labels give Configurations 1, 2 and 3 as C1, C2 and C3, respectively, followed by the release pressure as a numerical value and the release size as small-internal (S-I), medium (M) and large (L). Results for the F1.5 and D5 wind conditions are shown as blue and red columns, respectively.

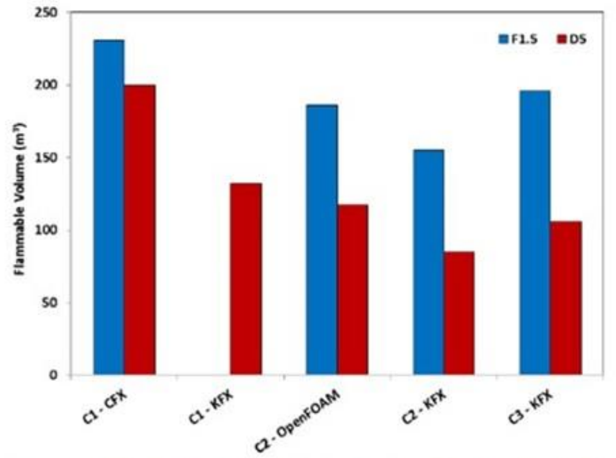


Figure 66 – Comparison of the predicted flammable cloud volumes for the 350 bar, full bore rupture release scenarios across all three forecourt configurations

WP2.1.3 – ignition probabilities

MultHyFuel

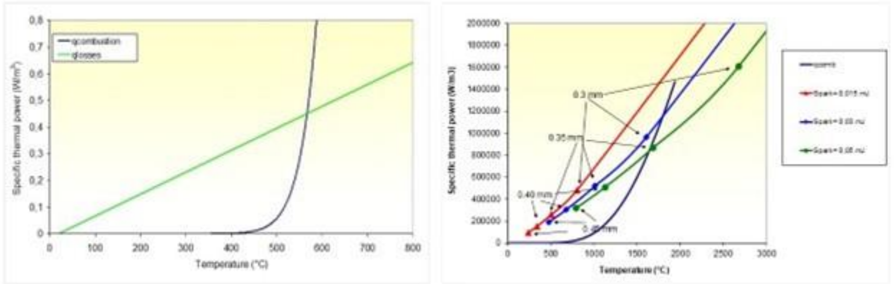
Potential ignition mechanisms

Method : theoretical modelling using basic experimental data

Results :

- ignition might be spontaneous only resulting from the leakage or induced by an external source (like other ATEX)
- 3 potential ignition mechanisms =>
    - *Diffuse ignition* : ignition in the contact zone between the pressurized hot air and the discharging hydrogen. Rather specific to hydrogen pressure discharges in air (requires a very thin reaction zone and small auto ignition temperature)
    - *Hot surface ignition* which is a very traditional ignition mechanism
    - *Spark ignition* also a common ignition mechanism but a broader range of spark energies and then of discharge mechanisms is possible. Rather specific to hydrogen is the capability of corona discharges to ignite hydrogen leakages
- Influence of the discharge conditions (pressure, temperature, velocity) :
    - Diffuse ignition is possible if the discharge pressure is above 10 to 20 MPa
    - All characteristic ignition parameters drop when pressure rises increasing significantly the ignition sensitivity
    - The sudden discharge in the open air seems capable of tribocharging small quantities of powdered materials and generate enough current to ignite the leak via a corona discharge. A small fragment of 1 mm impacting inside a flammable cloud could also ignite.

Ignition parameters and variations with P, T



Parameter	Dquench	MIE	AIT	Tp	P_{min}
Standard	0.7 mm	0.017 mJ	833 K	863 K	0.15 W
Variations with T_0	$\sim(T_0/T_{st})^{-0.3}$	$\sim(T_0/T_{st})^{-0.6}$	N.A	$\sim(T_0/T_{st})^{-0.25}$	$\sim(T_0/T_{st})^{-1}$
Variations with P_0	$\sim(P_0/P_{st})^{-0.75}$	$\sim(P_0/P_{st})^{-1.5}$	$\sim(P_0/P_{st})^{-0.05}$	$\sim(P_0/P_{st})^{-0.25}$	$\sim(P_0/P_{st})^{-1}$

J. Adler, F.B. Carleton, F.J. Weinberg, Ignition of flammable atmospheres by radiation heated fibrous agglomerates, Proc. R. Soc. Lond. A. 440 (1993) 443-460.

ISFEH19, Oslo, 2022

INERIS

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WP2.1.3 – ignition probabilities

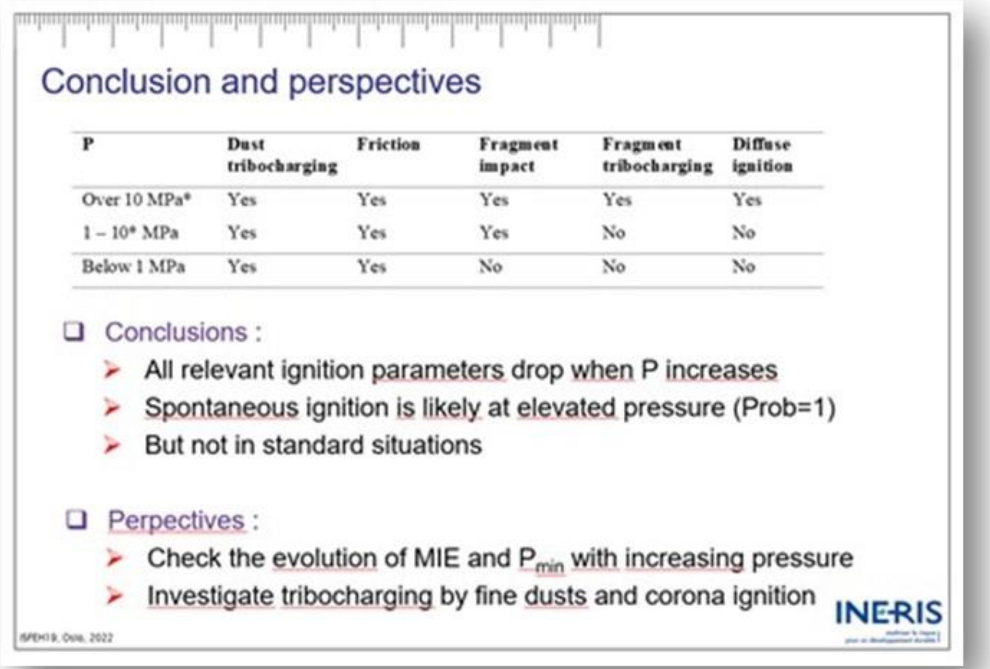
MultHyFuel

Ignition likelihood in MF configurations

Method : Risk analysis

Results :

