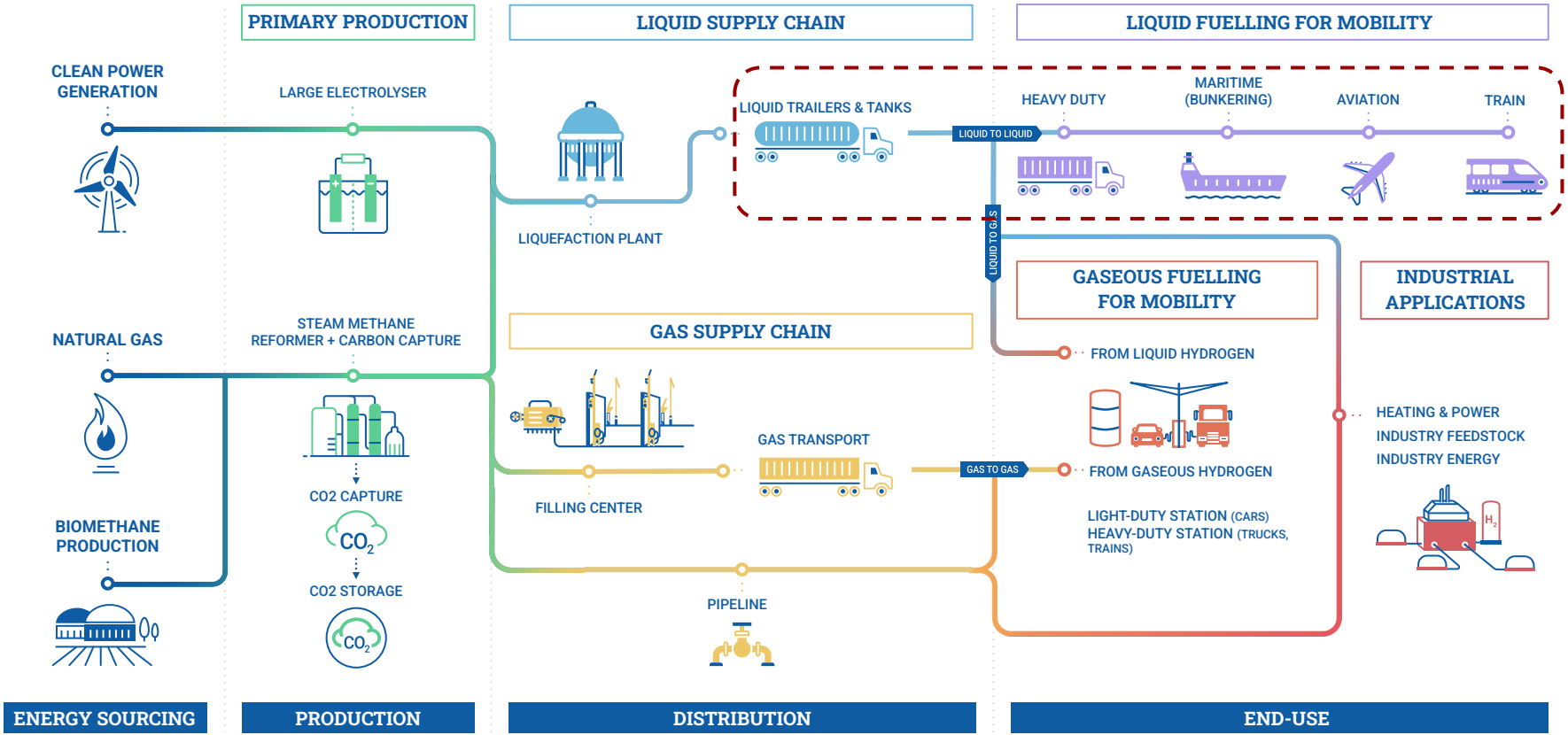
Safety strategies, engineering solutions and guidelines for inherently safer design of LH_2 transfer facilities

Dissemination Conference
Deborah HOUSSIN (AL)
17.09.2026

ELVHYS project No. 101101381 is supported by the Clean Hydrogen Partnership and its members. UK participants in Horizon Europe Project ELVHYS are supported by UKRI grant numbers 10063519 (University of Ulster) and 10070592 (Health and Safety Executive)

Hydrogen supply chain

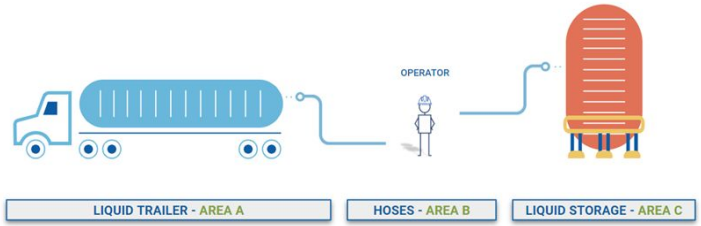
Infrastructure - From Production to End-Users



ELVHYS project studied configurations

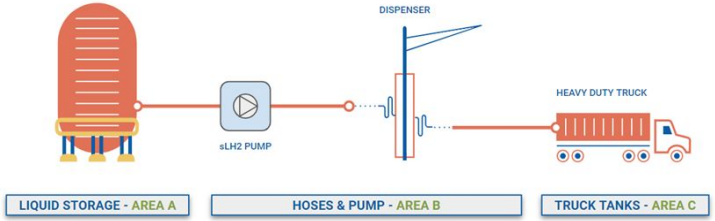
LH_2 bunkering configurations for Heavy Duty applications

Case study #1



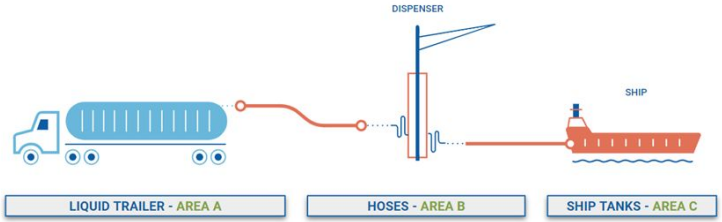
Loading of a LH_2 stationary tank by a LH_2 trailer

