PROTECTING PEOPLE
AND PLACES

HSE

Hydrogen knowledge gaps, research and ongoing work in the UK

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PHMSA Pipeline Safety Research and Development Forum, Arlington, Virginia, USA

31st October 2023

Outline

- Introduction to HSE
- UK Government support for Net Zero
- Knowledge gaps for risk assessment
- Recent and ongoing research
- HSE research publications
- Hydrogen pipelines and the role of HSE

Introduction to HSE

- HSE is the UK regulator for workplace health and safety
  - Includes onshore/offshore pipelines, chemical/oil/gas infrastructure, offshore platforms etc.
  - Activities: evidence gathering, policy development, consultation, regulation, incident investigation, enforcement
  - HSE acts as an enabling regulator, supporting the introduction of new technologies
  - 2,400 total staff
  - £230M (€260M) budget: 60% from Government, 40% from external income

- HSE Science and Research Centre, Buxton, UK
  - 400 staff, 550 acre test site
  - Scientific support to HSE and other Government departments
  - “Shared research” or joint-industry projects co-funded by HSE
  - Bespoke consultancy on a commercial basis

UK Government support for Net Zero

- UK Government has committed to reducing CO_2 emissions to below 1990 levels by 2050
- Growth of low-carbon hydrogen and CCUS based around
  1. Regional hydrogen and CCUS industrial clusters
  2. Hydrogen for heating:
     - Government policy decision on hydrogen heating in 2026
     - 2023/4: Neighbourhood trial (300 properties, new PE distribution network, https://www.h100fife.co.uk/)
     - 2025/6: Village trial (1,000 – 2,000 properties, repurposed gas distribution network)
     - By 2030: Town pilot (start of roll-out)
  - Targets of 5 GW of low carbon hydrogen production and 10 Mt carbon capture by 2030

Map data: © 2022 Google

- Other Net Zero ambitions
  - Offshore wind, nuclear, zero-emission vehicles/planes/ships, greener buildings, protecting environment, green finance and innovation

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Hydrogen risk assessment knowledge gaps

- Failure rates
  - Research conducted to investigate effect of hydrogen on steel but:
  - Still some uncertainty over material response to long-term exposure at typical pipeline pressures
  - Findings so far suggest:
    - Steel strength not significantly affected but effect on elongation to failure is significant
    - Fracture toughness reduced for most steel grades
    - Some studies indicate that theoretical net fatigue life in the presence of hydrogen is 10-100 times less than in natural gas. Greatest effect on crack growth rate
    - Effect of H_2 on resistance of steel to fast running fractures has not been evaluated
  - Ultimately leads to uncertainty in failure rates

Hydrogen risk assessment knowledge gaps

- Fire and explosion
  - Vapour Cloud Explosions (VCEs) not currently considered in Great Britain for natural gas pipelines, since the risk is dominated by fires
  - Higher flame speed for hydrogen implies greater detonation potential
  - VCEs observed in 60 bar hydrogen jet release experiments with delayed ignition (Jallais *et al*., 2018)
  - Implication is that explosions may need to be modelled
  - Is delayed ignition a credible event for transmission pipeline releases?
  - What overpressures are generated in VCEs from pipeline releases?
  - Is the overall VCE risk significant when compared to effects from fires?

Hydrogen risk assessment knowledge gaps

- Ignition probabilities
  - Lower MIE and wider flammable range mean that hydrogen is easier to ignite than natural gas
  - HSE previously reviewed ignition probabilities, but not specifically for hydrogen
  - No specific probabilities for hydrogen identified previously
    - Currently reviewing previous work to see if any suitable ignition probabilities have been identified in the interim
  - Always an area of uncertainty

Other knowledge gaps

- Leak tightness
  - Pipelines and all associated assets e.g. valves, flanges, etc.
- Coating and CP effectiveness
- Hazardous area impacts
- Relative impacts of different % hydrogen
- Procedures
- …

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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

DNV HSE Northern Gas Networks fluxys Durham University

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.