- ignition might be spontaneous only resulting from the leakage OR induced by an external source (like other ATEX)
- Data* suggest between 1 and 2% probability of ignition in the industry excl; hydrogen but ten times more for hydrogen leakages which might reflect the fact that MIE and Pmin are ten times lower than for standard fuels although a detailed analysis is to be done. This could be the basic ignition probability (10-20%) in **ATEX conditions e.g. Excluding spontaneous ignition**.
- Spontaneous ignition could occur during **catastrophic rupturing** of high pressure equipements because fragments can be ejected, powdered material resulting from wear expelled and produce corona discharges and the diffuse ignition mechanism could be also at work. So in such situation **100% probability of ignition** could be postulated.
- **Leakage from restricted areas**, like through untightened fitting may not induce the conditions for a spontaneous ignition because first the flow is strongly laminated so that shocks will not be created and second because the possibility to create static electricity would be reduced. So ignition by an external source is more probable (Cf **ATEX mechanism**).


Conclusion and perspectives

P	Dust tribocharging	Friction	Fragment impact	Fragment tribocharging	Diffuse ignition
Over 10 MPa*	Yes	Yes	Yes	Yes	Yes
1 – 10* MPa	Yes	Yes	Yes	No	No
Below 1 MPa	Yes	Yes	No	No	No

- Conclusions :
  - All relevant ignition parameters drop when P increases
  - Spontaneous ignition is likely at elevated pressure (Prob=1)
  - But not in standard situations
- Perpectives :
  - Check the evolution of MIE and P_{min} with increasing pressure
  - Investigate tribocharging by fine dusts and corona ignition

INERIS

ISFEH 9, Oslo, 2022

WP2.1.4 – safety barriers

MultHyFuel

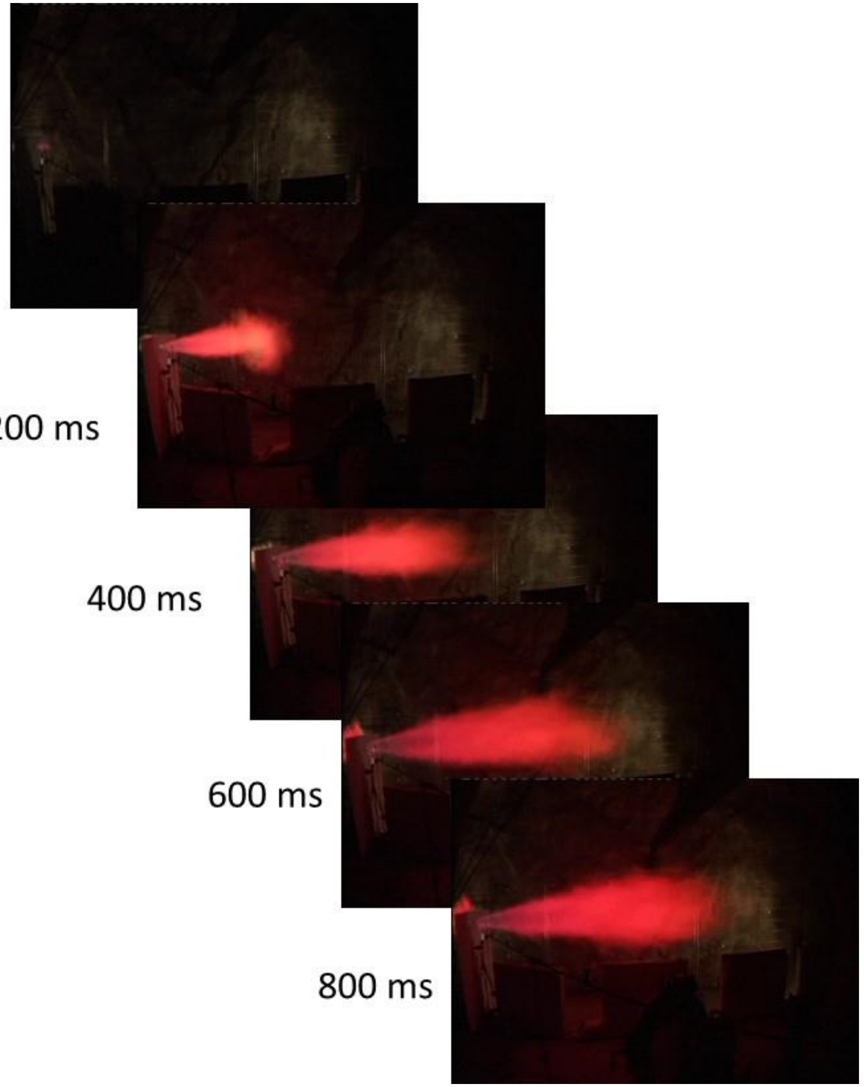
Preliminary considerations : fast acting valves

Method : analysis of previous relevant data :

- From HyPER E.U. Project giving indications on the rapidity of the full extension of a H_2 HP jet and on the explosion development
- From actual data about the performance (relevancy, rapidity) of ATEX detection as part of a mitigation technique => data from HSE ?

Results:

- For a 2 mm release under 900 b of pure H2, total development of the flame in 400-500 ms
- The combustion engulfes immediately all the jet (ignition source : close to the release and active from the beginning)



