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HSE

Hydrogen research

Simon Gant, Fluid Dynamics Team, HSE Science and Research Centre, Buxton, UK

EU Technical Working Group for Seveso Inspections and OECD Working Party on Chemical Accidents
Hydrogen Fuel Risks Part 1, 15 September 2023

Outline

- Knowledge gaps and research priorities
- Cryogenic liquid hydrogen
  - Research related to transport and storage applications
- Gaseous hydrogen
  - HyTunnel
  - MultHyFuel
  - Hazardous area classification
  - HSE hydrogen materials testing facility
  - HyDeploy
  - Hydrogen heating programme research
- NFPA 2
- HSE research publications

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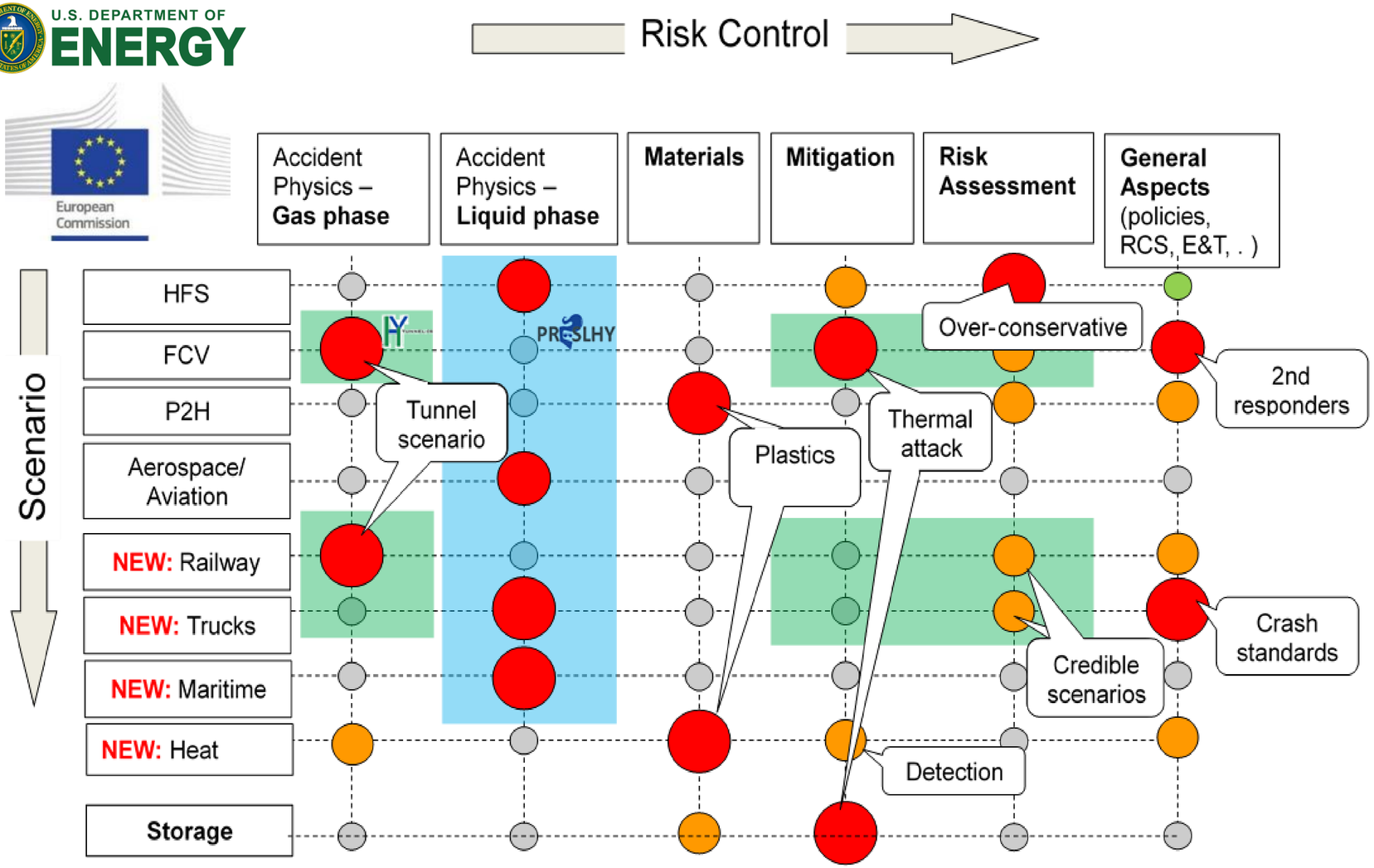
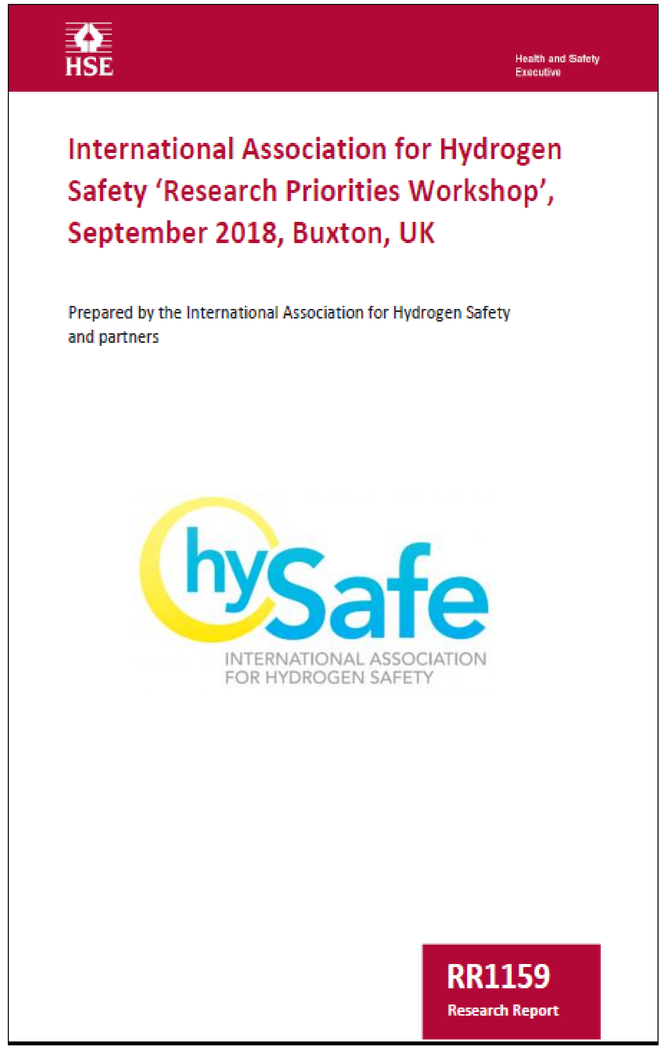
U.S. DEPARTMENT OF ENERGY

