Enhancing safety of liquid and vaporised hydrogen transfer technologies in public areas for mobile applications (ID179)

ICHS 2023 conference

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20.09.2023

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)

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Introduction

ELVHYS

Focus of the study: pre-normative research on liquid and cryogenic hydrogen transfer technologies in public areas for mobile applications.

Aim: (i) provide a brief state of the art of cryogenic and liquid hydrogen technologies and (ii) present the new Horizon Europe project ELVHYS.

ELVHYS

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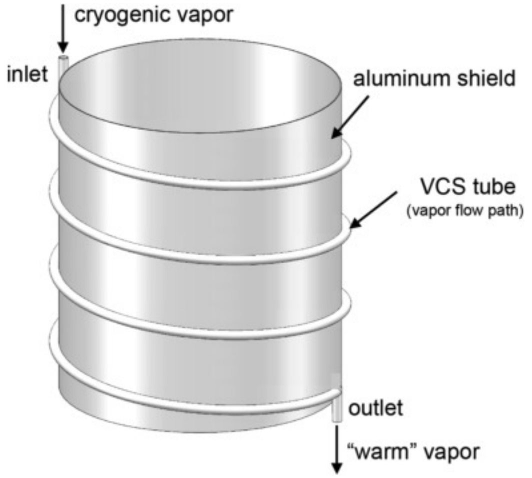
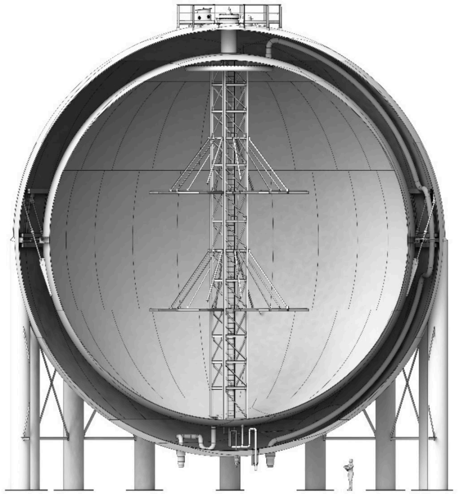
State of the art of LH2 technologies

LH2 and cryogenic hydrogen storage

- Double walled tanks with vacuum insulation (order of mPa) must be used
- Typical types of insulations:
  - perlite (silica powder)
  - multi-layer insulations (MLI)
  - glass bubbles
- Vapor cooled shields (VCSs) can be used
- Materials must not be susceptible to H2 & low-temperature embrittlement
- Typical shape is cylindrical or spherical
- Size of largest LH2 tank: 4,730 m3 (new NASA tank)
- Zero-boil off concept: Integrated Refrigeration and Storage (IRAS)



Source: https://doi.org/10.1016/j.energy.2021.120859



Swanger A, World's Largest Liquid Hydrogen Tank Nearing Completion, 2022

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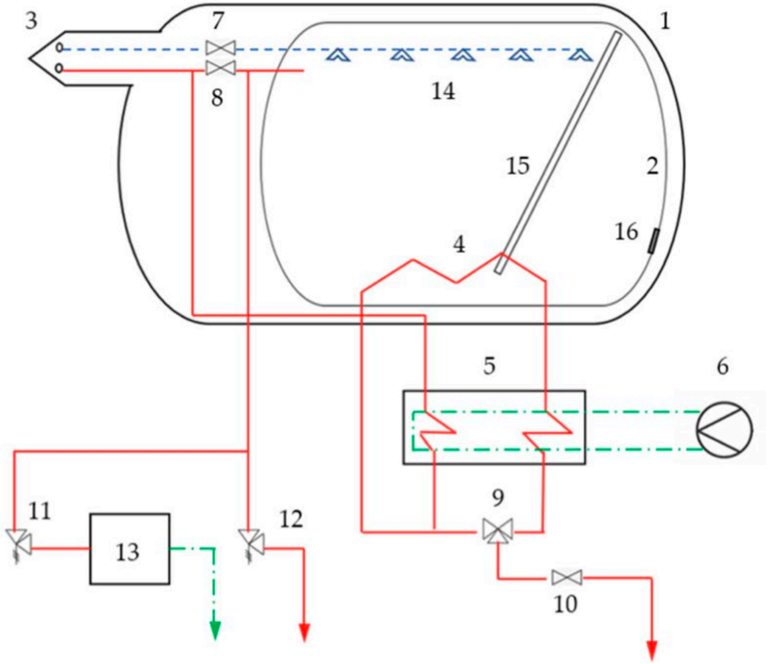
State of the art of LH2 technologies

