

Hydrogen knowledge gaps, research and ongoing work in the UK

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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

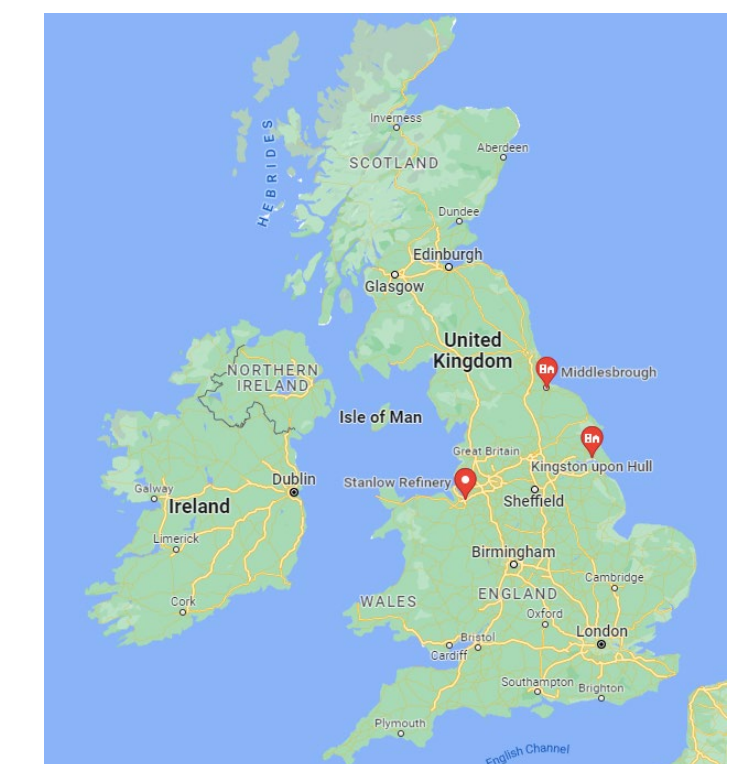
Introduction to HSE

- 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 CO₂ 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
- Other Net Zero ambitions
 - Offshore wind, nuclear, zero-emission vehicles/planes/ships, greener buildings, protecting environment, green finance and innovation



Map data: © 2022 Google

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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 H₂ 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

PROTECTING PEOPLE AND PLACES



FutureGrid
Status Report
April 2023 Issue
Updates as of 27th March 2023

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.

Overall Status Update

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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.

Opportunities

#	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

#	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

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 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.

Project Spend Performance

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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

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.

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 21 st 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 H2 Test Facility)	Feb-23	Completed	
	Rupture Tests (Standalone Test Module)	Jun-23	On Track	
	Pre-Commissioning (Offline H2 Test Facility)	Mar-23	On Track	
	Commissioning (Offline H2 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	
1C QRA & Safety Case	100% Hydrogen Testing	Nov-23	Not Started	→ 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.
	Fatigue Tests (Standalone Test Module)	Nov-23	On Track	
	Procedure Review	Aug-22	Complete	
	Hazardous Area Impact	Apr-23	On Track	
	Quantitative Risk Assessment (QRA)	Nov-23	Not Started	
1D Engagement & Reporting	Overpressure Risk	Jul-23	Not Started	→ 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
	Safety Case Review	Mar-23	On Track	
	Progress Report 2021	Dec-21	Complete	
	Progress Report 2022	Dec-22	Complete	
	Closure Report 2023	Nov-23	Not Started	
	Engagement & Dissemination Events	Nov-23	On Track	