European Commission

HSE



Red dots indicate where both the Risk Control and Scenario scored high, generally the top priority



https://www.hse.gov.uk/research/rrhtm/rr1159.htm

HySafe Research Priorities Workshop 2022

- Research priorities workshop held in November 2022 in Quebec
- 24 leading world hydrogen safety experts
- Defined and ranked the most immediate research priorities needed to safely advance the deployment of hydrogen technologies
- Report summary will be published shortly

Liquid Hydrogen: PresLHy

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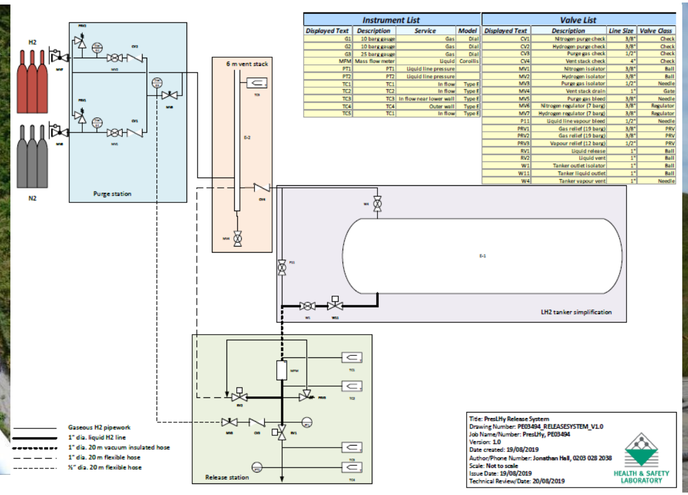
- Aims: to identify safety critical areas where knowledge gaps exist and specific standards are needed for the safe use of liquid (cryogenic) hydrogen (LH2) as an energy carrier
- 3 year programme (release & mixing, ignition and combustion), 2018 – 2020
- Designed, built and reported pre-normative experiments on source term characterisation, near and far-field dispersion, fire fighting measures, explosion overpressures, electrostatic charging and condensed phase assessment
- Flows ranged from 1-5 barg at source with flow rates up to 300 g/s in 1” pipework

https://preslhy.eu/



Instrument List

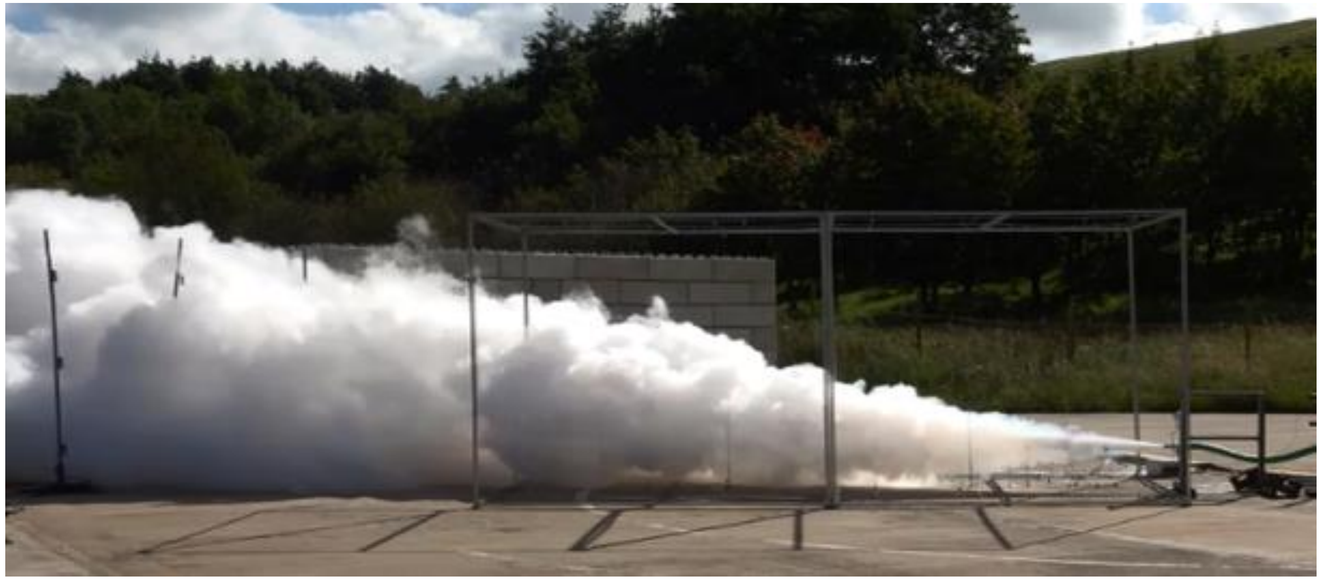
Displayed Text	Description	Service	Model
G1	10 barg gauge	Gas	Dial
G2	10 barg gauge	Gas	Dial
G3	25 barg gauge	Gas	Dial
MFM	Mass flow meter	Liquid	Coriolis
PT1	PT1	Liquid line pressure	
PT2	PT2	Liquid line pressure	
TC1	TC1	In flow	Type E
TC2	TC2	In flow	Type E
TC3	TC3	In flow near bowl wall	Type E
TC4	TC4	Outer wall	Type E
TC5	TC5	In flow	Type E