Case study #2



Filling of a LH_2 tank from a LH_2 stationary tank with a pump

Case study #3



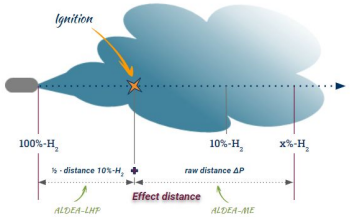
Filling of a LH_2 ship from a LH_2 trailer by pressure build-up

Hazard analysis

Potential feared events for consequences assessment

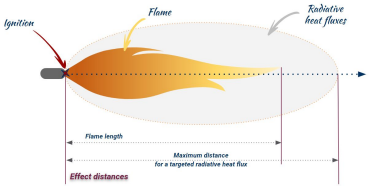
RELEASE
Jet ignition

- Delayed ignition - UVCE



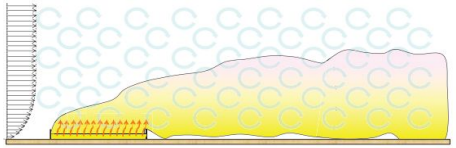
Or

- Immediate ignition - Jet fire

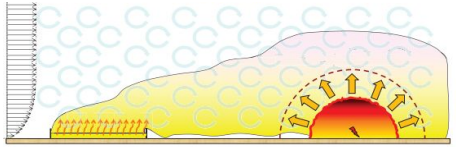


MASSIVE LH_2 SPILLAGE
Pool / Vaporization / Dispersion

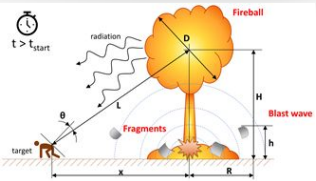
- Spreading and vaporization



- Explosion



TANK BURST



RELEASE IN CONFINED SPACE

- Accumulation & Explosion

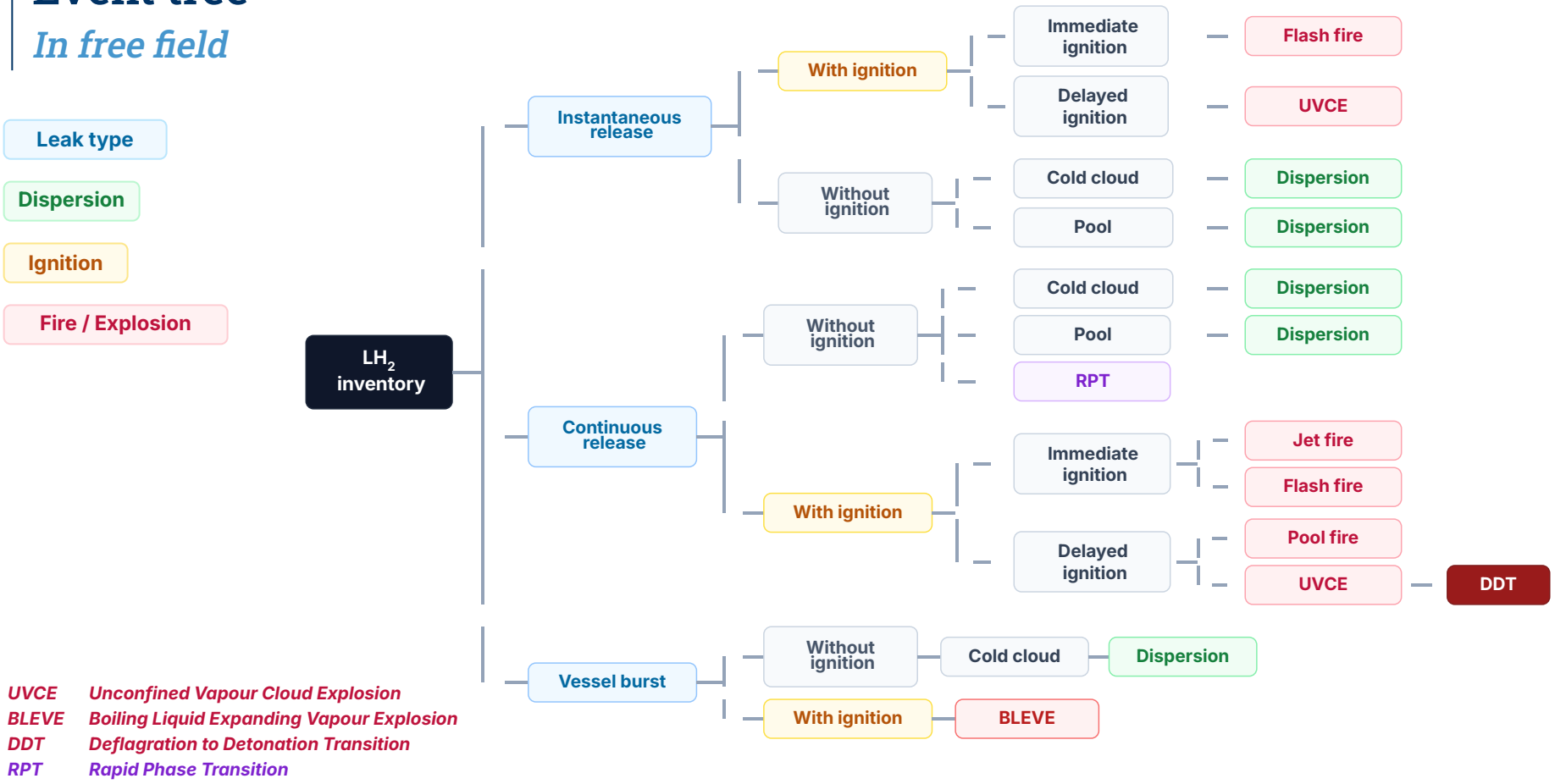


Innovative findings from ELVHYS project

Hazardous phenomena

Event tree

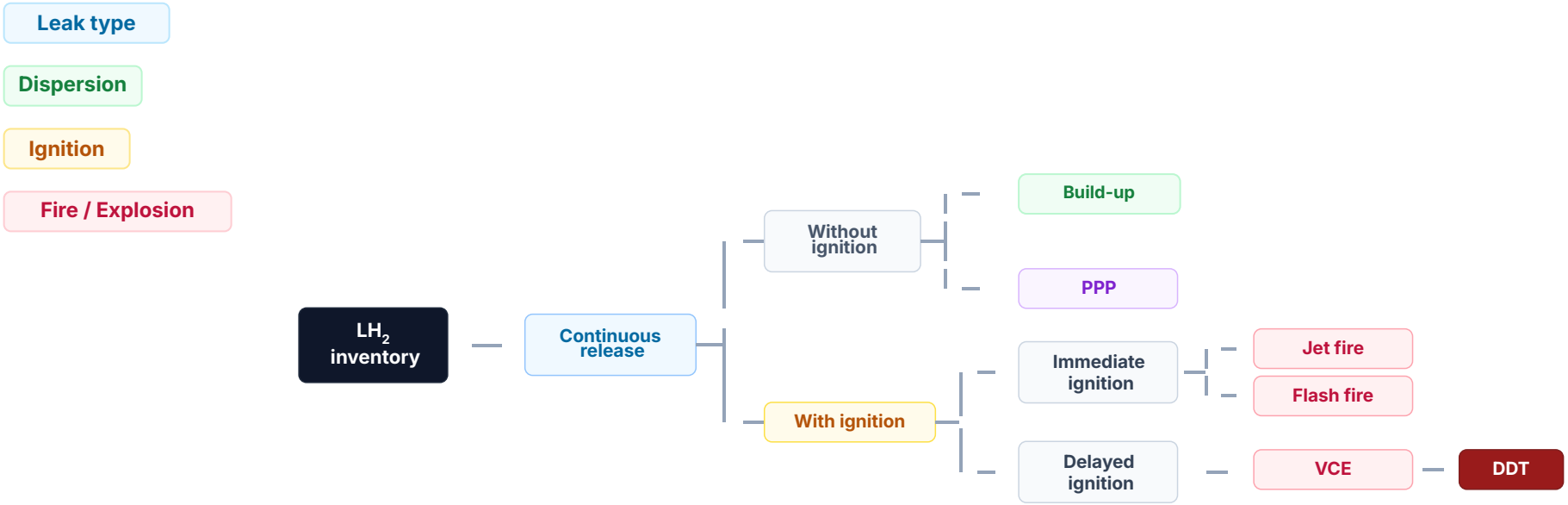
In free field



UVCE *Unconfined Vapour Cloud Explosion*
BLEVE *Boiling Liquid Expanding Vapour Explosion*
DDT *Deflagration to Detonation Transition*
RPT *Rapid Phase Transition*

Event tree

In enclosed spaces



VCE *Vapour Cloud Explosion*
PPP *Pressure Peaking Phenomena*

BLEVE

Boiling Liquid Expanding Vapour Explosion



- **Description**
  - **Burst of a cryogenic liquid storage** tank due to **vaporization**, increase of the internal pressure and mechanical rupture of the vessel

- **Experiments**
  - Existing literature for large scale cases
  - Small scale simulations performed by KIT, but results not already available
    - No self-ignition was observed due to the shock wave, either in the partially inertized atmosphere (10% O_2) or in the air atmosphere