HyDeploy: 20% hydrogen in natural gas

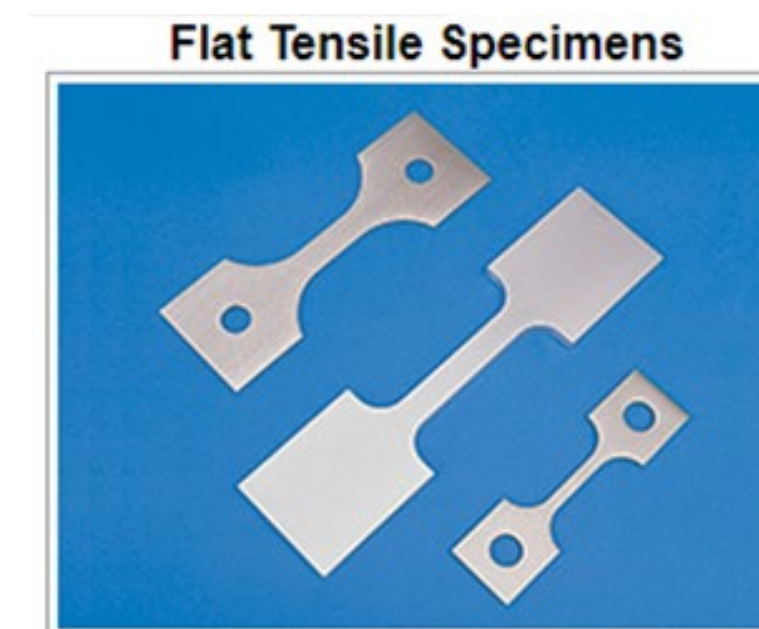
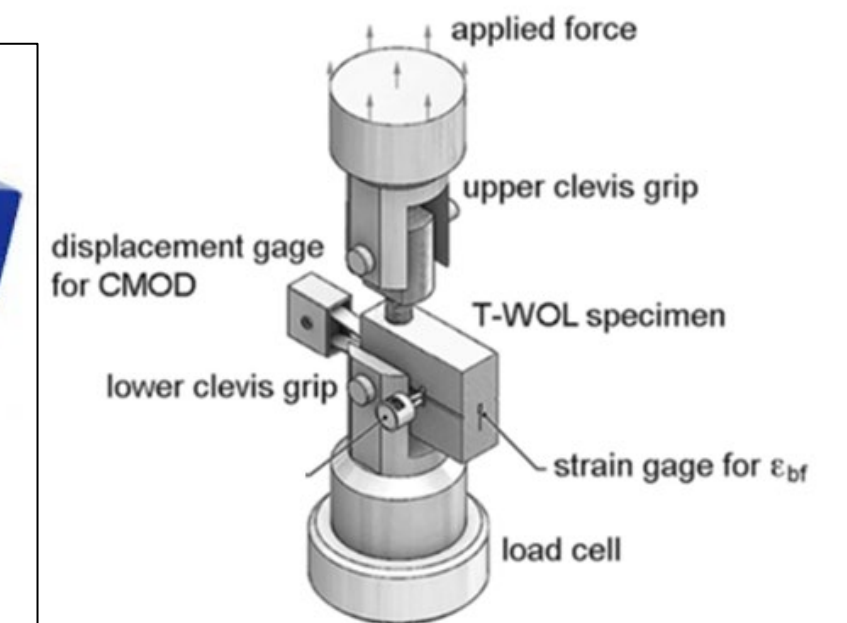
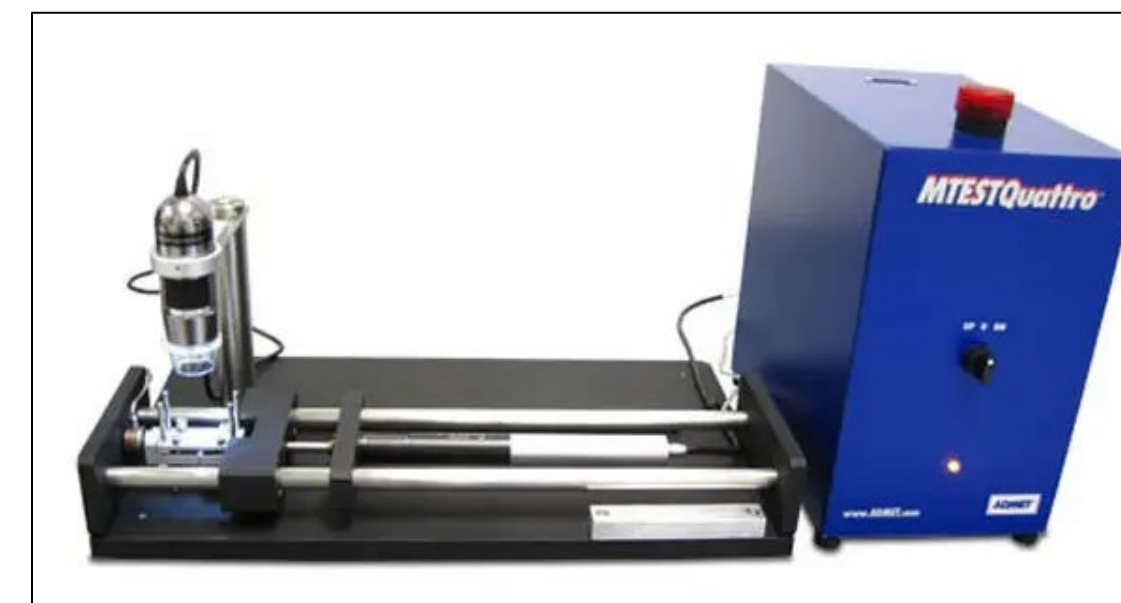
- Numerous safety studies undertaken on:
 - Leakage
 - Indoor accumulation
 - Ignition and consequences (fire and explosion)
 - Control and updated gas network procedures (e.g., pipeline purging)
 - Building proximity distances to pipelines
 - Hazardous area classification
 - Material compatibility (work 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