Valve List

Displayed Text	Description	Line Size	Valve Class
CV1	Nitrogen purge check	3/8"	Check
CV2	Hydrogen purge check	3/8"	Check
CV3	Purge gas check	1/2"	Check
CV4	Vent stack check	4"	Check
MV1	Nitrogen isolator	3/8"	Ball
MV2	Hydrogen isolator	3/8"	Ball
MV3	Purge gas isolator	1/2"	Needle
MV4	Vent stack drain	1"	Gate
MV5	Purge gas bleed	3/8"	Needle
MV6	Nitrogen regulator (7 barg)	3/8"	Regulator
MV7	Hydrogen regulator (7 barg)	3/8"	Regulator
P11	Liquid line vapour bleed	1/2"	Needle
PRV1	Gas relief (10 barg)	3/8"	PRV
PRV2	Gas relief (10 barg)	3/8"	PRV
PRV3	Vapour relief (12 barg)	1/2"	PRV
RV1	Liquid release	1"	Ball
RV2	Liquid vent	1"	Ball
W1	Tanker outlet isolator	1"	Ball
W11	Tanker liquid outlet	1"	Ball
W4	Tanker vapour vent	1"	Needle

Title: PresLHy Release System
Drawing Number: P605494_RELEASESYSTEM_V1.0
Job Name/Number: PresLHy, P605494
Version: 1.0
Date created: 19/08/2019
Author/Phone Number: Jonathan Hall, 0203 028 2038
Scale: Not to scale
Issue Date: 19/08/2019
Technical Review/Date: 20/08/2019
HEALTH & SAFETY LABORATORY

Liquid Hydrogen: PresLHy



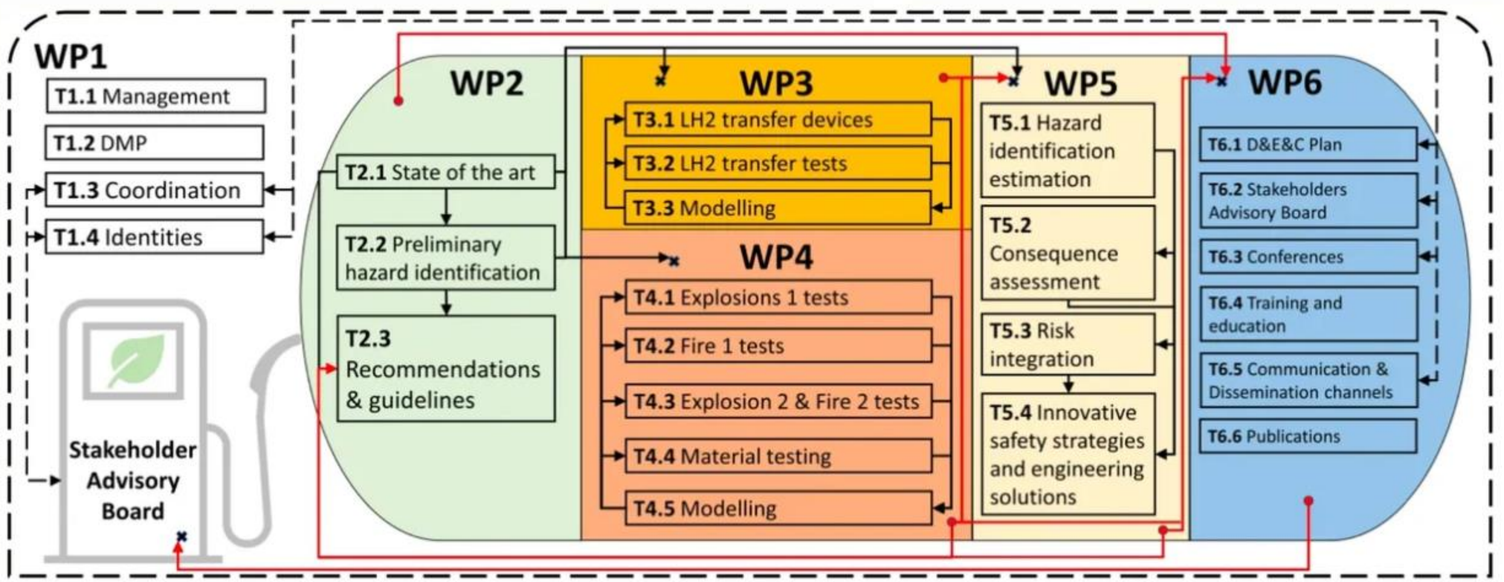
Liquid Hydrogen: PresLHy

PresLHy: Congested explosions

Liquid Hydrogen: Elvhys

- Aim: to improve understanding of inherently safer and efficient cryogenic hydrogen technologies and operations in mobile applications
- LH2 transfer operations and loss of containment scenarios
- Selection of effective safety barriers and hazard zoning strategies
- Experimental, theoretical, and numerical studies

€2m budget
Timeline: 2023-2025
https://elvhys.eu/



NTNU Norwegian University of Science and Technology
Ulster University
DLR
HSE Health & Safety Executive
KIT Karlsruher Institut für Technologie
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
Air Liquide

Gaseous Hydrogen: HyTunnel

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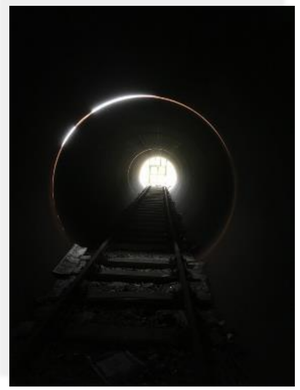
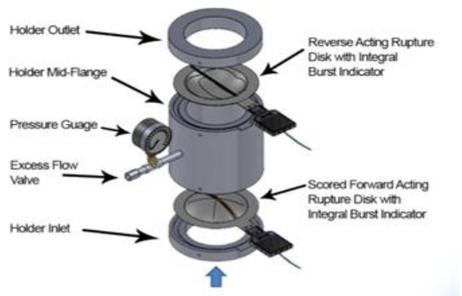
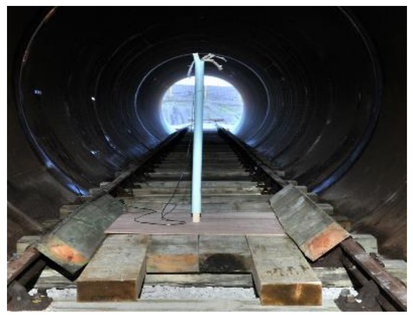
- Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces
- Project partners: academia, emergency services, research and standard development organisations
- Releases in a 70 m tunnel assessing mitigation systems, dispersion rates (from TPRDs) and explosion prevention
- Effect of jet impingement on tunnel wall and road materials
- Fire engulfment tests on pressurised type IV tanks
- €2.5m budget, March 2019 – Feb 2022

https://hytunnel.net/







Ulster University · KIT Karlsruher Institut für Technologie · Technical University of Denmark DTU · USN Universitetet i Sørøst-Norge · Ha Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón · ifa International Fire Academy · Sapienza Università di Roma · NEN · ibz · cea · Pro-Science