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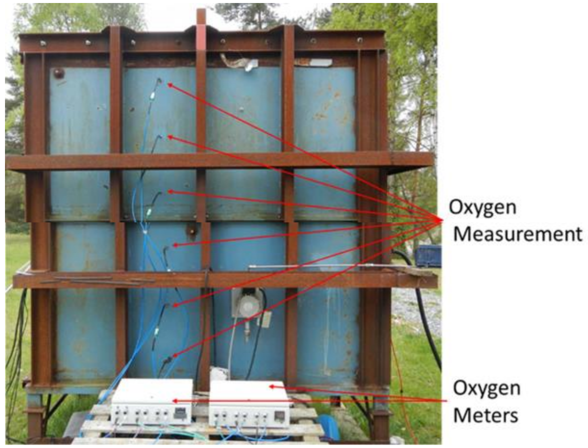
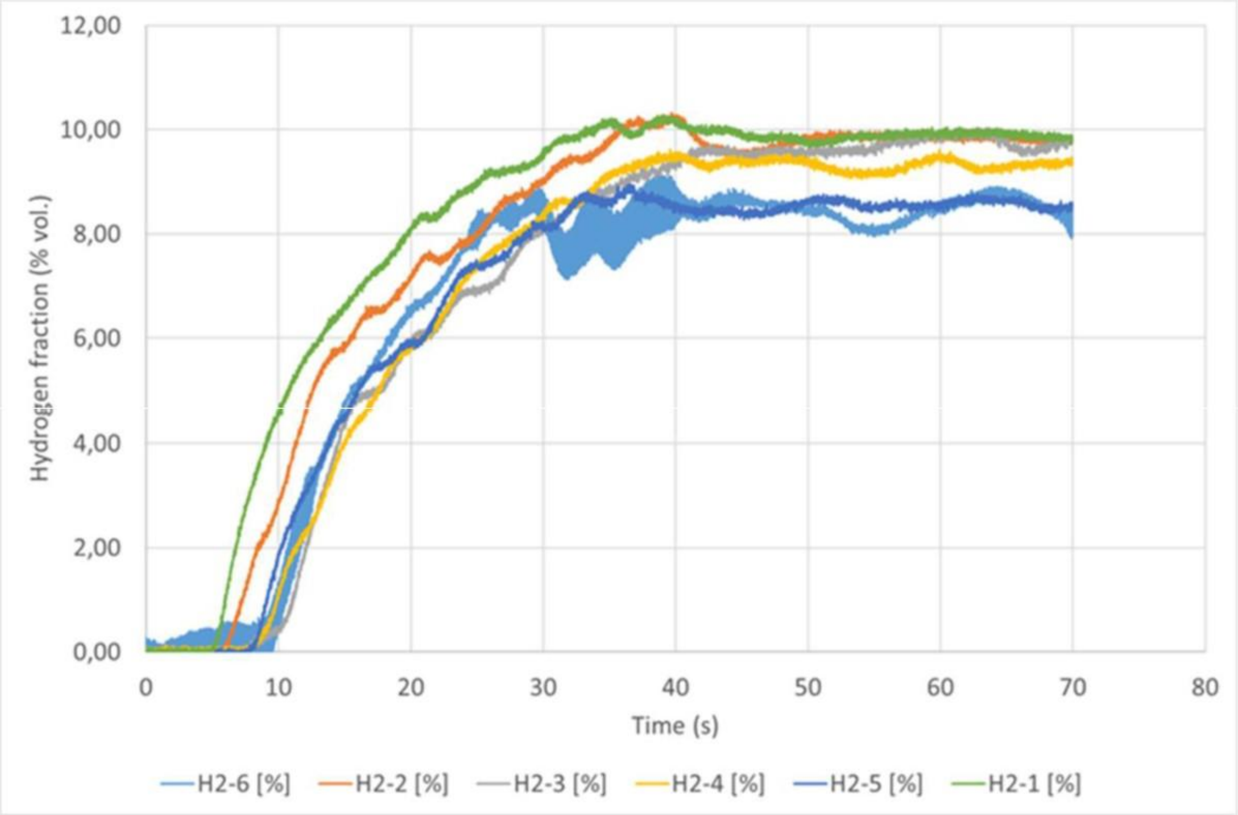
WP2.1.4 – safety barriers

Detection





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WP2.1 – Conclusions -perspectives

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Apart from finalizing the various deliverables.

- **Findings :**
  - A rather predictive tool was produced to propose a failure database even if little experience exists
  - Large flammable clouds can be produced in case of medium leaks
  - Ignition may be considered very high probability for catastrophic rupturing 10-20% otherwise.
  - Safety barrier should activate very fast to mitigate the consequences of explosions.
- **Perspectives :**
  - **Leakage F&Q :** comparison with ongoing developing databases.
  - **Ignition :** investigate tribo charging and subsequent corona discharges. Produce a clearer link between the leakage conditions and ignition.
  - **Safety barriers**: TBD.

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11:30-11:50	WP3 - Risk assessment and development of guidelines (WP 3)		ENGIE (Sebastien Quesnel)
	Break		
12:00-12:20	**WP 2 – Testing results**	Leakages, clouds and ignition	INERIS (Christophe Proust)
12:20-12:40		**Fire and Explosion**	**HSE (Louise O'Sullivan)**
12:40-12:50	Future events and engagement with industry stakeholders		Hydrogen Europe (Dinko Durdevic)
12:50-13:00	Q&A		

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Safety and Permitting for Hydrogen at Multifuel Retail

MultHyFuel

"(…) 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 HRS operators."

2018, https://www.hylaw.eu/

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.

Hydrogen Europe

Air Liquide creative oxygen

BESPOKE RESEARCH AND CONSULTANCY FROM HSE

INERIS maîtriser le risque pour un développement durable

ENGIE Lab CRIGEN

ITM POWER Energy Storage | Clean Fuel

kiwa

snam

Shell Hydrogen

ZSW

Clean Hydrogen Partnership

MultHyFuel Project – Work Package 2 Overview

Work Package 1: Detailed investigation of current status

Work Package 2: Practical research to address gaps in current understanding

- Determine leakage frequencies, flow rates, extent of hazardous zones and ignition probabilities for faults on HRS (hydrogen refuelling station) plant;
- Reproduce the key fire and explosion scenarios which cannot be investigated sufficiently using simpler modelling tools, studying these both experimentally and using Computational Fluid Dynamics (CFD);
- Test the performance and reliability of key safety barriers, identified in WP3, under realistic conditions;
- Conduct experiments to demonstrate the effect of hazardous occurrences on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt, and vice-versa.

Work Package 3: Generate good practice guidance

Work Package 4: Engagement

Work Package 5: Dissemination, communication and exploitation

WP2 – Fire & Explosion – Experimental design

MultHyFuel

To conduct experiments to demonstrate the effect of **hazardous occurrences** on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt , and vice versa.

- **Dispenser hose breakaway failure (ignited / unignited):** Simulation of a breakaway device failure where hydrogen supply is left open after a drive off. Hydrogen is released from an outlet pipe on the side of the dispenser. Ignited tests have been undertaken to establish flame length and temperature.
- **Burst hose / hose whip (ignited):** The scenario for this test is a vehicle drive away and a failure of the breakaway device. The hose will then be left whipping from the dispenser. The test was undertaken to establish whether an ignition of hydrogen was possible by a whipping hose.
- **Internal dispenser pipework leak (small leak source, ignited and unignited dispersion**): The scenario is a pipework leak within the dispenser housing, through a 0.2 mm diameter hole. Unignited tests were undertaken to establish the concentration of hydrogen within the dispenser with respect to time. Ignited tests were undertaken to investigate the effects of an ignition within the dispenser housing.
- **Internal dispenser pipework leak (medium leak source, ignited and unignited dispersion):** The scenario is a pipework leak within the dispenser housing, through a hole with 0.5 mm diameter - 10% of the pipe internal diameter (ID). Unignited tests were undertaken to establish the concentration of hydrogen within the dispenser with respect to time.