<https://hydeploy.co.uk/>

HSE hydrogen materials testing facility

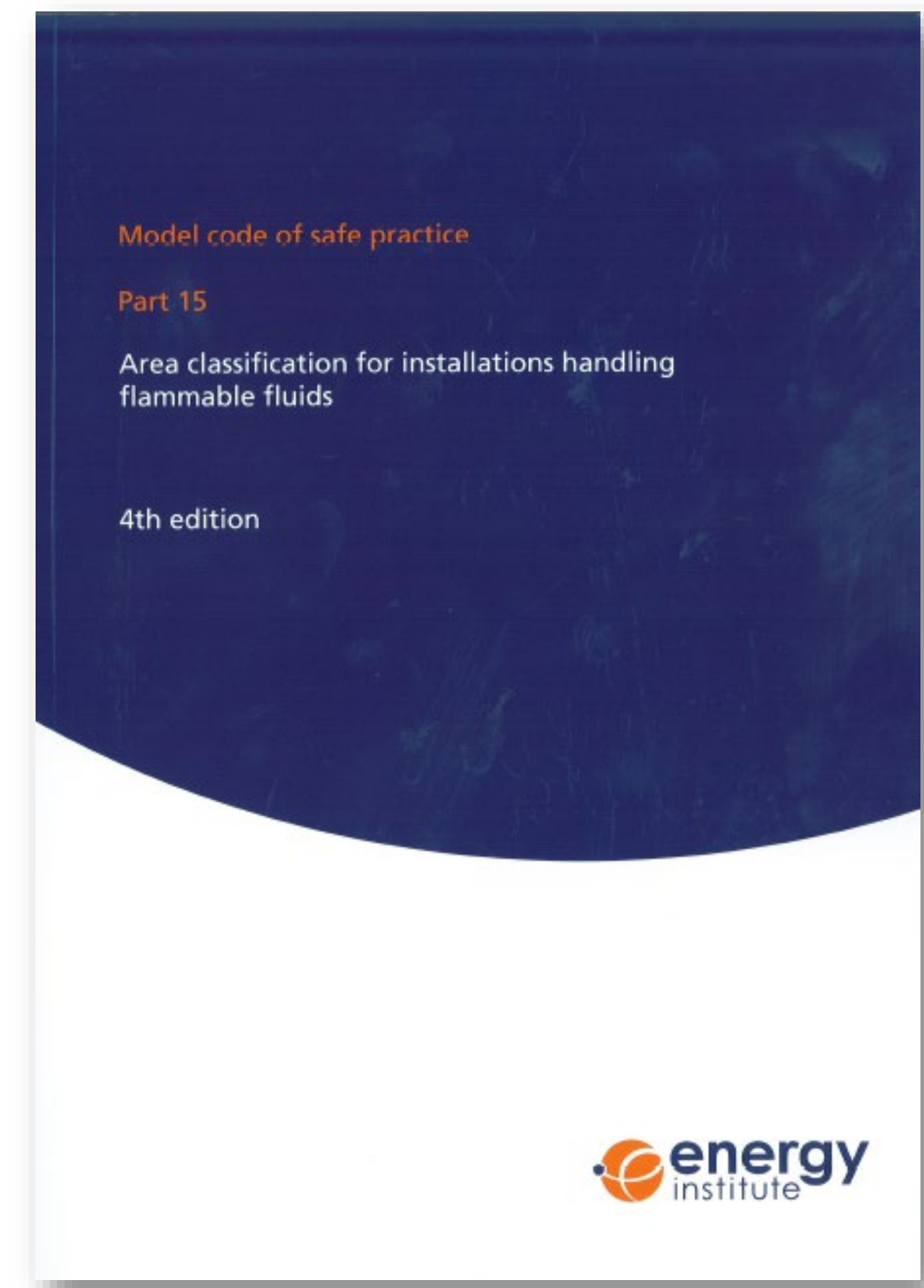
- HSE is investing in a new hydrogen materials testing facility at its Science and Research Centre in Buxton
- Aim to conduct long-term exposure tests of materials in gaseous hydrogen up to 8 bar
- Testing methods:
 - In-situ micro tensile testing
 - Ex-situ tensile testing
 - Ex-situ impact testing
- 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.



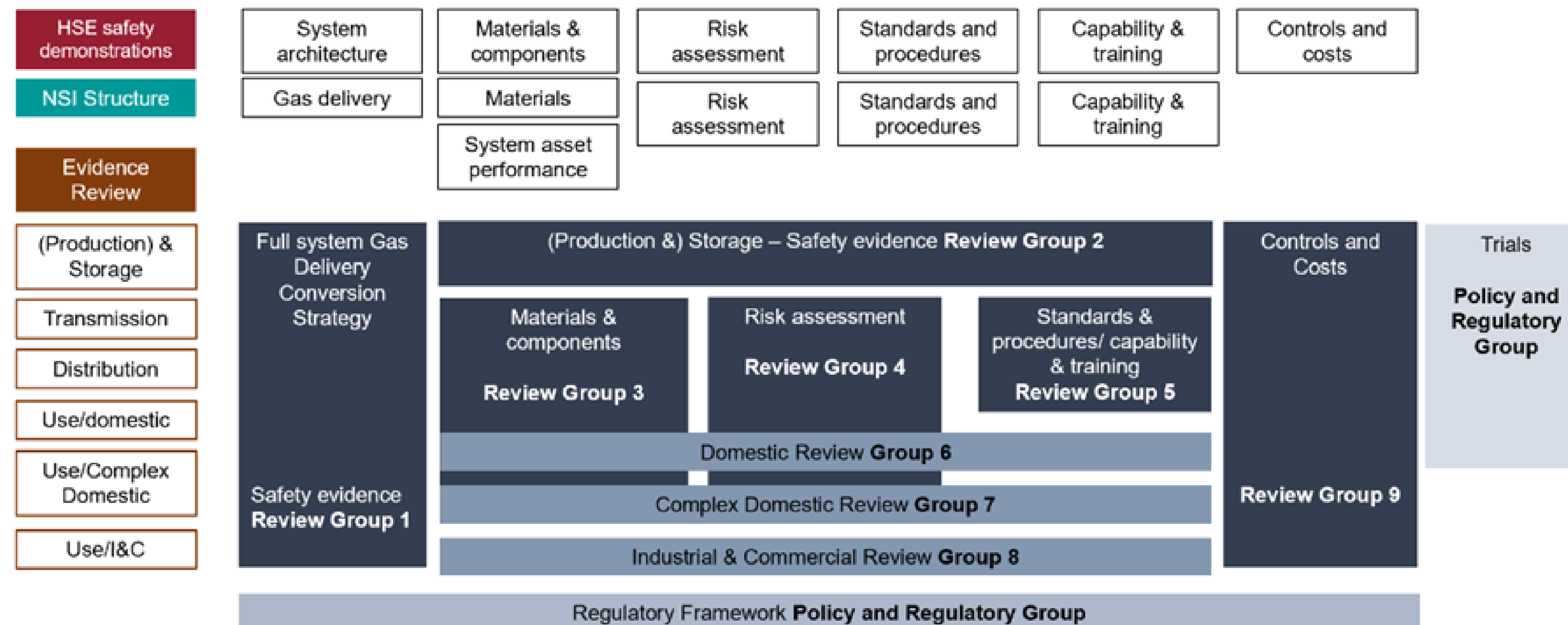
This Supplement to IGEM/SR/25 provides a procedure for hazardous area classification around installations handling hydrogen, including a 20% NG/H blend providing a basis for the correct selection and location of fixed electrical equipment in those areas. In addition, the recommended zoning restrictions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