- **Calculation means**
  - BLEXCOM (BLEVE explosion consequence model) developed by NTNU - validated against experimental data for both sub- and supercritical BLEVEs - to simulate all consequences:
    - blast wave, fragments, and fireball

- **Numerical simulations**
  - UU developed a multicomponent and multiphase **CFD model to assess blast wave and fireball** from LH_2 BLEVE
  - NCSRD performed overpressure calculation for **hot and cold BLEVE with ADREA-HF**

Tank in fire



- **Description**
  - Behaviour of a **LH_2 tank in a fire**

- **Modelling**
  - NTNU simulated the **thermodynamic behaviour of LH_2 tank lading and pressure build-up during external fire** exposure
    Two models were developed by NTNU
    - a 2D CFD multiphase model in Ansys Fluent,
    - and a lumped model based on the thermal nodes approach

    The degradation of the multi-layer vacuum insulation (MLVI) due to fire engulfment was modelled as well
    Both models were validated against two fire tests in which the final internal tank pressure
    was either sub- or supercritical
    The lumped model was employed to simulate the ELVHYS fire test on LH_2 components performed by KIT partner

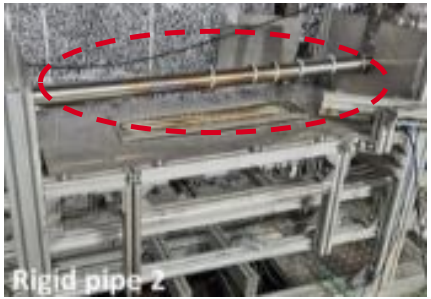
  - A novel method based on **digital image processing** was developed by NTNU to **analyse the LH_2 tank flame coverage** during different fire tests to quantify the heat transferred to the tank and provide valuable insights on boundary conditions for future modelling activities