WP2 – Fire & Explosion – Experimental design

MultHyFuel

To conduct experiments to demonstrate the effect of **hazardous occurrences** on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt , and vice versa.

- **Internal dispenser pipework leak (external ignition – domino effect test):** The scenario is an internal pipework release leaking through ventilation panels in the dispenser, with ignition originating elsewhere on a forecourt. For the tests, a strong ignition source was used, relatively close to the dispenser.
- **Pool fire impingement on charged dispenser:** The scenario is a hydrocarbon fire on the forecourt that may impact on a hydrogen dispenser. For the tests, a hydrocarbon-fuelled pool fire and a vehicle shell were placed beside the hydrogen dispenser and the pool ignited. To assess the impact of the external fire on the dispenser, hydrogen pipework pressure, dispenser temperature, and heat flux effects were recorded.

WP2 – Fire & Explosion – Experimental design

MultHyFuel

To conduct experiments to demonstrate the effect of **hazardous occurrences** on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt , and vice versa.

- **Internal dispenser pipework leak (external ignition – domino effect test):** The scenario is an internal pipework release of hydrogen into the dispenser housing. Hydrogen/air then leaks out from the dispenser housing through ventilation panels. Attempts were made to ignite the hydrogen/air outside of the dispenser via the use of a strong ignition source.
- **Internal dispenser pipework leak (small source, ignited and unignited dispersion**): The scenario is a hydrogen pipework leak within the dispenser housing, through a 0.2 mm diameter hole. Unignited tests were undertaken to establish the concentration of hydrogen within the dispenser with respect to time. Ignited tests were undertaken to demonstrate the effects of an ignition within the dispenser housing.

WP2 – Fire & Explosion – Experimental design

MultHyFuel

To conduct experiments to demonstrate the **effect** of hazardous occurrences on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt , and vice versa.

To inform the design of an experimental programme, demonstrating the effects of hazardous occurrences, we needed to identify key elements from:

- Project deliverables:
  - Identification of critical scenarios WP 3 D3.5;
  - Review of planning, safety methodology and requirements for HRS across Europe WP1 D1.2.
- Conversations with stakeholders and HRS (Hydrogen Refuelling Station) operators:
  - Forecourt configurations;
  - Dispenser contents and housing design.

A study of the above evidence identified that the following evidence gaps as properties requiring investigation by experiment:

- Separation distances;
- Multifuel escalation.

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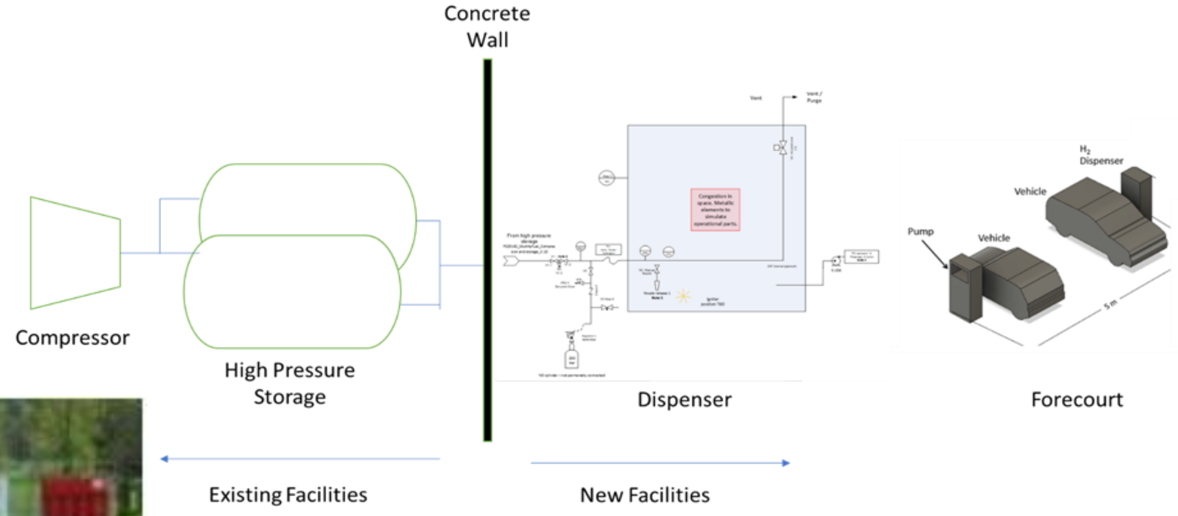
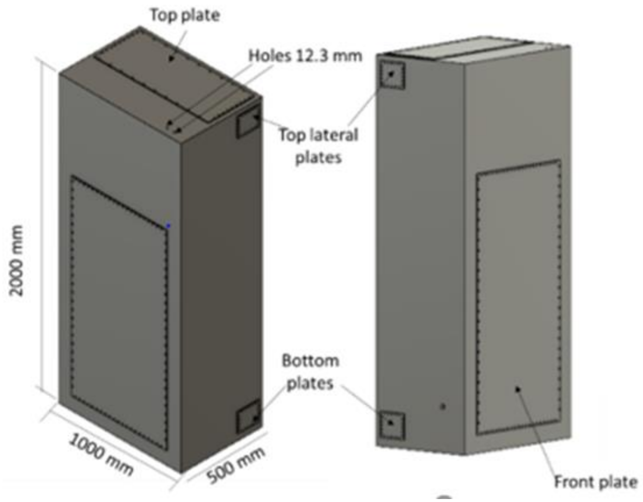
WP2 – Fire & Explosion – Experiment design

To conduct experiments to demonstrate the **effect** of hazardous occurrences on hydrogen dispensers affecting other dispenser types on a multi-fuel forecourt , and vice versa.