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/

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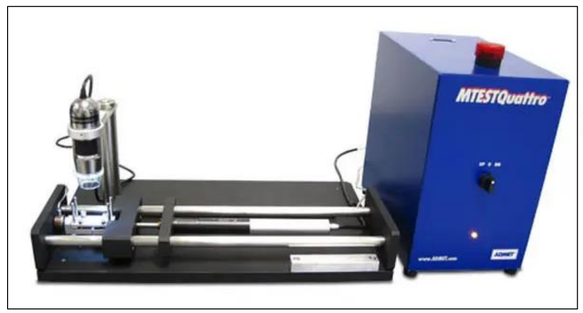
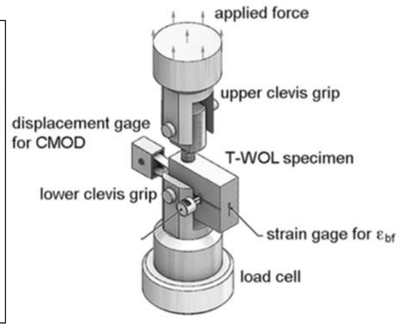
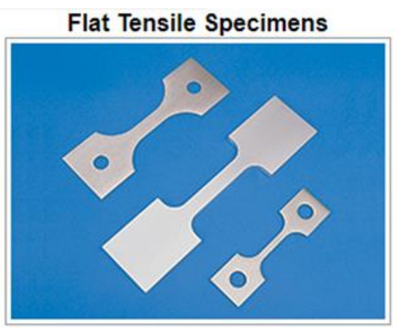
HSE hydrogen materials testing facility

- 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



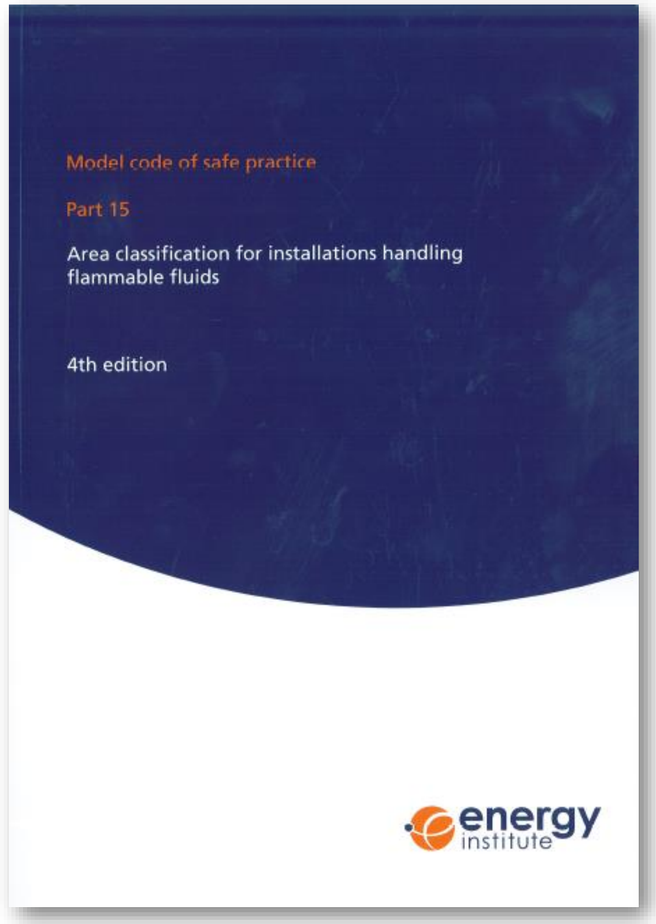




Hazardous Area Classification, EI15

- 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.