TPRD = Temperature/Pressure Relief Device

Gaseous Hydrogen: MultiHyFuel

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MultHyFuel

- Aim: to develop a common strategy for implementing Hydrogen Refuelling Stations (HRS) in multifunctional contexts, contributing to harmonizing laws and standards based on practical, theoretical and experimental data as well as on the active and continuous engagement of key stakeholders
- 3 year collaborative project with work ongoing by HSE to:

https://multhyfuel.eu/

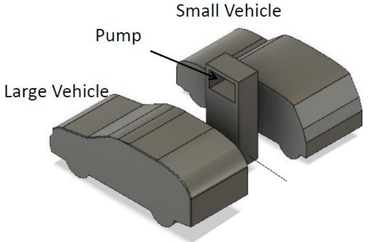
  - Assess critical hazards posed by 700 bar HRS dispensers to the public, equipment and other dispensers through full scale experiments

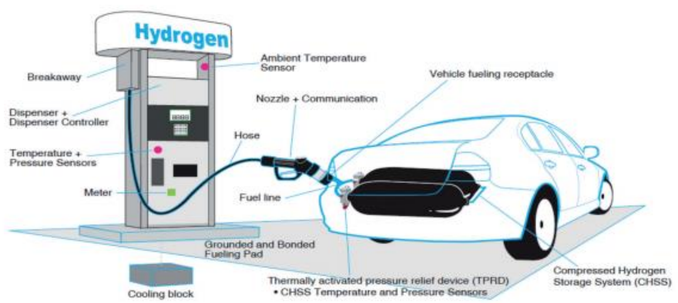
Pressure peaking phenomenon, propensity for detonation, ventilation effectiveness, overpressures

  - Assess critical hazards posed by conventional fuels and vehicles to HRS dispensers

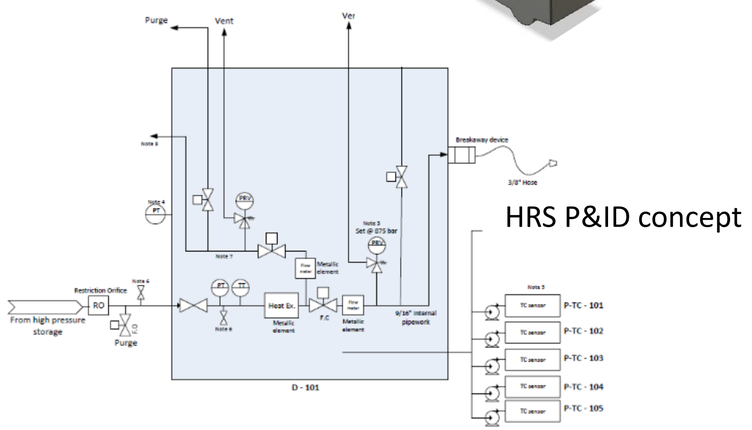
Pool fires, jet fire impingement, structural and component response and integrity

  - Examine the negligeable extent and minimum harm criteria with respect to flammable zoning
  - Perform Quantitative Risk Assessment (QRA) on example HRS configurations





Draft BS ISO 19880-2 Gaseous hydrogen — Fuelling stations. Part 2: Dispensers

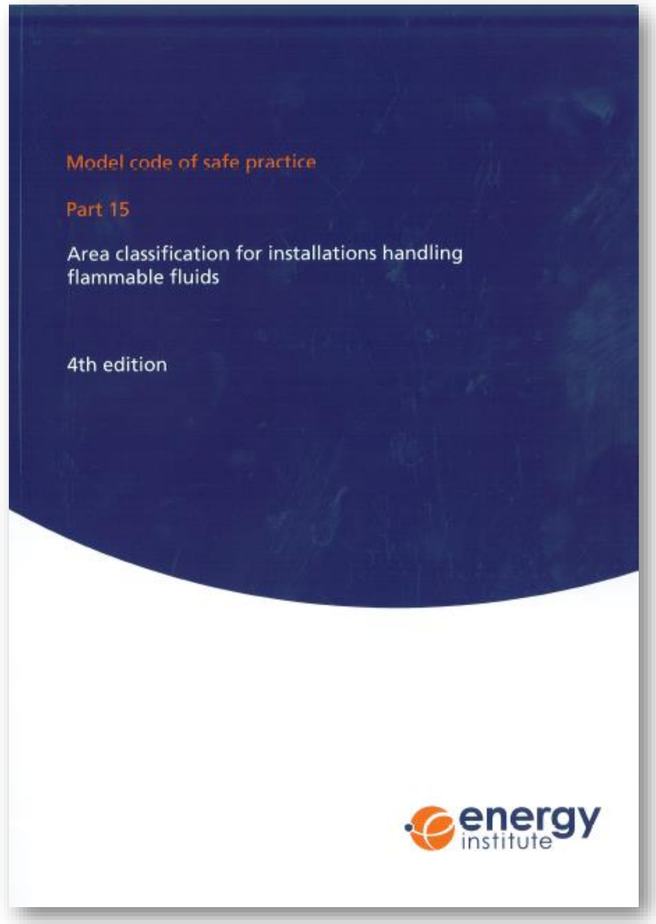


HRS P&ID concept

Hazardous Area Classification, EI15

- Energy Institute publication EI15: “Area classification code for installations handling flammable fluids” (formerly IP15)
- 4th edition published in 2015
- Widely used by the petroleum industry
- Can be used for a number of defined “fluid categories”
- One of which is refinery hydrogen G(ii)

- New revised edition of EI15 is currently being produced which will include pure hydrogen gas up to 1,000 bar and liquid hydrogen
- Revised version is based on hazard predictions using the DNV Phast model
- HSE has been involved in reviewing these Phast results



Hazardous Area Classification IGEM/SR/25

Safety (SR Series) Dec 2022 by Institution of Gas Engineers and Managers

IGEM/SR/25 Edition 2 with amendments 2013 Hydrogen Supplement 1

This Supplement is to be read in parallel with Standard IGEM/SR/25 Edition 2 – with Amendments August 2013. This Supplement outlines where there are differences in the approach for hazardous area classification of installations handling hydrogen, including blends of natural gas/hydrogen (subsequently referred to as NG/H blends with 20% NG/H referring to a 20% (by volume) blend of hydrogen in natural gas) versus the main Standard, which was written for Natural Gas (NG). The clause numbers in this Supplement are as in IGEM/SR/25 Edition 2, but preceded by the letter 'S'. Users of this Supplement should refer to the clause numbers in the main Standard and any specific, additional requirements and/or qualifications which are given in this Supplement.

This Supplement to IGEM/SR/25 provides a procedure for hazardous area classification around installations handling hydrogen, including a 20% NG/H blend providing a basis for the correct selection and location of fixed electrical equipment in those areas. In addition, the recommended zoning restrictions are relevant with regard to the introduction and use of any temporary mobile electrical equipment or other potential ignition source.

This Supplement is based on work detailed in HSE report FD/21/01 "Development of a Hydrogen Supplement for use with IGEM/SR/25". The principles in IGEM/SR/25 have been applied successfully in the UK for NG and this Supplement provides information on how to adapt these principles for hydrogen and NG/H blends.

https://www.igem.org.uk/resource/igem-sr-25-edition-2-with-amendments-2013-hydrogen-supplement-1.html

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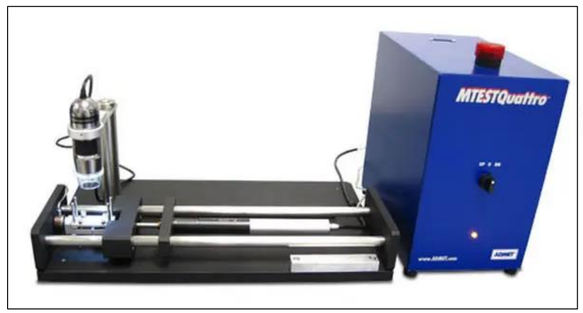
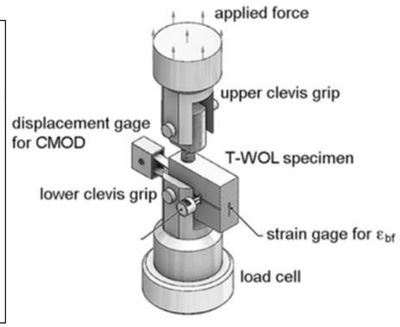
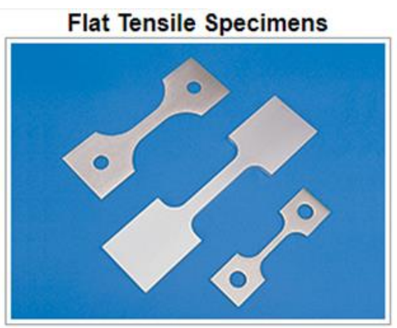
HSE hydrogen materials testing facility

- HSE is investing in a new hydrogen materials testing facility at its Science and Research Centre in Buxton
- Aim to conduct long-term exposure tests of materials in gaseous hydrogen up to 8 bar
- Testing methods:
  - In-situ micro tensile testing
  - Ex-situ tensile testing
  - Ex-situ impact testing
- Testing of metals, polymers and elastomers
- Facility build time is estimated at 6 months
- Due to be operational in 2024







HyDeploy: 20% hydrogen in natural gas

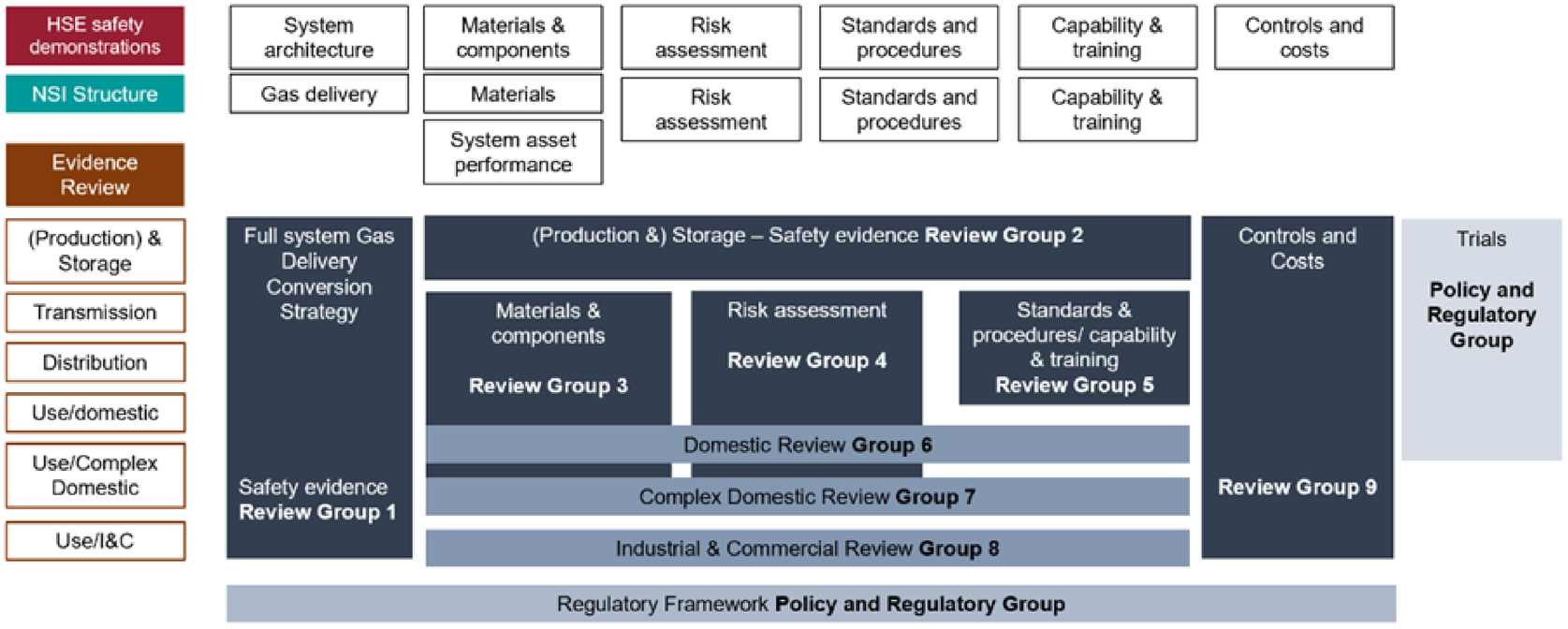
- Numerous safety studies undertaken on:
  - Leakage
  - Indoor accumulation
  - Ignition and consequences (fire and explosion)
  - Control and updated gas network procedures (e.g., pipeline purging)
  - Building proximity distances to pipelines
  - Hazardous area classification
  - Material compatibility (work on cast iron ongoing…)
  - Review of all gas-facing assets on network and risk ranking exercise
  - Quantified risk assessment for domestic users
  - Trials of 20% hydrogen at Keele University campus and Winlaton village
  - Public perception of 20% hydrogen use

HyDeploy

https://hydeploy.co.uk/

Hydrogen Heating Programme

- HSE review of technical safety evidence on hydrogen for heating in the UK
- Aim to inform UK Government decision on 100% hydrogen heating in 2026



Hydrogen Heating Programme

1. **Full system gas delivery conversion strategy**: The management of the actual process of changing from supplying natural gas to hydrogen and the potential safety impact on consumers.
2. **(Production) and storage**: The safety impacts of increased use of hydrogen storage at a variety of quantities and type of storage site.
3. **Materials and components**: The impact of hydrogen on the materials and components within the existing system which will be repurposed, how these will perform, long-term degradation and failure mechanisms. Additionally, considering suitable materials for new parts of the system and any existing components which may need replacing.
4. **Risk assessment**: The processes for identifying and assessing the risks of hazards in the new hydrogen environment, the demonstration of risk in people's homes will be particularly critical.
5. **Standards and procedures / capability and training**: What is needed to ensure a competent workforce, including the need to upskill existing workers or train new workers, training material and assurance processes, and ensuring suitably robust standards are developed for all aspects of the system. This group should consider the number of resources that will be required not only to safely operate and maintain the system but also during the conversion process.

Hydrogen Heating Programme

6. **Domestic**: The impact of hydrogen use in domestic settings, including downstream use and impact on domestic appliances.
7. **Complex domestic**: Safety impacts of hydrogen use in complex domestic settings such as multiple occupancy buildings. This group will need to coordinate with HSE's Building Safety Regulator.
8. **Industrial and commercial**: Particular safety considerations which may not be relevant for domestic and complex domestic settings, but arise within industrial and commercial sites, including downstream and non-domestic appliances.
9. **Controls and costs**: Assessment of the relevant controls that will be needed throughout the system to ensure safety, and associated costs.
10. **Trials** (Policy and regulatory group): HSE's regulatory approach to upcoming hydrogen trials, and assessment of safety evidence submitted to HSE in relation to trials (particularly H100 and the Village Trial).
11. **Regulatory framework (Policy and regulatory group)**: Consideration of needs to be regulated and how the various aspects of the system will be regulated, development of a suitable regulatory framework to provide clarity to both the operators and public.

Examples of evidence reviewed by HSE

- HyNTS compression on the gas transmission network
- Risk assessment of individual domestic properties
- Hydrogen purging and tightness testing
- Pipe sizing and pressure drop criteria
- Material suitability
- Hydrogen gas detection instruments
- Salt caverns for hydrogen storage
- Leakage management in the energy system transition
- Functional and test requirements for hydrogen gas metering
- Impact of hydrogen on cathodic protection and degradation of coatings
- Gas network operative skills and competences for hydrogen
- Requirements for ancillary valves, devices and components
- Granton to Grangemouth pipeline repurposing live trial

Over 100 reports and only part-way through review process

FutureGrid

FutureGrid Status Report — April 2023 Issue

Updates as of 27th March 2023

DNV | national gas transmission

Phase 1 – Test Facility Overview

FutureGrid is an ambitious programme to build a hydrogen test facility from decommissioned assets at DNV's facility in Cumbria to demonstrate the National Transmission System (NTS) can transport hydrogen.

Testing will be conducted in two parts:

Offline Hydrogen Test Facility

NTS assets of different types, sizes & material grades will be tested with 2, 5, 20 & 100% hydrogen

Standalone Hydrogen Test Modules

Standalone hydrogen test modules will provide key data required to feed into the main facility

This will help us understand how hydrogen interacts with our assets, so that we can develop appropriate safety standards required to operate our network.

Project Spend Performance

G

£10.1m

January's application of payment is under review. The total spend is £7,073,191. A bank account mirror request has been conducted in September

Overall Status Update

G

Build Started | Leak & Lab Tests Start | Groundworks Complete | Leak Tests End | Lab Test End | Build Complete | Rupture Tests | Facility Commissioning | Natural Gas Test | 2% | 5% | 10% | 20% | 100% Hydrogen Testing | Fatigue Tests | Safety Case & QRA | Project Complete

In March, most pre-commissioning activities have been completed. The site was visited by DSEAR team to discuss the commissioning. The build has been completed. The hydrotest has successfully completed on Friday 24th March (which was slightly delayed due to weather condition but no overall impact) with drying being conducted currently. The commissioning process will continue in the next few weeks.