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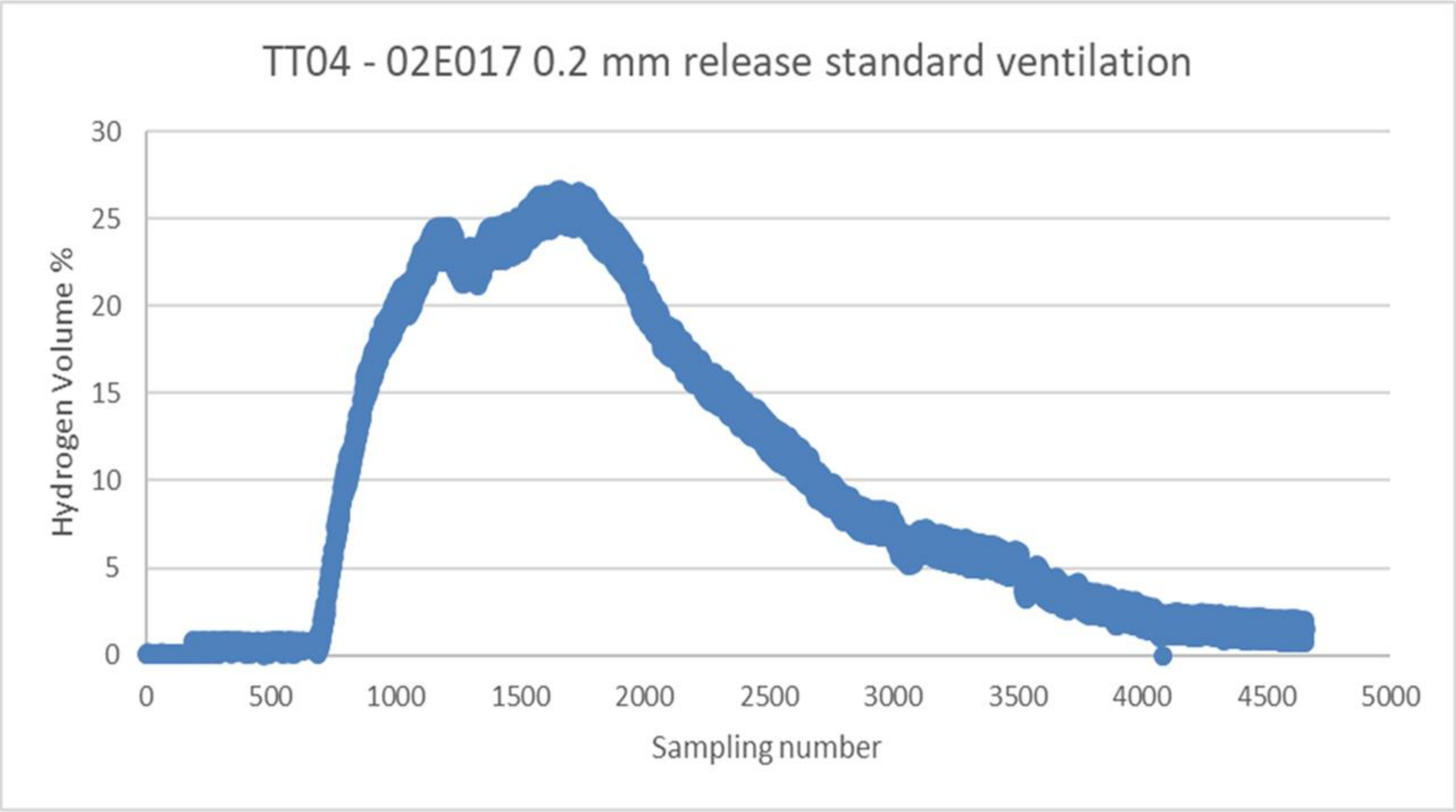
WP2 – Fire & Explosion – Separation distance

Hazardous occurrence : Internal leak within dispenser housing, 60 seconds duration hydrogen release

- Release size 0.2 mm or 0.5 mm diameter holes in dispenser pipework within dispenser housing
- Release pressure 350 or 700 bar
- 60 second release timed from the high-pressure facility
- Traces ran until natural ventilation reduced the hydrogen concentration to zero
- Passive ventilation sizes varied: standard and increased
- Releases persisted for a short duration of time.



WP2 – Fire & Explosion - Ignitions

MultHyFuel

Hazardous occurrence: Internal dispenser pipework leak (external ignition – domino effect)

- A 0.2 mm diameter leak from pipework contained within the dispenser housing occurs. This forms a hydrogen/air mixture within the dispenser housing.
- This mixture exits the dispenser housing through passive ventilation.
- An ignition source is located on the forecourt.

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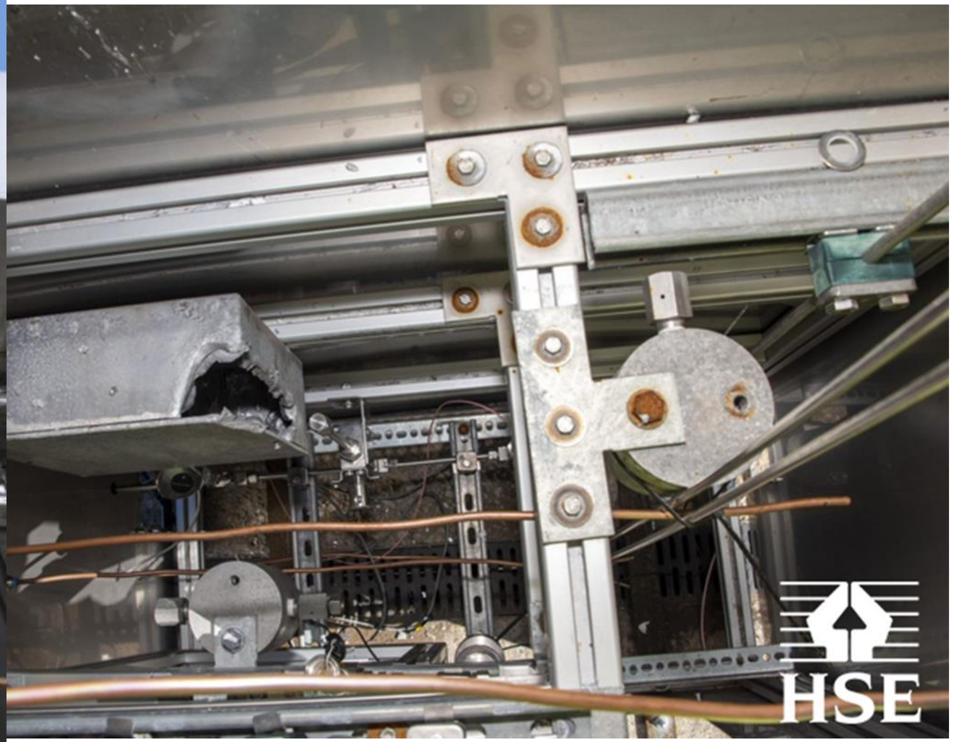
WP2 – Fire & Explosion - Ignitions

MultHyFuel

Hazardous occurrence: Internal dispenser pipework leak (external ignition – domino effect)



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WP2 – Fire & Explosion - Ignitions

Hazardous occurrence: Internal pipework leak within dispenser, ignited

- A small leak (0.2 mm diameter hole) occurs on the dispenser pipework within the dispenser housing.
- Non-ignited tests were undertaken to establish the concentration of hydrogen within the dispenser housing with respect to time.
- Ignited tests were undertaken to investigate the effects of an ignition within the dispenser housing.