LH2 equipment and safety devices

- LH2 storage and transfer system components:
  - valves,
  - joints, welding, gaskets
  - compensators (for thermal contraction)
  - insulation
  - instrumentation
  - support structure (e.g. rods or hooks)
  - pressurization systems (including heat exchangers)
  - cryogenic pumps
  - venting mast
- Safety devices: pressure relief valves (PRVs), sensors, shut-down valves, emergency release system (ERS)



1	Outer tank
2	Inner tank
3	Coupling
4	Heater
5	Heat exchanger
6	Cooling water pump
7	Cryogenic filling valve
8	Cryogenic return valve
9	Pressure regulation valve
10	Shut-off valve
11	Boil-off valve
12	Safety relief valve
13	Boil-off system
14	Support post
15	Liquid level sensor
16	Rupture disk

Source: doi.org/10.3390/jmse10091222

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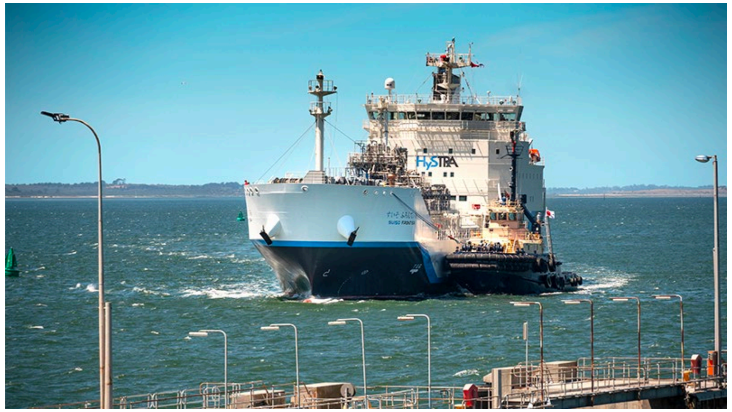
State of the art of LH2 technologies

LH2 delivery

- Continuous methods:
  - Pipelines
- Non-continuous methods:
  - Road transport (trucks)
  - Trains
  - Maritime (ships or barges)

Storage components are used for non-continuous means of transport

LH2 pipeline at NASA. Source: https://www.nasa.gov/feature/going-with-the-flow-egs-team-tests-flow-of-cryogenic-fluids



HySTRA project, Suiso Frontier. Source: https://www.hystra.or.jp/en/gallery/article.html

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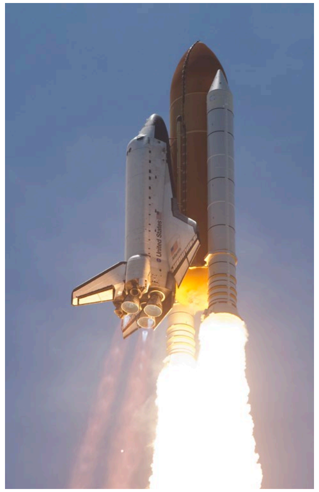
State of the art of LH2 technologies

LH2 mobile applications

- Aerospace
- Maritime
- Automotive
- Aviation
- Railway



Space shuttle. Source: https://www.nasa.gov/mission_pages/shuttle/flyout/ssme.html

Many new projects came to light in the last decade. A list can be found in:

[Ustolin, F., Campari, A., Taccani, R., An Extensive Review of Liquid Hydrogen in Transportation with Focus on the Maritime Sector. Journal of Marine Science and Engineering, 10, 2022, 1222.]