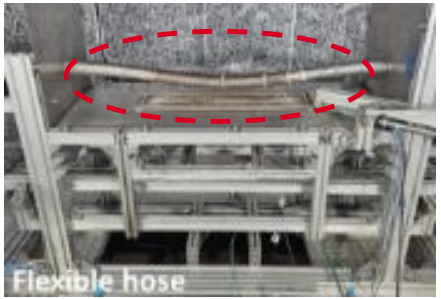
Tank in fire

- **Remarks**
  - Fire scenario → Often : **static fire** and **total engulfment**
  - Behaviour of a **LH_2 tank in a fire is depending of several parameters** which have to be considered
    - **Size** of the tank according to the fire
    - **Orientation** of the tank: vertical vs horizontal

    Considering **engulfment** of the storage in a fire **could be not realistic** and **conservative** for some cases

Transfer line in fire

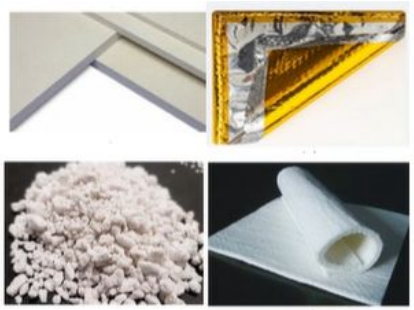




- **Description**
  - **Fire resistance** of **transfer lines**
- **Experiments**
  - Tests performed
    - **Rigid** line
    - **Flexible** line
- **Findings**
  - **Acceptable resistance of the transfer lines**, even for the flexible line
    - **No rupture** of any transfer line element could be achieve, despite temperature higher than 700°C
  - **Loss of vacuum after 20 min** in the fire
  - Improvements of the test rig were proposed for potential future tests

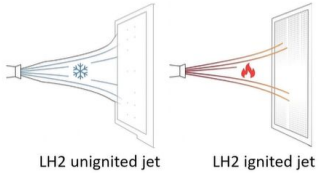
Impinging jet on materials

Impact of unignited and ignited LH_2 jet



- **Description**
  - **Resistance of materials** - Tests according to ISO 20088
  - Against **unignited and ignited LH_2 jet**

- **Experiments**
  - Tests performed
    - Dry **wall**, **Aerogel**, **MLI40**
    - with release at 1 m and 50 cm



- **Findings**
  - **About jet**
    - Unignited: not remain liquid after 10 cm
    - Ignited: more heat fluxes with jet at 1 m compared to 50 cm
  - **About materials**
    - **Aerogel** seems to be promising
    - Warning with MLI → different types, so different behaviours



Ignited LH2 jets during WP4 material impingement tests at KIT

Release in free field

Modelling



- **Description**
  - Assessment of release flow rate and consequences in free field
- **Experiments**
  - No test performed in ELVHYS project → **PRESLHY project**
- **Modelling**
  - **Integral dispersion tools** practically work with **single phase flow**
    - In case of a two-phase release, they convert it to a gaseous phase one within a single zone next to the source, before proceeding to the calculation of the downstream Gaussian flow and dispersion
  - **CFD** on the other hand usually solves **two-phase flow**, using/assuming:
    - Thermodynamic equilibrium (phases share the same temperature) and equilibrium phase change modelling (e.g. Raoult's law)
    - or Thermodynamic equilibrium and non-equilibrium phase change (e.g. Lee's model)
    - More complex models/techniques (e.g. thermodynamic non-equilibrium)
  - **DISCHA tool** - integral model - developed by NCSRD integrates these points

Release in free field

Modelling - Impacting parameters

Key points for modelling

- **Wind effects**
  - Wind effects are **usually not considered** in risk assessment with integral dispersion tools
    - Wind **increases safety distances** for **dispersion** and **jet flames**,
    - while the **opposite effect** seems to exist for delayed ignition in large releases

    Therefore **wind effects should be considered** in risk assessment

- **Ground effects**
  - Integral dispersion tools **do not account for ground** effects as in CFD
    - Ground proximity (release parallel and close to the ground) **can increase safety distances**

- **Humidity effects**
  - Integral dispersion tools **do not account for ambient humidity** effects as in CFD
    - **Humidity can reduce** safety distances

- **Initial thermodynamic state in the tank or the release line**
  - Beyond pressure and temperature, **hydrogen thermodynamic state** in the tank can have an impact on the release and the associated hazard distances

Release in free field

Risk assessment

Key points for risk assessment

- **Flash fire**
  - **Flash fire scenario sometimes is not considered** in risk assessment assuming that safety distances are determined by jet fire and delayed ignition scenarios
  - But, **flash fire** (represented as flammable 4% cloud) **can give safety distances larger** than **explosion** or jet fire

Therefore, **flash fire scenario may/should be considered** in risk assessment

Condensed phase



- **Description**
  - Air condensation occurring during a LH_2 release
- **Experiments**
  - Experiments were performed to attempt to simulate the phenomenon at HSE
- **Findings**
  - **Oxygen enrichment** does not necessarily occur during condensation, but **primarily during evaporation**, where nitrogen evaporates preferentially
  - This process creates a short-lived, high-risk situation **conducive to detonations should a second spill** - or second contact with LH_2 - occur
- **Recommendations**
  - A key recommendation for future regulations, codes, and standards (RCS) should be to **eliminate any risk of a secondary release** during the evaporation phase of condensed air → e.g. stop quickly a continuous release
  - **Managing ignition sources** and **stopping leaks** remain absolute priorities for preventing these risks