WP2 – Fire & Explosion - Ignitions

Hazardous occurrence: Internal pipework leak within dispenser, ignited

- A small leak (0.2 mm diameter hole) occurs on the dispenser pipework within the dispenser housing.
- Non-ignited tests were undertaken to establish the concentration of hydrogen within the dispenser housing with respect to time.
- Ignited tests were undertaken to investigate the effects of an ignition within the dispenser housing.

WP2 – Fire & Explosion - Ignitions

Hazardous occurrence: Internal pipework leak within dispenser, ignited

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WP2 – Fire & Explosion - Ignitions

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Hazardous occurrence: Internal pipework leak within dispenser, ignited

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WP2 – Fire & Explosion - Effect

Hazardous occurrence: Internal pipework leak within dispenser, ignited

- The pressure wave exerted on the forecourt was not sufficient to cause primary blast injuries. However, a secondary blast effect i.e., impact from the dispenser door or a structural forecourt item which has been impacted by a piece of the dispenser housing would be sufficient to cause serious harm / fatality.
- The design of a dispenser housing will inform the potential for pieces to be ejected from the housing following an internal ignition event. The orientation of a weak point such as a door should be considered. A potential barrier / tethering between the weak point and the forecourt to reduce the velocity of any ejected panel could also be considered.
- A localised fire which extended from the dispenser to the van stationed as if refuelling was observed until the release ceased. The effect of the fire was localised to the van at the refuelling point, and the dispenser impacted by the ignition. The effect on persons would likely be burns if the person was able to flee or escape the flames.

WP2 – Fire & Explosion - Ignitions

Hazardous occurrence: Internal pipework leak within dispenser, ignited , with mitigation

- A foil blowout panel was installed at the top of the dispenser housing
- This replaced the original steel lid
- The scenario for this test is a small leak (0.2 mm diameter hole) occurs on the dispenser pipework within the dispenser housing for 30 seconds.
- The resultant hydrogen in air within the dispenser housing is ignited from an ignition source within the dispenser.

WP2 – Fire & Explosion - Mitigations

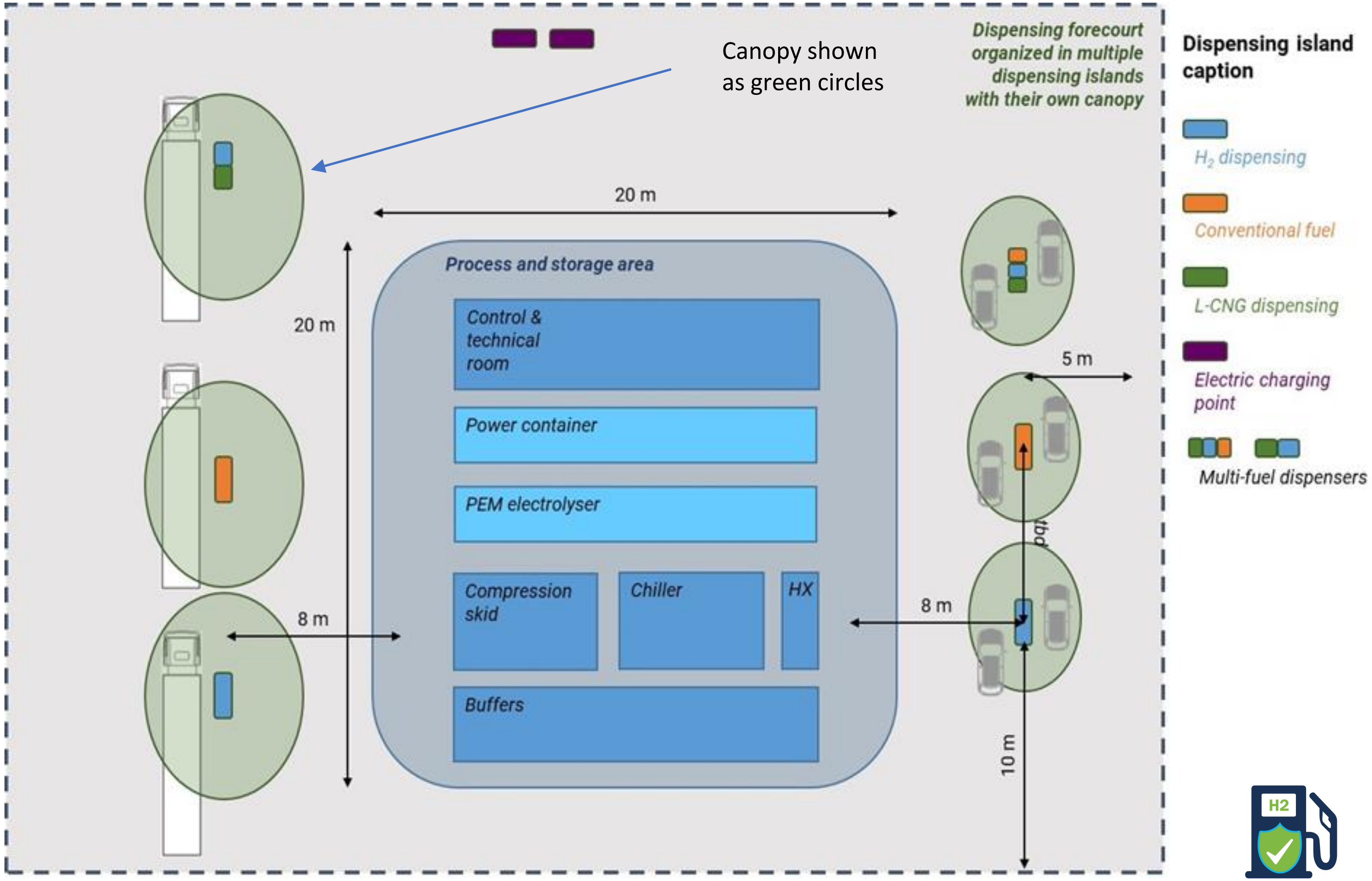
Hazardous occurrence: Internal pipework leak within dispenser, ignited , with mitigation

- Inclusion of a foil panel as part of the dispenser housing to act as a pressure relief (blowout) panel. The panel replaces the steel cover in the roof of the dispenser housing.
    - It was found that the inclusion of a foil blow-out panel partially relieved the overpressure generated.
    - However - the inclusion of the foil panel did not prevent bowing of the dispenser door or the jet fire which ensued inside the dispenser
    - The foil blowout panel did prevent removal of the dispenser door
    - The blowout panel could prevent the majority of secondary blast effects om persons dependent on the orientation of the panel on the forecourt.
    - However, the placement of any mitigation measure should be considered as part of overall forecourt design, so as to not introduce new / additional hazards.