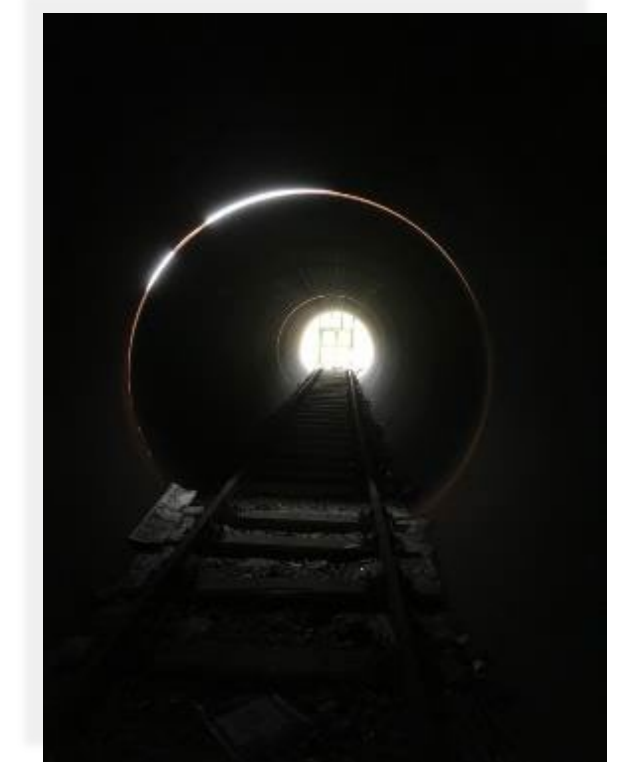


Over 100 reports and only part-way through review process

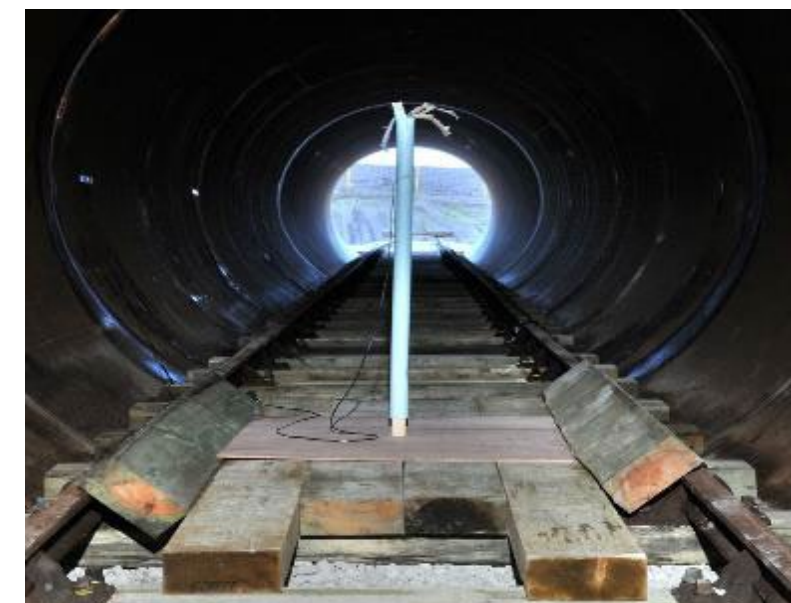
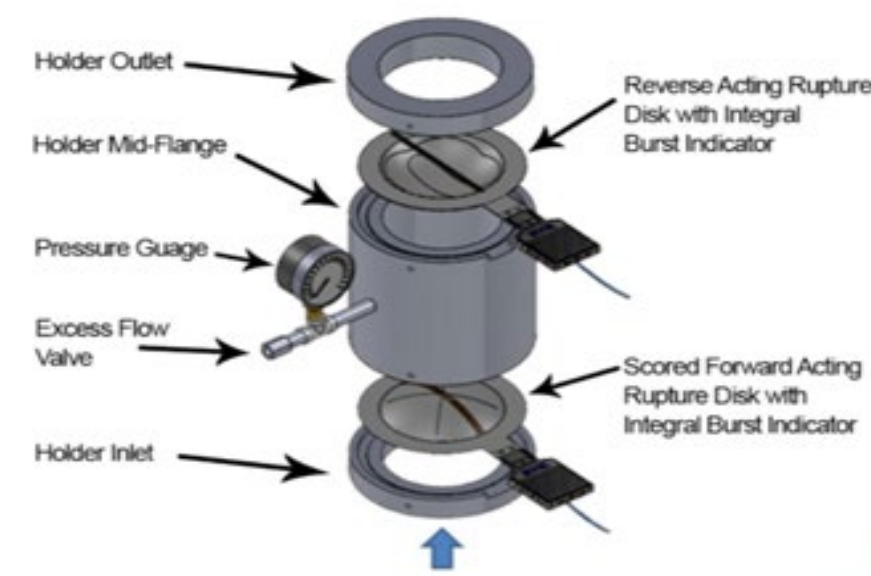
Gaseous Hydrogen: HyTunnel