Release in enclosed space

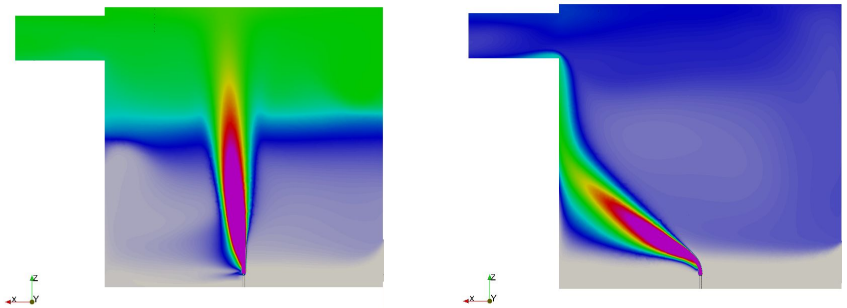
Dispersion

- **Description**
  - **LH_2 release in an enclosed space** with passive or forced ventilation (TCS - Tank Connection Space)
- **ELVHYS experiments**
  - Release in a 1-m^3 enclosure simulating a tank connection box, up to 150 $g.s^{-1}$
  - Forced ventilation: 500 L/min (30 ACH) and 2000 L/min (120 ACH)
- **Findings**
  - **Ventilation is an efficient mitigation** way to limit build-up inside the enclosure
  - **Forced ventilation provide a better efficiency** except for certain conditions where passive ventilation revealed better (buoyancy driven effects possibly higher than forced ventilation flow), highlighting the importance of
    - the **sizing** of the forced ventilation (i.e. ventilation rate)
    - the **location** of apertures, and fan
    - outlet in the opposite wall of the outlet could be a better design
    - avoid ventilation near the ground
  - **Negligible impact of the orientation** of the release (vertical upward vs horizontal) at least up to stoichiometry
    - but depending of the ratio between release rate and ventilation rate, behaviour can be different → to be investigated
  - **Wind can impact** concentration inside the enclosure, even for forced ventilation cases

Release in enclosed space

Dispersion

- **Numerical simulations**
  - Can help for optimization of the design of the forced ventilation, but need adjustment before being reliable



Forced ventilation - Different mixing and concentration distribution depending on ventilation flow rate. Other parameters can impact as well.

Release in enclosed space

Explosion - VCE



- **Description**
  - LH_2 release in an enclosed space with **concentration reaching flammable limits**, followed by **ignition**

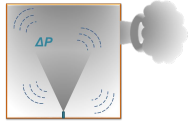
- **ELVHYS experiments**
  - Release in a 1-m^3 enclosure simulating a tank connection box

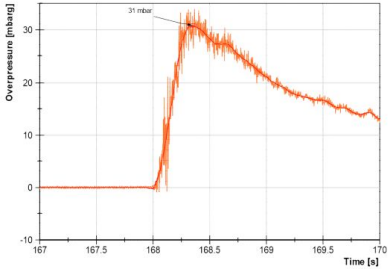
- **Findings**
  - Explosion panels are efficient mitigation way to limit overpressure inside the enclosure
  - Maximum overpressure inside the enclosure measured at **500 mbar** without destruction of the structure for the studied case
  - Impact of congestion attempted, but information limited → need more investigations to have a clear position

- **Numerical simulations**
  - Can help for optimization of the design of the venting panels

Release in enclosed space

Pressure peaking phenomenon

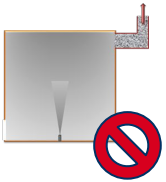




- **Description**
  - **LH_2 release in an enclosed space** with passive or forced ventilation
  - **PPP**: a transient safety hazard in unventilated or partially ventilated enclosures where a high-momentum **hydrogen release** initially **causes internal pressure to rise** to a peak - **potentially exceeding structural design limits**

- **ELVHYS experiments**
  - Release in a **1-m^3 enclosure** simulating a tank connection box
  - Releases around **100-130 $g.s^{-1}$** - close to the highest mass flow rate studied in ELVHYS project

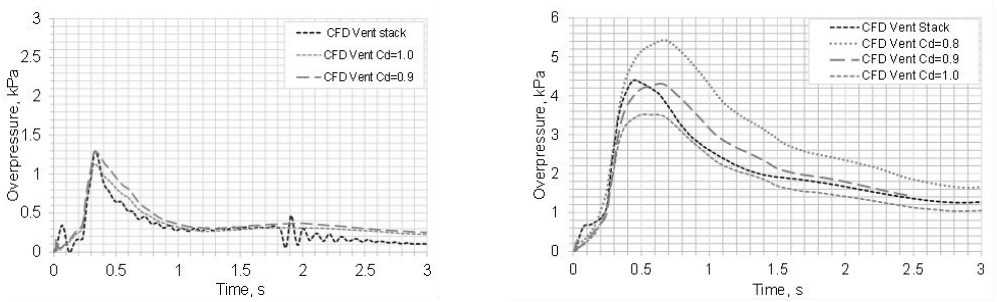
- **Findings**
  - With small vent area, **effects of PPP are limited** for the ELVHYS studied case (i.e., TCS = Tank Connection Space)
    - For less than 0.2% of the TCS surfaces open for venting, a maximum of 30 mbar recorded
  - In most cases, **PPP risk and mitigation** will be covered by the case of the explosion venting
  - Simulations showed that venting through a stack decreases significantly the efficiency of overpressure reduction
    → this point is true for explosion panels and for ventilation as well
    Consequently it is recommended to **have vent on walls** without duct



Release in enclosed space

Pressure peaking phenomenon

- **Numerical simulations**
  - Can help to predict efficiency of complex venting when the design or location of the structure offer less freedom
  - UU developed a **CFD model to simulate leakage of cryogenic hydrogen from a storage tank or equipment** in a confined space, e.g., a tank connection space (TCS) and:
    - *i*) investigate the **effect of the vent stack inclusion** on the severity of PPP
    - *ii*) **characterise the cryogenic flow through the vent stack** and resulting flammable mixture in atmosphere, assessing hazard distances for the unignited release



Vent stack versus decrease of efficiency of rectangular vent area with a fictive Cd