WP2 – Fire & Explosion - Effect

Configuration #1 – ready to deploy multi-fuel station

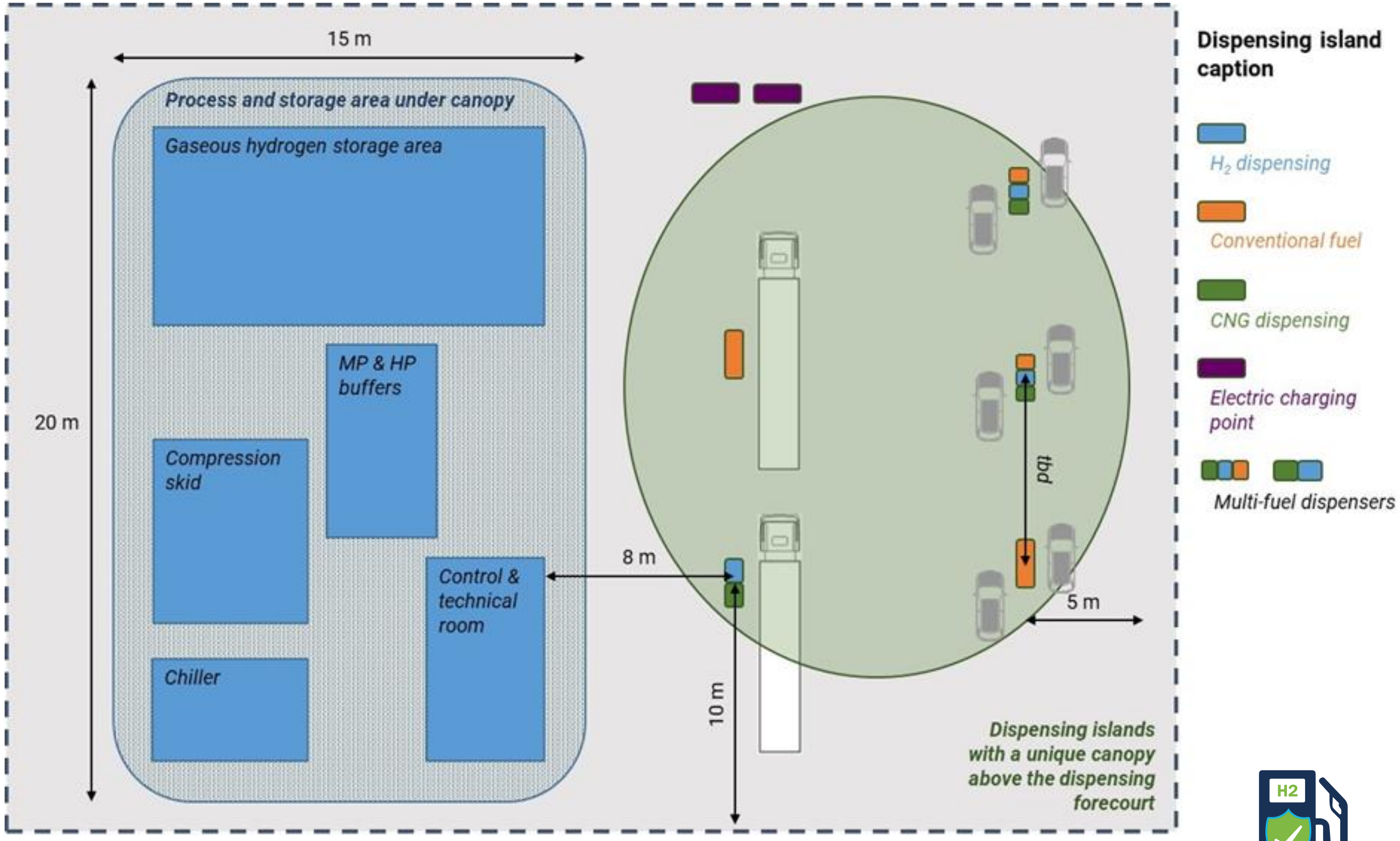
- Given a forecourt design as shown in configuration 1, an event within a dispenser is likely to impact a minimum of two vehicles if refuelling and potentially the canopy. The canopy could cause significant injury to persons if impacted across the whole of the forecourt.
- If there was not a vehicle stationed at the dispenser (acting as a barrier) an ejected door / piece of dispenser housing could travel outside of the forecourt or towards the control & technical room areas.



WP2 – Fire & Explosion - Effect

Configuration #2 – on site hydrogen production multi-fuel station

- In configuration #2, the multi-fuel dispensers concerned are shown in multiple-coloured blocks. An internal ignition within the dispenser could spread to the conventional fuels and escalate the hazards on the forecourt.
- Additional fire and explosion hazards would be likely.
- Where only hydrogen dispensers are located on a dispensing island, there is a reduced chance of escalation to additional fuels from an internal ignition of hydrogen within the dispenser housing.



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WP2 – Fire & Explosion – Next steps

MultHyFuel & beyond

- Formally report the results of the experimental work (deliverable) to the work package lead and project officer (not publicly available)
- Continued support of the work of being undertaken as part of work package 3 (the creation of good practice guidelines) to be published and shared by the MultHyFuel project website / engagement publications
- Report recommendations and considerations for further testing / additional projects in the area of multifuel refuelling station design.

Content

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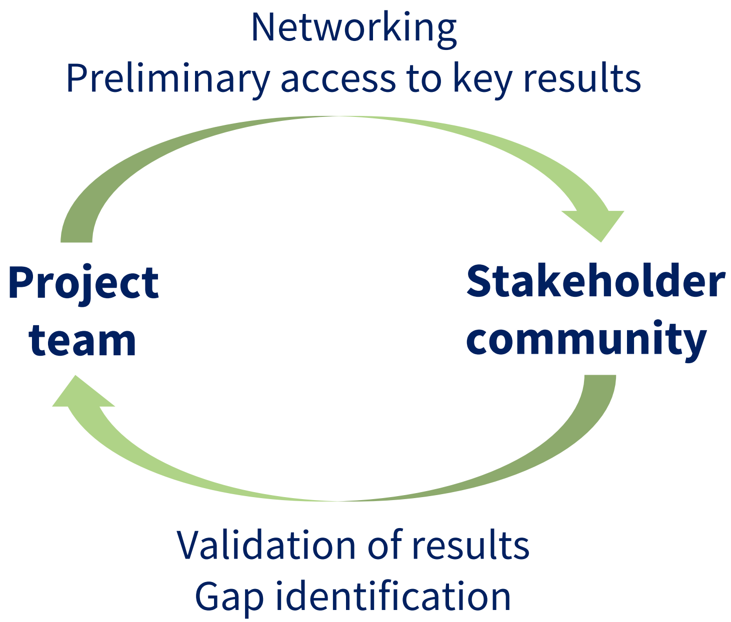
12:20-12:40		Fire and Explosion	HSE (Louise O’Sullivan)
12:40-12:50	**Future events and engagement with industry stakeholders**		**Hydrogen Europe (Dinko Durdevic)**
12:50-13:00	Q&A		

HOW TO GET INVOLVED



Feedback on results, suggestions, recommendations, etc. welcome!