MF Hydra LH2 ferry. Source: https://www.norled.no/en/news/the-mf-hydra-first-in-the-world/

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State of the art of LH2 technologies

LH2 standards

ISO20421:2019 – Cryogenic vessels – Large transportable vacuum-insulated vessels

- Part 1: Design, fabrication, inspection and tests
- Part 2: Operational requirements

ISO21009:2022 – Cryogenic vessels – Static vacuum insulated vessels

- Part 1: Design, fabrication, inspection and tests
- Part 2: Operational requirements

ISO21029-1:2018 – Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1 000 litres volume

- Part 1: Design, fabrication, inspection and tests
- Part 2: Operational requirements

ISO13985:2006 – Liquid hydrogen – Land vehicle fuel tanks

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State of the art of LH2 technologies

LH2 standards

- Other ISO standards on Cryogenic vessels:
  - ISO21013:2016 – Pressure-relief accessories for cryogenic service
  - ISO21011:2008 – Valves for cryogenic service
  - ISO21012:2018 – Hoses
  - ISO24490:2016 – Pumps for cryogenic service
  - ISO21010:2017 – Gas/material compatibility
  - ISO21028:2016 – Toughness requirements for materials at cryogenic temperature
  - ISO21014:2019 – Cryogenic insulation performance
  - ISO23208:2005 – Cleanliness for cryogenic service
- ISO20088-1:2016 – Determination of the resistance to cryogenic spillage of insulation material — Part 1: Liquid phases

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State of the art of LH2 technologies

LH2 standards

- AIGA, 087/14 - Standard for Hydrogen Piping Systems at User Locations
- EIGA 06/19, 2019 - Safety in Storage, Handling and Distribution of Liquid Hydrogen

Observations:

1. Many standards are not focused on hydrogen
2. Lack in detailed standards on LH2 transfer technologies and procedures

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Safety issues related to LH2 technologies

Consequences of failure

Consequences of loss of containment of loss of containment of LH2 components:

- LH2 or two-phase hydrogen jet
- Material embrittlement impacted by LH2 jet
- Pool formation
- Air component condensation or solidification
- Dispersion and flammable cloud formation
- Pressure peaking phenomenon (**PPP**)

In case of ignition:

- fires: jet fire, pool fire, flash fire
- explosions: vapor cloud explosion (**VCE**), deflagration to detonation transition (**DDT**), **condensed phase explosion** (detonation), boiling liquid expanding vapour explosion (**BLEVE**)

LH2 large-scale release and delayed ignition PRESLHY project - HSE

LH2 BLEVE test, SH2IFT project - BAM

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Safety issues related to LH2 technologies

Experiments and modelling on LH2 consequences

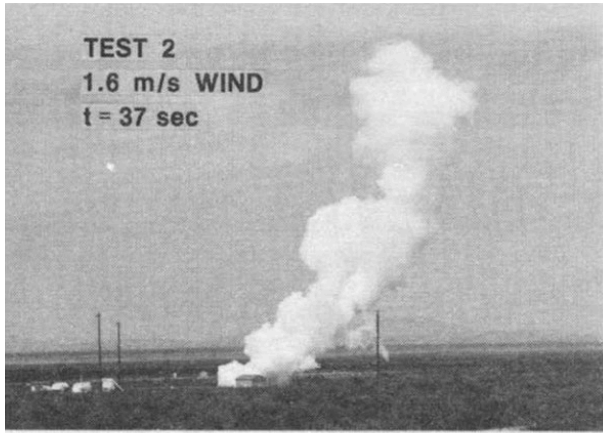
Experiments on LH2 releases on ground or water:

- Zabetakis and Burgess, ground, USA (1950s)
- NASA, sand, New Mexico (1984)
- BAM & Jülich, water & aluminium, Germany (1994)
- HSL, concrete, UK (2012)
- DNV, concrete, UK (2020)
- BAM, water, Germany (2021)