Risk assessment

Master Logic Diagram

A few words on the method

- **Master Logic Diagram (MLD)**
  - Method for **identifying events that initiate accidents** in installations handling flammable or toxic substances
  - MLD starts with a **Top Event "Loss of Containment"** and **decomposes it into simpler** contributing events
  - In the framework of **ELVHYS project**, it was **developed** to describe the Loss of Containment decomposition for an **installation that addresses Liquid Hydrogen** (LH_2)
  - Based on a generic MLD developed by Papazoglou and Aneziris (2003), with a systematic analysis of past accidents
    - Ordin, 1974; Verfondern, 2008; Verfondern et al., 2021; Wen et al., 2022; Hydrogen Tools Portal-h2tools.org

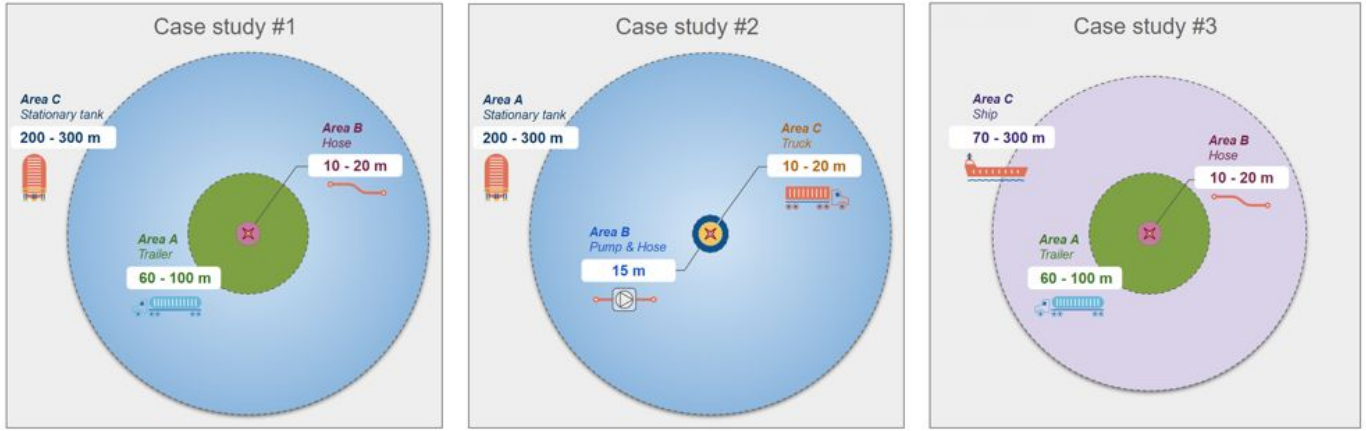
- **Advantages**
  - **Easy to apply** compared to Hazop

- **Drawbacks**
  - Come from accident analysis → require to have access to **reliable accidentology database** in parallel

Preliminary hazardous distances

Calculated at the beginning of ELVHYS project

- **Hazardous distances calculated with simple analytical approaches**



- **Refinement**
  - Use of **combination of more appropriate tools** (including CFD) to consider phenomena complexities and more impacting parameters
  - and application of MLD method integrating likelihoods

⇨ **Allow to rationalize these distances** and propose new figures

Likelihoods

Assessed by MLD analysis in ELVHYS project

- **Stationary tank to LH_2 tank**

Feared event	Infrastructure component	Likelihood
BLEVE	LH_2 storage / LH_2 tank	$5.8 \cdot 10^{-8}$ /year
Continuous release break from large connection	LH_2 storage / LH_2 tank	$5.0 \cdot 10^{-7}$/year
Pipe full bore rupture	Hose	$4.0 \cdot 10^{-4}$ /year
Pipe leak (5% nominal diameter)	Hose	$4.0 \cdot 10^{-3}$ /year

- **LH_2 trailer to ship tank**

Feared event	Infrastructure component	Likelihood
Trailer tank rupture	LH_2 trailer / Ship tank	$7.1 \cdot 10^{-5}$ /year
Ship tank rupture	Ship	$6.9 \cdot 10^{-5}$ /year
Pipe full bore rupture	Hose	$5.0 \cdot 10^{-5}$ /year

MLD analysis on ELVHYS scenarios

A few remarkable conclusions

- **Some identified events after event tree analysis showed a low frequency**
- **It is specifically the case for**
  - **BLEVE**
  - Pipe full bore **rupture for low diameter**

⇨ Depending on the studied scenarios, considering these events into the risk assessment may be reasonably open to question

- **Calculation approaches and considered parameters in the calculations can have a significant impact on the final risk level (e.g. wind effects, humidity…)**

- **Unified accident database is missing**

Fuelling protocols

Fuelling protocols

Good practices and Modelling

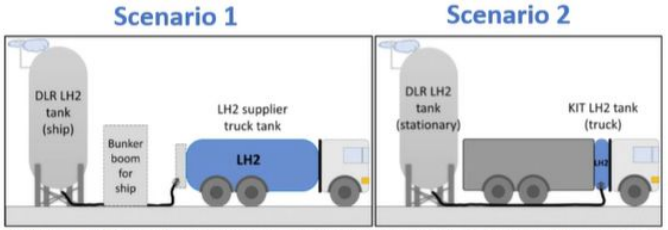


Figure 5: simulation of mobile applications, bunkering of a ship (left) and truck fuelling and defuelling of stationary tank (right)

- **2 studied scenarios**
  - From a LH_2 trailer to a tank → LH_2 trailer to a ship
  - Fuelling and defuelling of a tank
- **Findings**
  - Importance of **knowing the initial temperature** of both tanks
  - Depending on the pressure difference between the two tanks at the initial stage, more or less cycles are needed to reach equilibrium in pressure → higher filling efficiency for higher pressure difference
  - Top- vs bottom-filling
    - Top filling allows efficient cooling of a “warm” tank
    - **Top filling only** can be realised, however **not for a warm/nearly empty tank**. Nearly everything evaporates instantly without any significant mass transfer to the tank
    - **Standard practice is bottom filling only** or adding top filling at a later point in the transfer
    - Depending of the state of the receiving tank, **top- followed by bottom-filling** may be the most efficient solution
  - Use of cryopump for filling from low pressure vessel as described in the newly published ISO 13984:2026 seems to be promising
- **Modelling**
  - Interesting preliminary results obtained with **DISCHA tool** - further adjustment still needed for LH_2
  - “**LH_2 no-venting**” tank filling: The model can simulate the filling of small LH_2 tanks with either subcooled or saturated hydrogen