WP4 – Engagement plan:

- Series of workshops with targeted stakeholders to share methodology and results and receive feedback in a co-creation environment

Targeted stakeholders:

- HRS operators
- HRS component manufacturers
- Public authorities
- Standards developing organizations

Join the community:

- info@multhyfuel.eu
- Subject: “MultHyFuel stakeholder community”
- You will be added to the mailing list and be invited to the workshops specially targeted for you

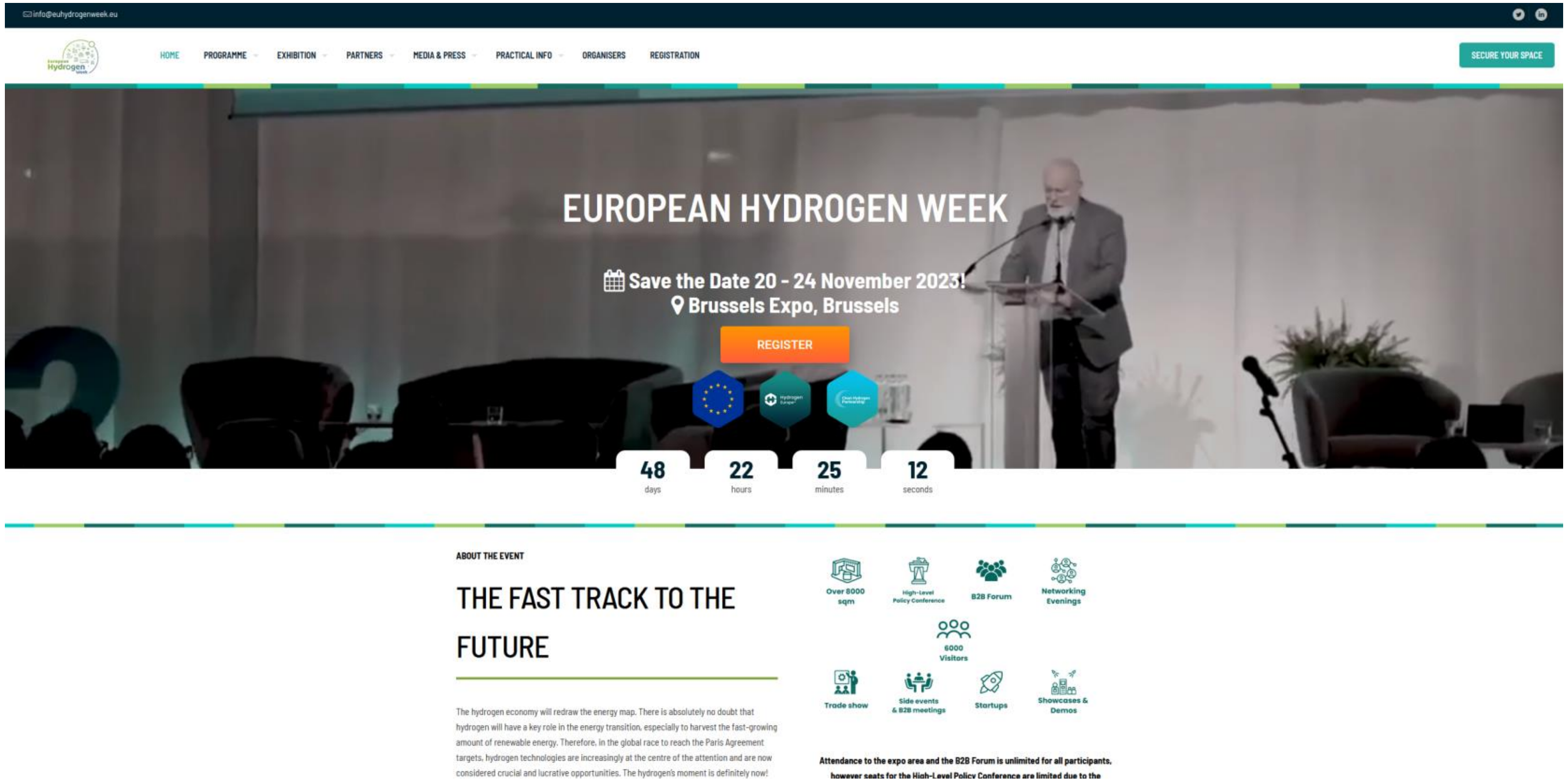
Stakeholder engagement plan

- Involvement of key stakeholders for **validation** of solutions proposed and final results.
- A series of **workshops** will be organised at strategic stages of the project.

WS #	Topic	Planned Date
1	Validation of the 3 case study configurations defined in T3.1	8th June 2021
2	WP2 methodology	25th January 2022
3	**Interim results presentation**	**4th October 2023**
4	Results from WP2 and WP3 + stakeholders engagement	November 2023 (H2 Week)
5	Development of the best practice guidelines	April 2024
Final	Adoption of best practice guidelines	September 2024

H2 Week event

- Side event during European Hydrogen Week
- November 21st 2023, 9.00-13.00h CEST
- Participation of relevant stakeholders (HRS operators, public authorities, manufacturers, end-users, etc.)
- More info on [H2Week]
- Invitations will be sent out in time!



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H2 Week preliminary content

<table>
<tr><th>Time</th><th colspan="2">Subject</th><th>Speaker</th></tr>
<tr><td rowspan="10">9.00 – 13.00 h CEST</td><td colspan="2">Welcoming words</td><td>Hydrogen Europe + Clean Hydrogen JU</td></tr>
<tr><td colspan="2">Introduction to MultHyFuel</td><td>Hydrogen Europe</td></tr>
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<tr><td>Fire and Explosion</td><td>HSE</td></tr>
<tr><td colspan="2">Engagement with industry stakeholders – Think Tank (feedback!)</td><td rowspan="3">All partners</td></tr>
<tr><td colspan="2">Discussion on results</td></tr>
<tr><td colspan="2">Q&A</td></tr>
</table>

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Website

Launched July 2021

Includes:
- Summary of project
- Public deliverables
- Slides / recordings from launch event & workshops
- News from project
- Communication, dissemination and exploitation plan

Contact email: info@multhyfuel.eu

Thank you for your attention!

info@multhyfuel.eu

MultHyFuel

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101006794. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

Clean Hydrogen Partnership