5 Key Activities to Remove Programme Delivery Risk

1 Pressure on key delivery partners	2 Escalating key delivery elements	3 Dedicated DNV Resources	4 Pause all non-essential site activity	5 Programme Re-baseline
Pressure on Schneider to deliver electrical pillar to complete electrical infrastructure on site. Escalation to Severn Trent to resolve issues / delays in the adoption and commission of water supply.	Senior DNV engagement to ensure workstreams at risk of delay are reviewed by team and prioritized with additional effort to ensure no slippage of outputs or quality.	DNV are splitting key resources across too many programmes affecting delivery performance. Key people identified and DNV instructed to improve performance to increase effective delivery.	All obstacles to working on site removed to ensure full access during working hours to optimise project delivery. All site visits except VIPs (agreed via Hydrogen LT) are paused to support this.	Full programme overhaul with a re-baseline of milestones which cannot be recovered to provide a realistic delivery plan to be agreed at Senior DNV management level.

Stage	Activity	Due	Status	Progress
1A Facility Build	Groundworks *(Offline H2 Test Facility)*	Nov-21	Complete	→ **Asset Pre-Assessments:** PMC re-scheduled to re-grease valves after hydrotest. → **Leak tests:** DNV provided the final test report in March. → **Lab tests:** Permeation test report issued for review. → **Construction:** Re-compressor SAT is penciled for 21st April. → **Rupture tests:** Transient test done in Feb, steady state in Jul. → **Commissioning:** Hydrotest completed. Pneumatic leak test is scheduled to be completed in March.
	Leak Tests *(Standalone Test Module)*	Dec-22	Completed	
	Lab Tests *(Standalone Tests)*	Feb-23	Completed	
	Construction *(Offline H_2 Test Facility)*	Feb-23	Completed	
	Rupture Tests *(Standalone Test Module)*	Jun-23	On Track	
	Pre-Commissioning *(Offline H_2 Test Facility)*	Mar-23	On Track	
	Commissioning *(Offline H_2 Test Facility)*	Apr-23	Not Started	
1B Hydrogen Testing	100% Natural Gas Test	May-23	Not Started	→ Preparations underway for testing phase, review of the testing programme complete including agreement of the flows and order of operation of the facility for each test.
	2% Hydrogen Testing	Jun-23	Not Started	
	5% Hydrogen Testing	Aug-23	Not Started	
	10% Hydrogen Testing	Aug-23	Not Started	
	20% Hydrogen Testing	Oct-23	Not Started	
	100% Hydrogen Testing	Nov-23	Not Started	
1C QRA & Safety Case	Fatigue Tests *(Standalone Test Module)*	Nov-23	On Track	→ **Stand Alone Testing:** Testing has commenced. 18,500/150,000 cycles have already been conducted as of 15 Feb 2023 Testing will continue till the fatigue rig delivers final results later in 2024. → **Hazardous Area:** The compressor site has been reselected. → **Safety Case Review:** NGT issued report comments to DNV.
	Procedure Review	Aug-22	Complete	
	Hazardous Area Impact	Apr-23	On Track	
	Quantitative Risk Assessment (QRA)	Nov-23	Not Started	
	Overpressure Risk	Jul-23	Not Started	
	Safety Case Review	Mar-23	On Track	
1D Engagement & Reporting	Progress Report 2021	Dec-21	Complete	→ **Utility Week Live (16-17 May):** exhibition space & speaking slot confirmed, FutureGrid model being updated → **Innovation Zero (24-25 May):** following week to UWL with a government / policy maker focus – final prep underway
	Progress Report 2022	Dec-22	Complete	
	Closure Report 2023	Nov-23	Not Started	
	Engagement & Dissemination Events	Nov-23	On Track	

#	Opportunities
1	Learning from FutureGrid can be used to enhance other NG Hydrogen Projects
2	Identifying efficiencies in commissioning stage to reduce any timescale impacts

#	Top 3 Risks
1	Severe weather conditions may impact commissioning and testing phase
2	Risk of Re-compression unit not functional during commissioning stage
3	Assets unsuitable for facility or fail during testing

Progress This Month

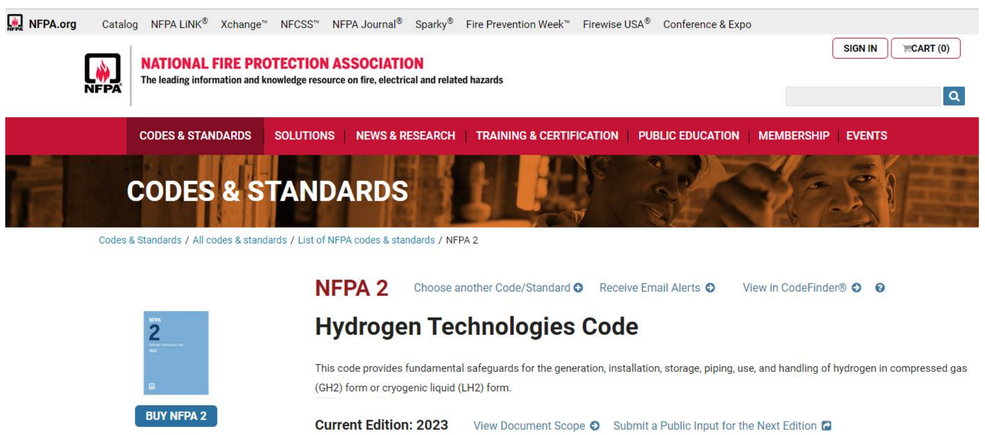
- → Build stage has been completed
- → Fatigue rig has conducted 18,500 cycles
- → Continue installation of infrastructure
- → Safety Engineering Visit
- → Transient test conducted
- → Revised Master Test plan agreed
- → Commissioning interactions agreed
- → Lab permeation test report is issued to NGT for review.
- → Control room set up with meeting facilities and control centre prepped for controlling the operation of the FutureGrid facility
- → Department of Energy Security and Net Zero successful visit with NGT and rep sent to DNV visit.

Actions Next Month

- → Pneumatic test
- → Pre- Commissioning & Commissioning activities
- → Confirmation of GO/NO Go reporting process
- → Commissioning runs
- → Site hazardous area drawings to be delivered
- → Commission instrumentation systems
- → EC&I Final Detailed Design
- → Complete infrastructure activities
- → Continue operational improvements of site
- → 100% NG Test
- → QRA: Complete compressor station drawings
- → Complete HAZOP/ HAZID Actions.

NFPA 2, edition 2023

- New version of NFPA 2 proposes use of LFL = 8% v/v for hydrogen?



LIMITS OF FLAMMABILITY OF GASES AND VAPORS

BY H. F. COWARD AND G. W. JONES

Bulletin 503
BUREAU OF MINES

Although this explanation of the mechanism of flame propagation in hydrogen-air mixtures is entirely acceptable, it seems undesirable, and possibly dangerous, to accept Goldmann's conclusion that the true limits of flammability are those for downward propagation of flame. If so, a 6-percent hydrogen-air mixture and a 5.6-percent methane-air mixture would be described as nonflammable. Both these mixtures propagate flame upward indefinitely and if ignited near the floor of a closed room would produce pressures of the order of 1 and 4 atmospheres, respectively, and mean temperatures of about 350° and 1,200° C. Such conditions would burst windows and burn men. It is inconceivable that anyone who has seen a 5.6-percent methane-air flame traveling up a long tube would term this mixture nonflammable, although it fails to propagate flame downward.

TABLE 1.—*Limits of flammability of hydrogen in air in smaller vessels*

Upward Propagation of Flame

Dimensions of tube, cm.		Firing end	Limits, percent		Content of aqueous vapor	Reference No.
Diameter	Length		Lower	Higher		
7.5	150	Closed	4.15	75.0	Half-saturated	356
5.3	150	Open	4.19	74.6	Dried	94
5.3	150	do	[1] 4.12	[1] 74.3	do	94
5.3	150	do	[2] 4.17	[2] 74.8	do	94
5.0	150	Closed	4.15	74.5	Half-saturated	356
5.0	180	Open	4.0	72.0	Dried	133
4.8	150	do	4.0	73.8	do	38
4.5	80	Closed	[3] 4.1			56
4.5	80	do	3.9			57
2.5	150	Open	4.2		Dried	271
2.5	150	Closed	4.25	73.0	Half-saturated	356
2.5	96	do	4.1	72.8		98
2.2	45	do	3.9	73.0	Saturated	274
1.6	96	do	4.22	71.2		98
.8	96	do	5.1	67.9		98

Horizontal Propagation of Flame

7.5	150	Closed	6.5		Half-saturated	356
5.0	150	do	6.7		do	356
2.5	150	do	7.15		do	356
2.5	150	Open	6.2		Saturated	271
2.5		do		71.4		273
.9	150	do	6.7	65.7	Saturated	276

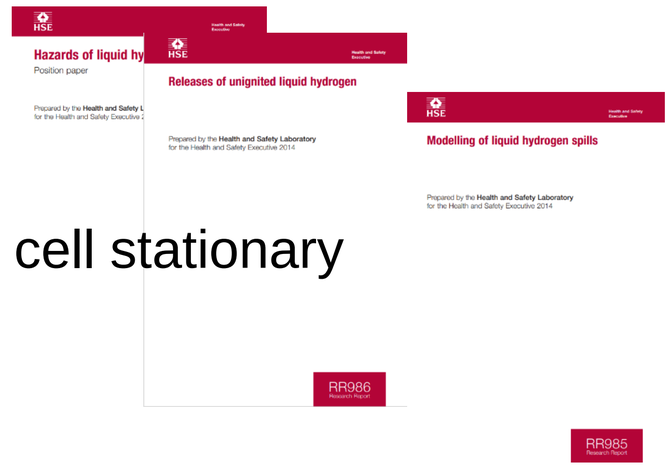
Downward Propagation of Flame

21.0	31	Open	9.3		Saturated	63
8.0	37	Closed	8.9	[4] 68.8	do	324
7.5	150	do	8.8	74.5	Half-saturated	356
7.0	150	do		74.5		115
6.2	33	Open	8.5		Saturated	95
6.0	120	do	9.45		Partly dried	325
6.0	120	Closed	9.3		do	325
6.0	120			[4] 68.0	do	325
5.3	150	Open	9.0		Dried	94

See footnotes at end of table.

HSE Research Publications

- RR1133 - Maintaining the integrity of process plant susceptible to high temperature hydrogen attack. Part 1: analysis of non-destructive testing techniques
- RR1134 - Maintaining the integrity of process plant susceptible to high temperature hydrogen attack. Part 2: factors affecting carbon steels
- RR1169 - Hydrogen in the natural gas distribution network: Preliminary analysis of gas release and dispersion behaviour
- RR1047 - Injecting hydrogen into the gas network – a literature search
- RR985 - Modelling of liquid hydrogen spills
- RR986 - Releases of unignited liquid hydrogen
- RR987 - Ignited releases of liquid hydrogen
- RR715 - Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version
- RR769 - Hazards of liquid hydrogen: position paper



https://www.hse.gov.uk/research/rrhtm/index.htm

International Conference on Hydrogen Safety

Presentations at the conference with HSE contributions:

- ID154 - Hydrogen dispersion following blowdown releases into a tunnel
- ID151 - CFD dispersion simulations of compressed hydrogen releases through TPRD inside scaled tunnel
- ID155 - Sudden releases of hydrogen into a tunnel
- ID192 - CFD analysis of delayed ignition hydrogen releases from a train inside a tunnel
- ID156 - Deflagrations of non-uniform hydrogen/air clouds in a tunnel
- ID113 - Erosive effects of hydrogen jet fires on tunnel structural materials
- ID183 - Visualisation and quantification of wind-induced variability in hydrogen clouds following releases of liquid hydrogen
- ID128 - Zone of Negligible Extent: Example of specific detailed risk assessment for low pressure equipment in a hydrogen refuelling station
- ID263 - Identification of critical scenarios of hydrogen refuelling stations in a multifuel context
- ID252 - Detailed Assessment of Dispersion for High-Pressure H2 in Multi-fuel Environment
- ID114 - Ignition and Flow Stopping Considerations for the Transmission of Hydrogen in the Existing Natural Gas Network
- ID131 - Purging hydrogen distribution pipelines: literature review, description of recent experiments and proposed future work
- ID177 - UK HSE hydrogen for heating evidence review process

https://hysafe.info/ichs2023/

Thank you

Any questions?

- Contact: simon.gant@hse.gov.uk

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