- 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/>



TPRD = Temperature/Pressure Relief Device

Gaseous Hydrogen: MultiHyFuel



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- 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/>

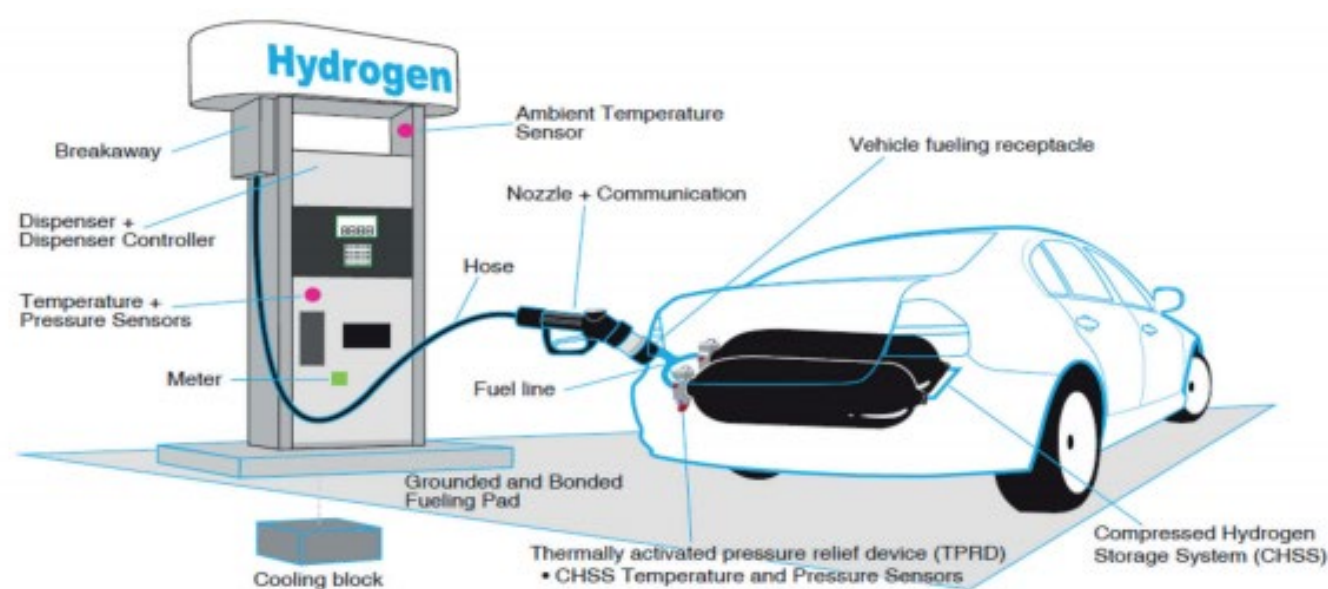
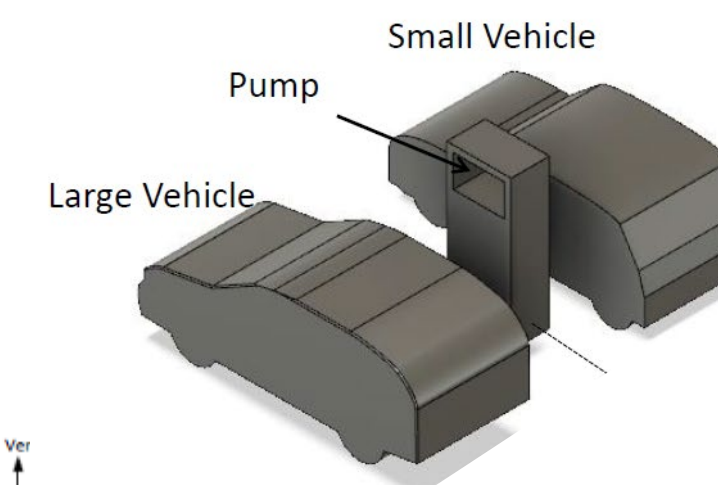
- Assess critical hazards posed by 700 bar HRS dispensers to the public, equipment and other dispensers through full scale experiments