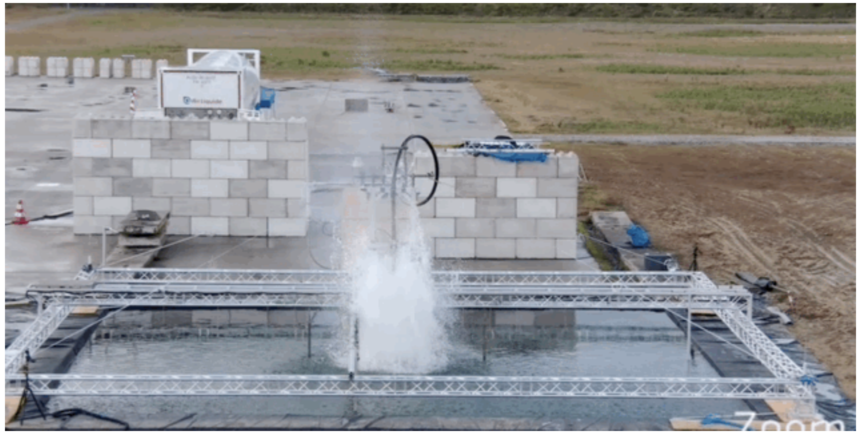
Models:

- Mostly CFD models were used to simulate LH2 consequences
- A list of investigation can be found in:

[Ustolin, F., Asholt, H.Ø., Zdravistch, F., Niemi, R., Paltrinieri, N., Computational fluid dynamics modelling of liquid hydrogen release and dispersion in gas refuelling stations, Chemical Engineering Transactions, 86, 2021, 223–228.]



Witcofski & Chirivella (1984), https://doi.org/10.1016/0360-3199(84)90064-8



LH2 RPT test, SH2IFT project - BAM

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ELVHYS project

ELVHYS

Enhancing safety of liquid and vaporised hydrogen transfer technologies in public areas for mobile applications

Funding: 2.0 M€

Duration: 2023-2026

Coordinator: NTNU

Partners:

NTNU Norwegian University of Science and Technology

Ulster University

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

DLR

HSE Health & Safety Executive

KIT Karlsruher Institut für Technologie

Air Liquide

Website

Objective: provide indications on inherently safer and efficient cryogenic hydrogen technologies and protocols in mobile applications by proposing innovative safety strategies including selection of effective safety barriers and hazard zoning strategies, which are the results of a detailed risk analysis.

NTNU role: coordinator, consequence analysis, risk analysis

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ELVHYS project

Expected outcomes

1. Detailed risk analysis for LH2 transferring operations for mobile applications (ships, trucks, stationary tanks) fillings
2. Generic hazard distances for LH2 transferring operations in the different applications, also addressing SimOps
3. Guidelines for design of LH2 transferring facilities
4. Consensual loading procedures for LH2 transferring operations
5. Provide inputs for developing Standards, Technical Specifications, or Technical Reports at the international level

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ELVHYS project

ELVHYS

NTNU (Coordinator)

Ulster University

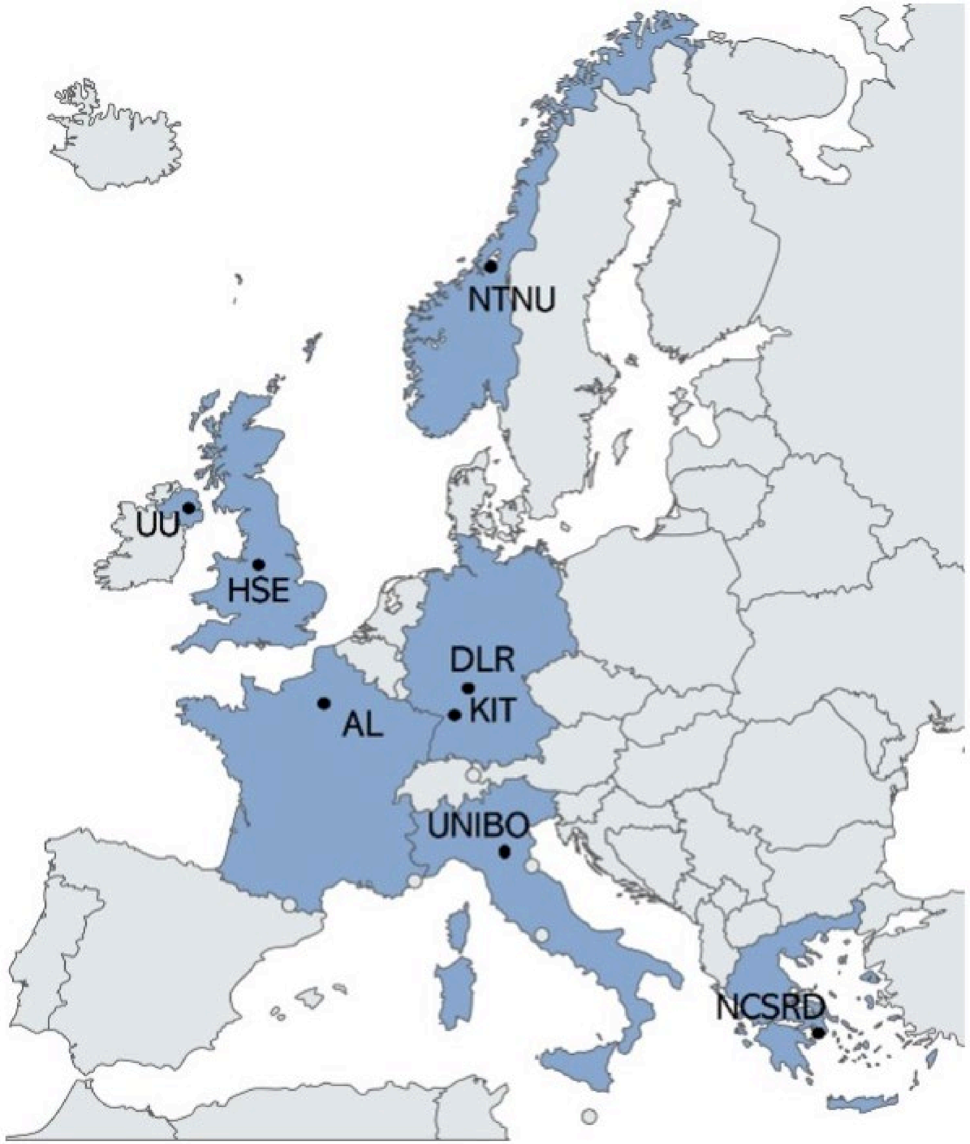
DEMOKRITOS

DLR

HSE

KIT Karlsruher Institut für Technologie

Air Liquide



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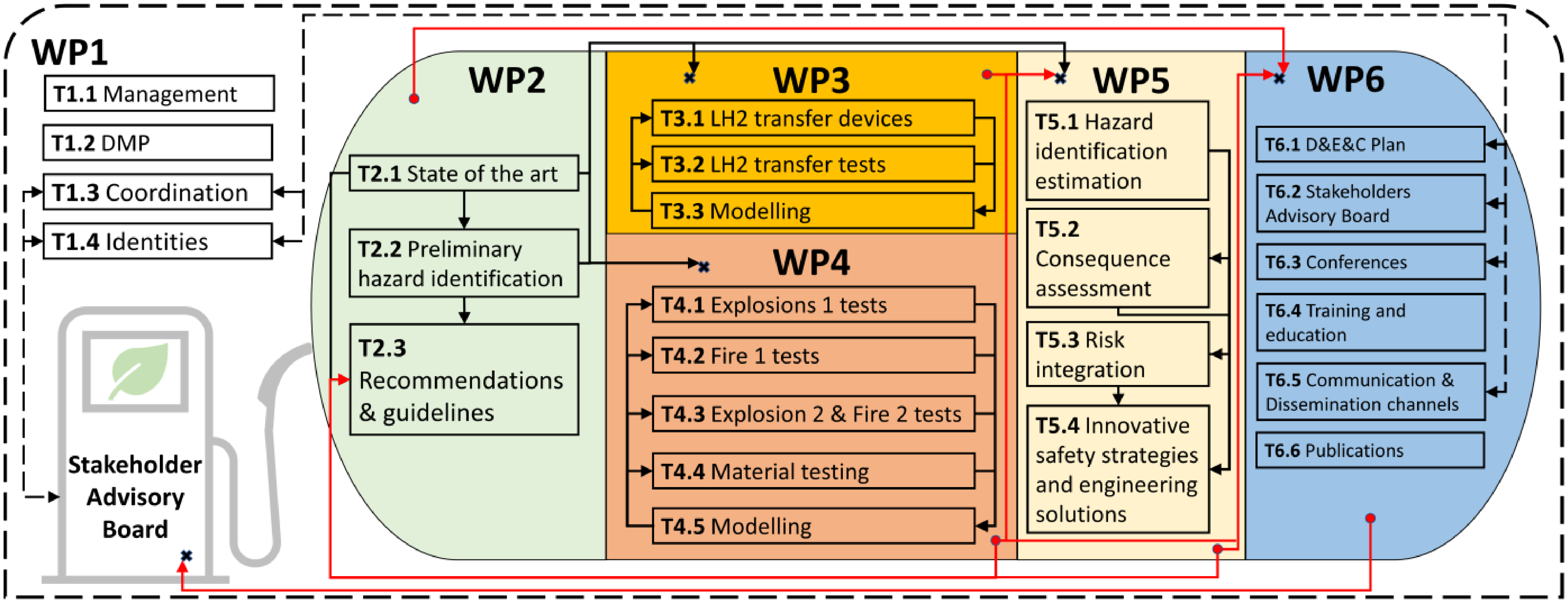

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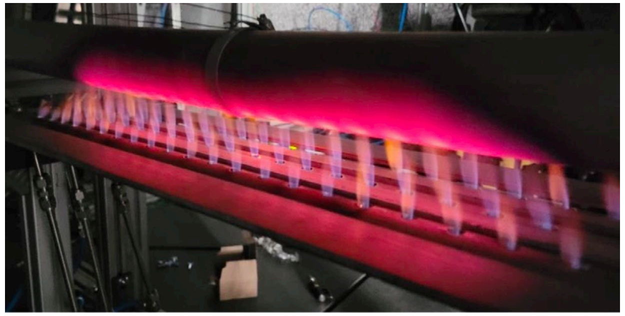
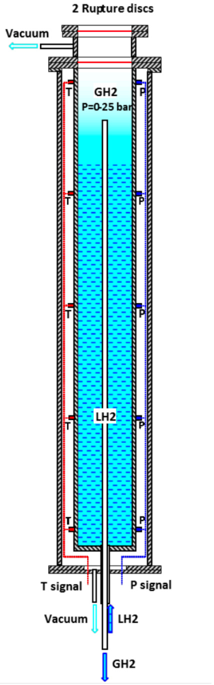
Experiments and modelling (WP3 & 4)

- **T3.2**: **LH2 transfer tests**: bunkering, fuelling, refuelling, defueling
- **T4.1**: **Oxygen enrichment** and condensed phase explosions
- **T4.2**: **Leakage** into cold room/tank connection space considering barriers and obstacles
- **T4.3**: Performance of LH2 components and explosion consequences:
  - **T4.3.1**: **BLEVE tests** with a shock tube filled with LH2
  - **T4.3.2**: **Fire tests** of short transfer line elements
- **T4.4**: **Material testing** against unignited and ignited jets (MLI, glass spheres, perlite layers and fire protecting wall)

Source: HSE





Source: KIT

Thank you for your attention

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