Modelling / Calculation means

Analytical and Integral approaches and tools

Feared events	Name of the tool	Assessed phenomena	Developer	Status
Storage burst				
BLEVE	BLEXCOM	Blast wave overpressure [1], [2]	NTNU	- Not yet a public tool but modelling approach published
		Blast wave impulse		
		Fragment projection range [3]		
		Fireball radiation [4]		
Boil-off	DISCHA	Self-pressurization in LH_2 storage tanks	NCSRD	- Validation against NASA experiments [5]

Analytical and Integral modelling approaches and tools

Feared events	Name of the tool	Assessed phenomena	Developer	Status
Releases				
H_2 Release (gaseous, liquid and two-phase)	DISCHA [6-11]	Choked flow	NCSRD	- Partially public tool Available in Net-Tools / e-Laboratory platform - Other modules under further development/validation
		Two-phase flow		
		Heat transfer inside tank walls		
		Discharge line effects (resistance, area change, heat transfer within pipe walls)		
		Phase change		
		Non-equilibrium phenomena		

Analytical and Integral modelling approaches and tools

Feared events	Name of the tool	Assessed phenomena	Developer	Status
Releases				
H_2 ignited release (venting or flaring of hydrogen)	Thermal effects from ignited hydrogen venting releases [12]	Evaluation of thermal effects, including thermal radiation and thermal dose from hydrogen releases through a vent stack	UU	- Modelling approach published - Predictive model for thermal radiation from hydrogen jet fires validated against experiments [12]
H_2 release	DNV PHAST	Choked gaseous mass flow prediction, jet centreline trajectory and expansion conditions	HSE	- Modelling approach used to inform experimental design and provide input conditions to HSE's CFD model

Analytical and Integral approaches and tools

Feared events	Name of the tool	Assessed phenomena	Developer	Status
LH_2 transfer procedure				
Tank-to-tank LH_2 transfer	DISCHA [5], [13]	Non-vented pressure filling of an LH_2 tank from the bottom (diffuser)	NCSRD	- Validation against NASA experiments [5] - Further development / validation is planned against related ELVHYS experiments
		Non-vented pressure filling of an LH_2 tank from the top (spraying)		
LH_2 **tank no-vent filling** [14]	Aspen HYSYS	Investigation of liquid hydrogen tank no-vent filling operations	NTNU	- Modelling approach published - Compared with NASA experiments

Analytical and Integral approaches and tools

Feared events	Name of the tool	Assessed phenomena	Developer	Status
Storage				
Fire engulfment of a cryogenic hydrogen storage tanks	Lumped model based on thermal node approach	Tank pressurization during fire engulfment and time to failure assessment	NTNU	- Validated on BMW and SH2IFT project experiments - Model and results published in ELVHYS deliverable D4.12 [24]
Boundary conditions				
Flame characterization	DIP [15]	Digital image processing for the advanced characterization and simulation of experimental fire tests	NTNU	- Modelling approach published - Validated on SH2IFT project experiments

Numerical modelling approaches and tools

Feared events	Assessed phenomena	Numerical tool	Developer	Modelling approach status
Storage				
Fire engulfment of a cryogenic hydrogen storage tanks	Tank pressurization during engulfment [16]	ANSYS FLUENT	NTNU	- Validated on BMW and SH2IFT project experiments
Catastrophic failure of LH_2 storage tank in a fire	BLEVE consequences (i.e. blast wave impulse and overpressure, fireball size, thermal effects	ANSYS FLUENT	UU	- Validated against BMW experiments [17] on burst of LH_2 storage tank in the 2 - 11.3 bar pressure range
Catastrophic failure of LH_2 storage tank	Hot and cold BLEVE	ADREA-HF	NCSRD	- Validated against past BMW experiments [17], see also ELVHYS D4.12 [24]
Hydrogen venting during normal or emergency operations	Pressure recovery phenomenon and LH_2 flash boiling during hydrogen venting	ANSYS FLUENT	UU	- Modelling approach published in [18] - Validated against experiments detailed in [19]
Exchange of **heat transfer** at the LH_2 storage system wall	Self-pressurization in LH_2 storage systems	ANSYS FLUENT	UU	- Validated against NASA experiments detailed in [20]

Numerical modelling approaches and tools

Feared events	Assessed phenomena	Numerical tool	Developer	Modelling approach status
Release in free field				
Venting of hydrogen	Evaluation of flammable cloud from hydrogen releases through a vent stack installed in a tank connection space	ANSYS FLUENT	UU	- Experiments with detailed data required for validation
LH_2 unignited release	Evaluation of flammable cloud for LH_2 releases from hose rupture and large loss of containment	ANSYS FLUENT	UU	- Experiments with detailed data required for validation
LH_2 unignited release	Jet dispersion under windy conditions	ADREA-HF	NCSRD	- Validation against experiments performed by DNV GL [21] and also ELVHYS D4.12 [24]
GH_2 ignited jet	Thermal effects	ADREA-HF	NCSRD	- Validation against experiments from SANDIA
Delayed ignition after LH_2 release	Explosion consequences (Deflagration, Overpressure)	ADREA-HF	NCSRD	- Experiments with detailed data required for validation

Numerical modelling approaches and tools

Feared events	Assessed phenomena	Numerical tool	Developer	Modelling approach status
Release in confined space				
LH_2 release in an enclosure (TCS)	Mixing, natural ventilation through a vent stack	ADREA-HF	NCSRD	- Validation against experiments performed by DNV GL [21] and also ELVHYS D4.12 [24]
GH_2 cryogenic release in an enclosure (TCS)	Mixing, forced ventilation (fan + vent stack)	ADREA-HF	NCSRD	- Validation against experiments performed by HSE within ELVHYS (tests 10, 12, see related ELVHYS final conference presentation as well as ELVHYS D4.12 [24])
GH_2 and LH_2 releases into an enclosure	Internal flammable cloud dispersion	ANSYS FLUENT	HSE	- Validation against WP4.2 HSE experiments of H_2 releases into a 1 m^3 enclosure actively and passively ventilated. Storage pressures of 2 barg - 8 barg and orifice sizes of 0.5 mm - 1.8 mm were simulated
LH_2 release in an enclosure	Pressure peaking phenomenon (PPP)	ANSYS FLUENT	UU	- Validation against experiments performed by HSE within the ELVHYS project in 1-m^3 enclosure, with different vent areas, LH_2 releases from storage pressure 3 bar and 25.4 mm nozzle diameter [22]

Numerical modelling approaches and tools

Feared events	Assessed phenomena	Numerical tool	Developer	Modelling approach status
LH_2 transfer procedure				
Attempted LH_2 refuelling through the complete HRS equipment chain into initially warm onboard tank	LH_2 evaporation within the refuelling line and two-phase flow development	ANSYS FLUENT	UU	- Modelling approach submitted for publication - CFD model validated against experimental data from Daimler Truck AG and KIWA ET GmbH [23]
	Pressurisation and temperature evolution			
	Boil-off gas (BoG) flowrate during venting			

General recommendations

Basics

- **Equipment supply**

  Delivery times can be problematic, but not only…

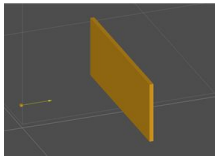
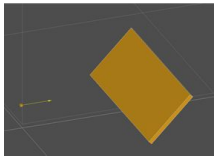
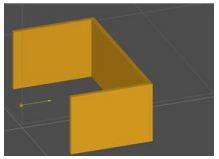
  - **Secure qualified suppliers** providing certified equipment
  - Diversify suppliers if possible
  - **Keep spare** equipment on hand
  - Pay attention to **regional regulatory** differences regarding equipment
  - Some of the technology needed for large scale LH_2 production is still in development and has not yet been tested at industrial scale

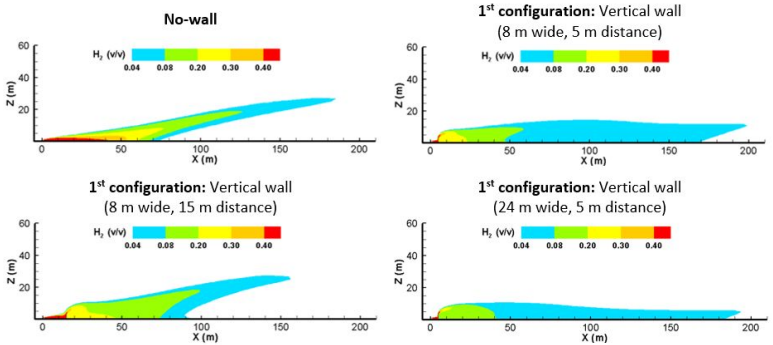
- **LH_2 quality / Pollution risk**
  - Impurities in LH_2 **may cause system malfunction/blockages** due to particles of solid ice forming at cryogenic temperatures
    - Vent blockage or relief panel failure

- **Material**
  - The choice of materials should consider H_2 propensity to leak and to cause damage to certain metals. Materials for seals/gaskets/valves should be suitable for H_2 service

Mitigation

Recommendations



- **Free field**
  - **Walls** can limit flammable cloud dispersion
    - Analysis required to choose the **relevant design** according to the infrastructure, its **neighborhood** and the **safety targets** (height, length, position from the risk source…)
    - Interesting for Simultaneous Operations (SimOps)
    - Technical feasibility must be studied

- **Confined space**
  - Concentration **detection** with reactive emergency protocol
  - **Ventilation**: **natural** at least, and **forced** for extreme cases
  - **VCE**: **explosion panels** correctly designed can limit overpressure and even avoid structure destruction
  - **PPP** risk is low regarding cases experimentally investigated with high release in a small volume
    In addition **explosion panels** can mitigate PPP risk
  - **Venting panel**: **vertical wall panel** should be preferred to vent stack → chimney configuration decreases mitigation efficiency for similar vent areas

Mitigation

Recommendations





- **Venting lines and flares**
  - Importance of the design
    - Safe location
    - Good location
  - Take into account relevant approach for consequences assessment, and consider weather conditions when possible

- **Storage tank**
  - PSV, overfilling system → Well-known, already mandatory

- **Limit release risk due to human error**
  - Quick-coupling
    - Automatic shut-off
    - ATEX area lower than 30 cm away from the connection when disconnected and dissipated in less than 10 s
  - Break-away with a disconnection force lower than 1000 N
    - Limit released volume in the event of the line being torn away before disconnection

Test rigs

Experimental simulations

Development of unique test rigs

- **Due to novelty, experimental program has to be adjusted during the project**
- **Nevertheless, the project enabled partners to gain experience and develop test benches for conducting further investigations**
  - **Tank to tank fuelling** test facility at DLR
  - **BLEVE** test facility at KIT
  - **Bonfire** test facility at KIT
    - Improvement proposed
    - Other equipment could be tested
  - **Enclosed space facility** for dispersion and explosion at HSE

Thank you for your attention

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Modelling / Calculation means

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Modelling & Calculation means (1/2)

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Modelling & Calculation means (2/2)

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