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

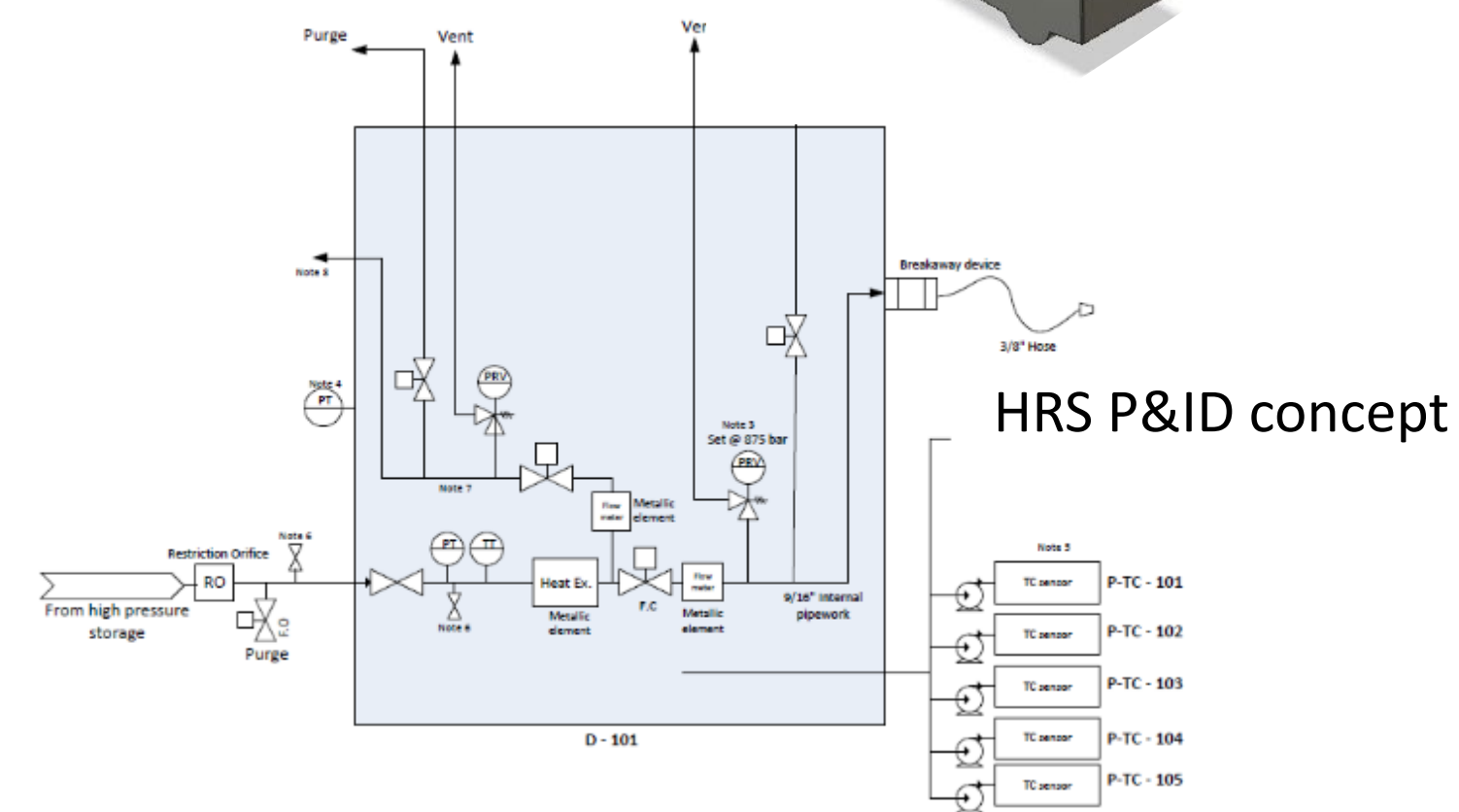
- Assess critical hazards posed by conventional fuels and vehicles to HRS dispensers

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



Liquid Hydrogen: PresLHy



- 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				Valve List			
Displayed Text	Description	Service	Model	Displayed Text	Description	Line Size	Valve Class
GS1	10 barg gauge	Gas	Dial	CV1	Nitrogen purge check	3/8"	Check
GS2	10 barg gauge	Gas	Dial	CV2	Hydrogen purge check	3/8"	Check
GS3	25 barg gauge	Gas	Dial	CV3	Purge gas check	1/2"	Check
MFM	Mass flow meter	Liquid	Coriolis	CV4	Vent stack check	1"	Check
PT1	PT	Liquid	PT	MC1	Nitrogen isolator	3/8"	Ball
PT2	PT	Liquid	PT	MC2	Hydrogen isolator	3/8"	Ball
TC1	TC	In Row	Type F	MC3	Purge gas isolator	1/2"	Needle
TC2	TC	In Row	Type F	MC4	Vent stack drain	1"	Gate
TC3	TC	In Row	Type F	MC5	Purge gas bleed	3/8"	Needle
TC4	TC	Outer well	Type F	MR6	Nitrogen regulator (7 barg)	3/8"	Regulator
TC5	TC	In Row	Type F	MR7	Hydrogen regulator (7 barg)	3/8"	Regulator
				RV1	Liquid line vapour bleed	1/2"	Needle
				RV2	Gas relief (10 barg)	3/8"	PRV
				RV3	Gas relief (10 barg)	3/8"	PRV
				RV4	Vapour relief (12 barg)	1/2"	PRV
				RV5	Liquid release	1"	Ball
				RV6	Liquid vent	1"	Ball
				W1	Tanker outlet isolator	1"	Ball
				W11	Tanker liquid outlet	1"	Ball
				W12	Tanker vapour vent	1"	Needle