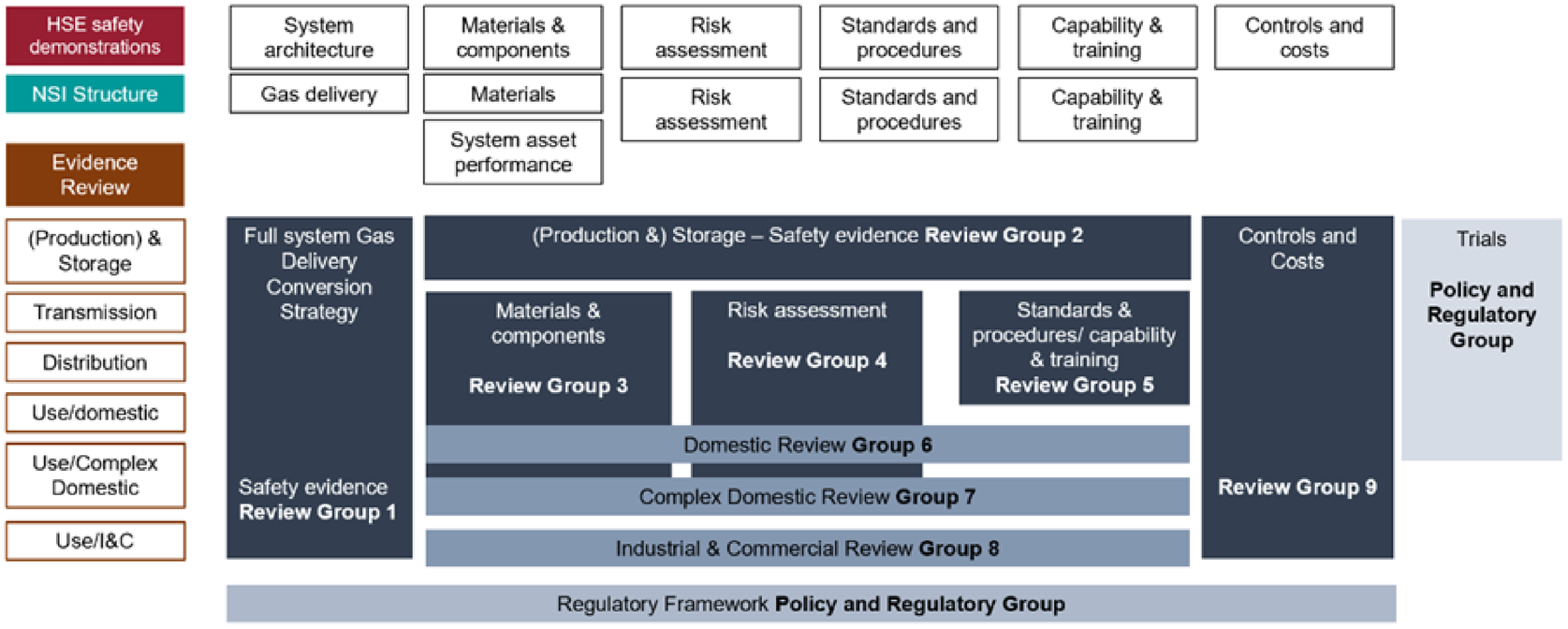
This Supplement to IGEM/SR/25 provides a procedure for hazardous area classification around installations handling hydrogen, including a 20% NG/H blend providing a basis for the correct selection and location of fixed electrical equipment in those areas. In addition, the recommended zoning restrictions 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

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



HHP Scope

- Production and Storage
  - Production is not in scope of this work, but elements do arise in the review
  - Storage in salt caverns
  - Storage in above ground installations
- Distribution and Transmission
  - National transmission system (NTS)
  - Local transmission system (LTS)
  - Storage in line pack
  - Compressor stations
- End use
  - Normal residential housing
  - Complex residential housing
  - Commercial
  - Industrial

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

Gaseous Hydrogen: HyTunnel

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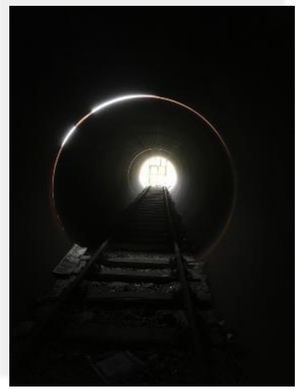
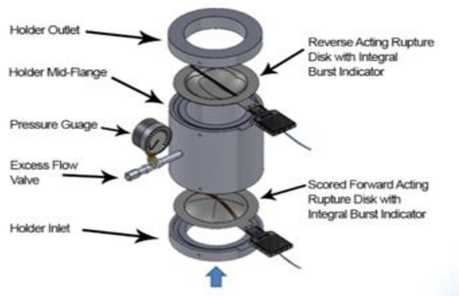
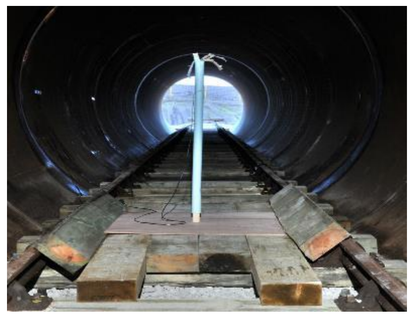
- Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces
- Project partners: academia, emergency services, research and standard development organisations
- Releases in a 70 m tunnel assessing mitigation systems, dispersion rates (from 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 multifuel 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/

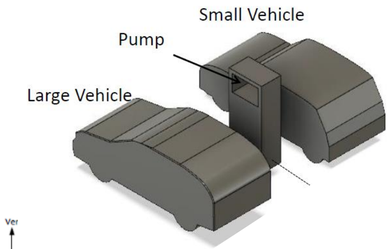
  - Assess critical hazards posed by 700 bar HRS dispensers to the public, equipment and other dispensers through full scale experiments

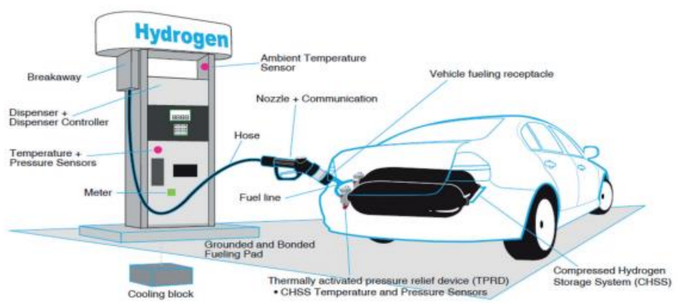
Pressure peaking phenomenon, propensity for detonation, ventilation effectiveness, overpressures

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

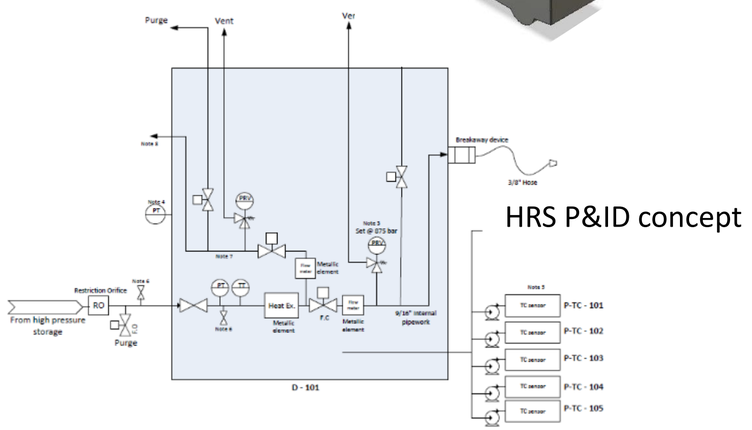
Pool fires, jet fire impingement, structural and component response and integrity