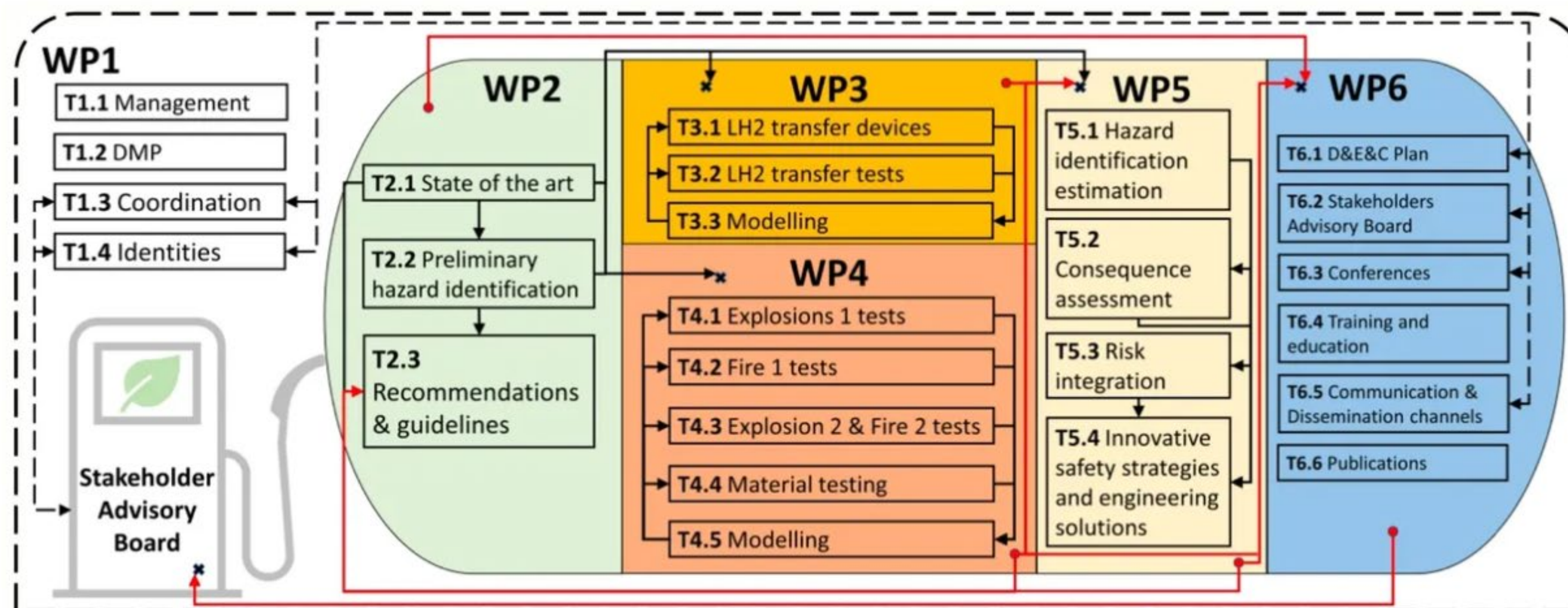
Gaseous H2 pipework
 1" dia. liquid H2 line
 1" dia. 20 m vacuum insulated hose
 1" dia. 20 m flexible hose
 3/4" dia. 20 m flexible hose

Title: PresLHy Release System
 Drawing Number: PE0494_RELEASESYSTEM_V1.0
 Job Name/Number: PresLHy, PE0494
 Version: 1.0
 Date created: 19/08/2019
 Author/Phone Number: Jonathan Hill, 0209 028 2038
 Scale: Not to scale
 Issue Date: 19/08/2019
 Technical Review/Date: 20/08/2019