  - Examine the negligible 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

Liquid Hydrogen: PresLHy

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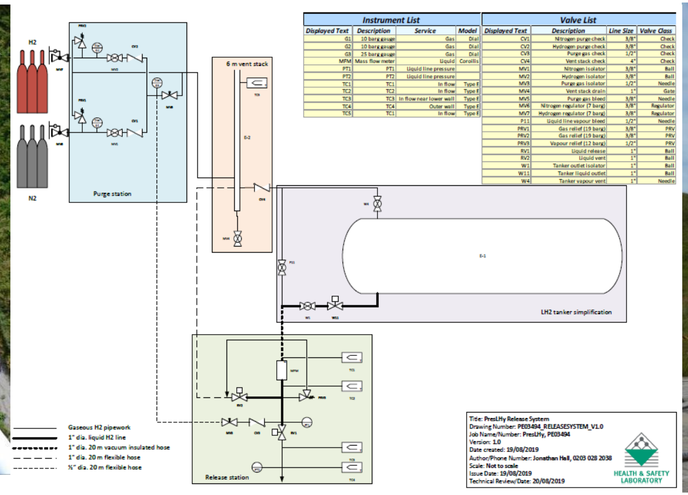
- Aims: to identify safety critical areas where knowledge gaps exist and specific standards are needed for the safe use of liquid (cryogenic) hydrogen (LH2) as an energy carrier
- 3 year programme (release & mixing, ignition and combustion), 2018 – 2020
- Designed, built and reported pre-normative experiments 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 sensor	Gas	Dial
G2	10 barg sensor	Gas	Dial
G3	25 barg sensor	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	Type E
TC4	TC4	Outer wall	Type E
TC5	TC5	In flow	Type E

Valve List

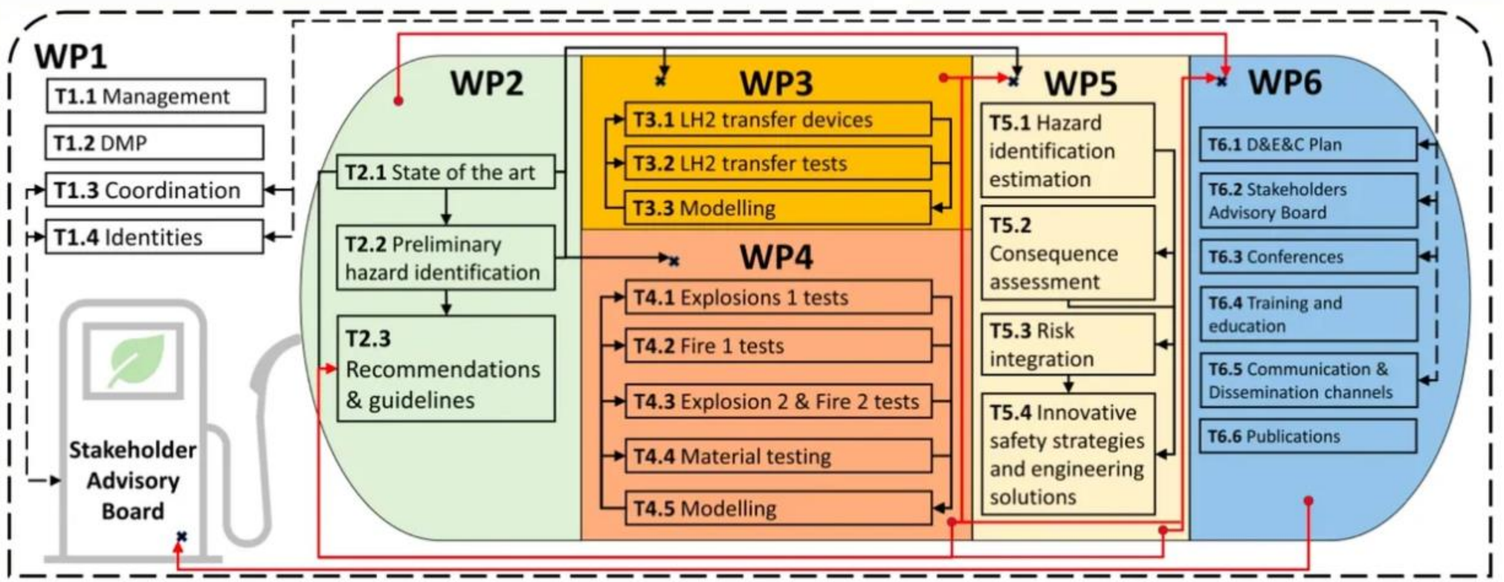
Displayed Text	Description	Line Size	Valve Class
CV1	Nitrogen purge check	3/8"	Check
CV2	Hydrogen purge check	3/8"	Check
CV3	Purge gas check	1/2"	Check
CV4	Vent stack check	4"	Check
MV1	Nitrogen isolator	3/8"	Ball
MV2	Hydrogen isolator	3/8"	Ball
MV3	Purge gas isolator	1/2"	Needle
MV4	Vent stack drain	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 (15 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: P655494_RELEASESYSTEM_V1.0
Job Name/Number: PresLHy, P655494
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: 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

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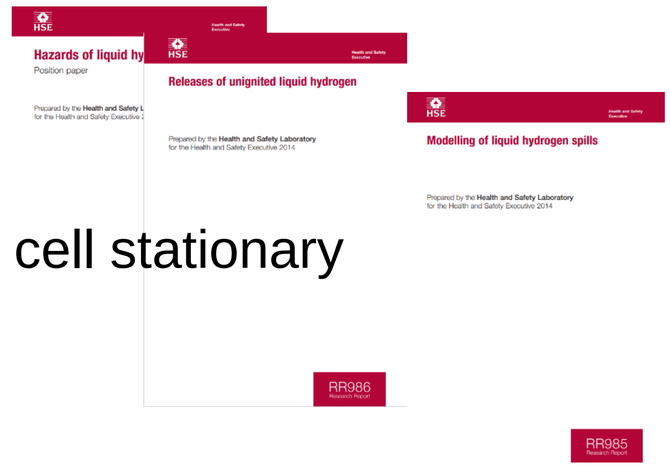
HSE Research Publications

- 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

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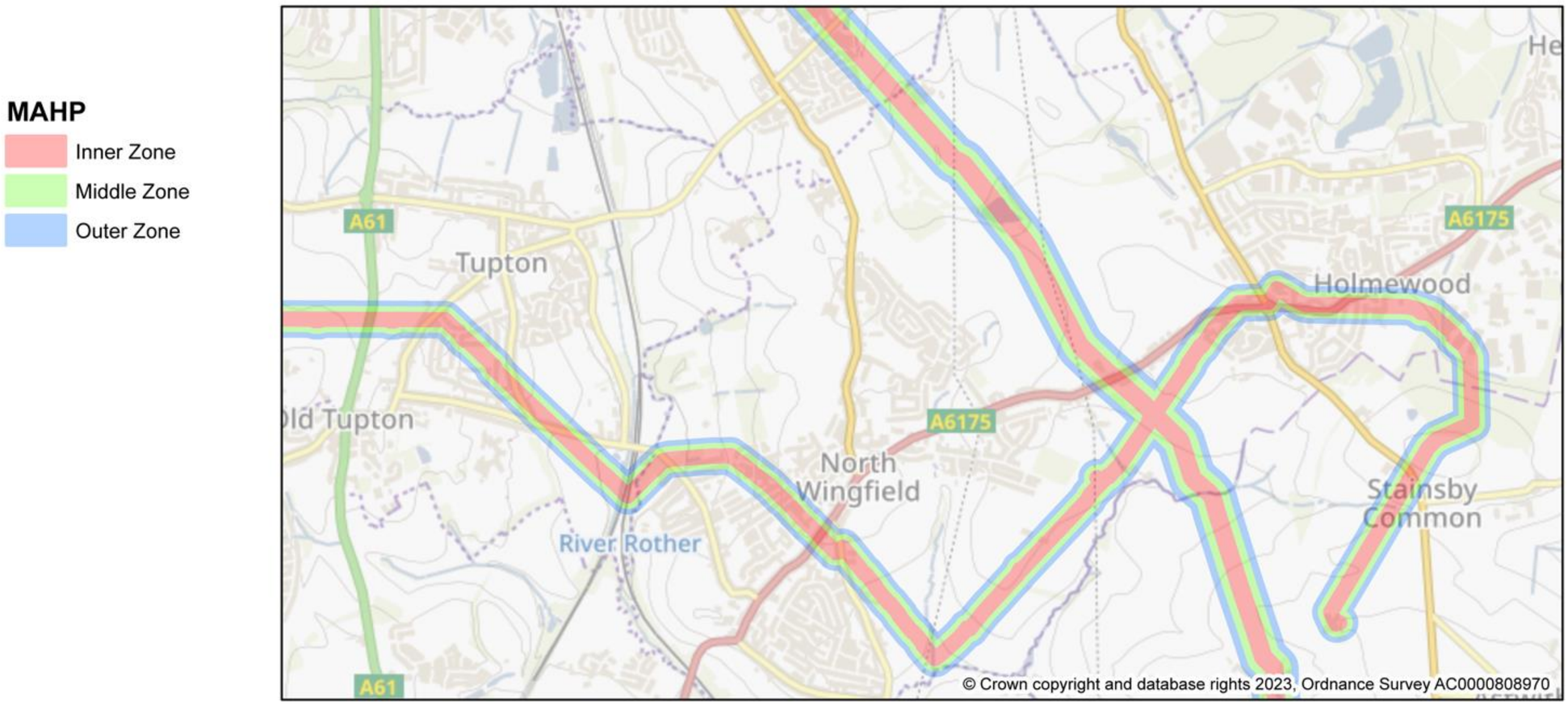
UK Pipeline Regulations and HSE

- Pipelines regulated under the Pipeline Safety Regulations 1996 (PSR)
  - Applies to all pipelines
  - Additional duties for pipelines carrying a dangerous substance as defined in the regs
  - Such pipelines are classified as being Major Accident Hazard (MAH) pipelines
  - For hydrogen, this applies to all pipelines at 7 barg and above
- HSE inspects and regulates MAH pipelines (not involved with routing)
- HSE additionally has a statutory duty to provide land-use planning (LUP) advice around MAH pipelines
  - Uses its own MAH pipeline risk assessment model (MISHAP)
  - Creates three LUP zones around the pipeline for which different advice applies
  - Advice used by local planning authorities when considering developments in the vicinity of the pipeline or to changes to an existing pipeline

LUP zones



Note: The LUP zones are fictitious

MISHAP and hydrogen

- MISHAP considers flammable substances only
  - In theory it applies to hydrogen, BUT …
- Current knowledge gaps
  - Risk of explosion compared to fire risks
  - Ignition probabilities
  - Materials effects on failure rates
- Additional MISHAP issues
  - Suitability of the release rate model
  - Suitability of the fire models
  - Identification of a suitable explosion model, if required

MISHAP and hydrogen

- Project to update MISHAP for hydrogen (and CO_2)
- Likely to require outputs from experiments e.g. from FutureGrid
- But …
- Hydrogen pipelines are already being constructed
- HSE expected to provide the land-use planning advice
- Work on MISHAP not due to be completed for another 2 years
- Solution: Currently deriving an interim position to deal with each pipeline, which will be subject to review once the experimental programme and modelling work is completed.

Thank you

Any questions?

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