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/>

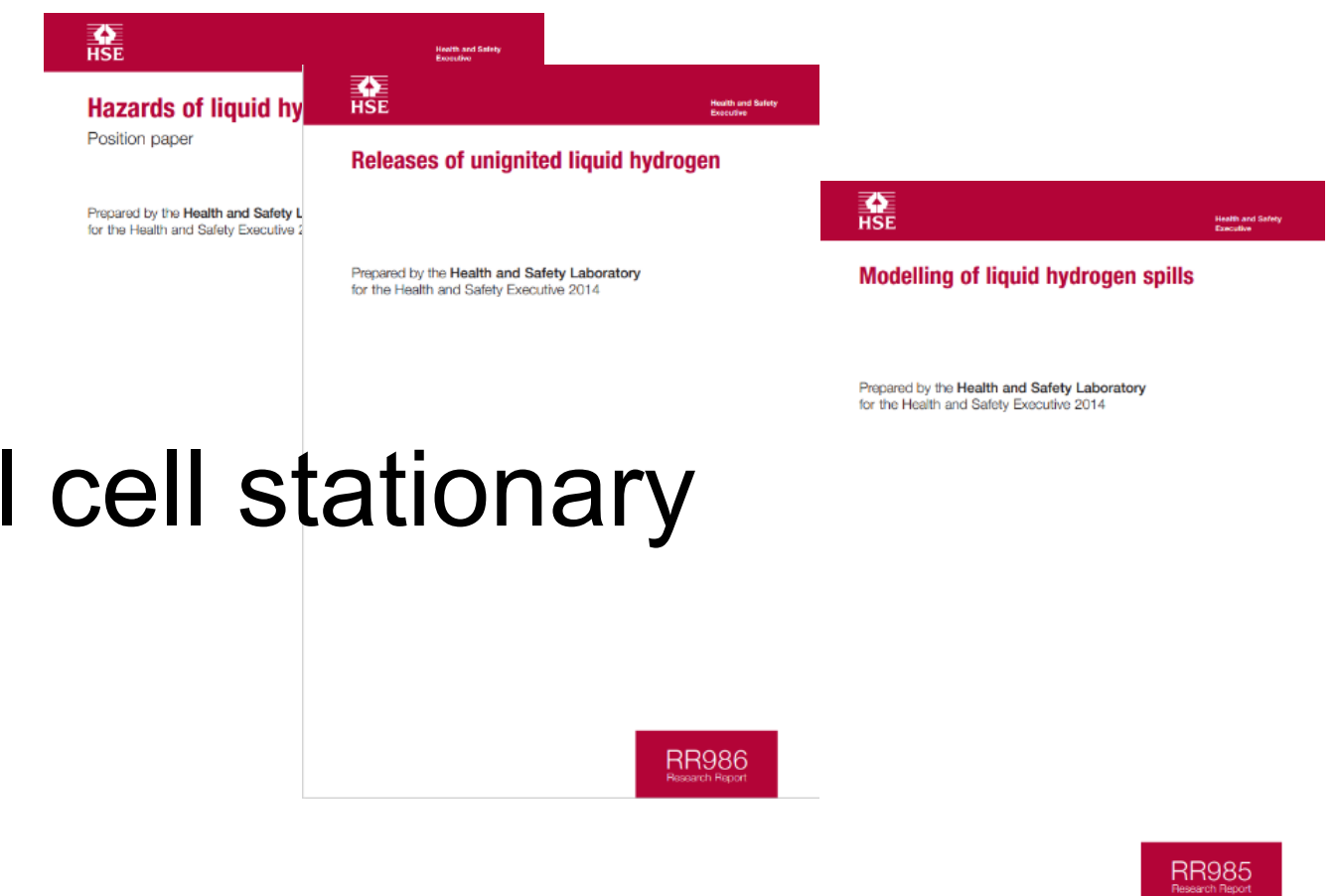


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HSE Research Publications

- 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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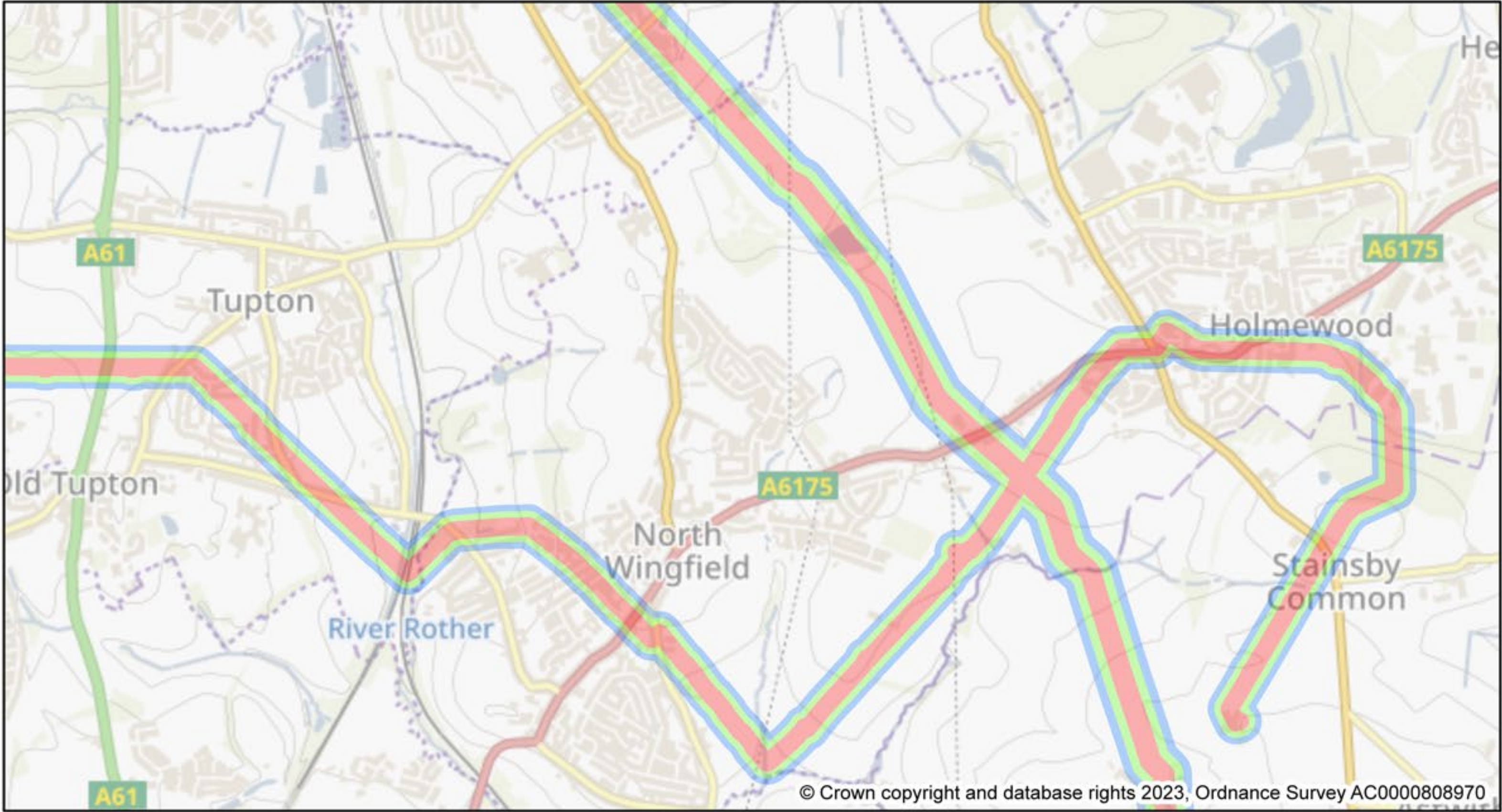
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- **Hydrogen pipelines and the role of HSE**

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

- MAHP**
- Inner Zone
 - Middle Zone
 - Outer Zone



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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 CO₂)
- 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?

- Contact: zoe.chaplin@hse.gov.uk, simon.gant@hse.gov.uk
- The contents of this presentation, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy