RESEARCH AND GUIDANCE FROM HSE

Hydrogen research initiatives, challenges, and opportunities

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PHMSA Public Meeting, Houston, Texas, 14 December 2022

Research - HSE funded to provide evidence which underpins its policy and regulatory activities
Guidance - freely available to help people comply with health and safety law

Outline

- Introduction to HSE
- UK Net Zero strategy
  - Hydrogen and CCUS industrial clusters
  - Hydrogen heating programme
- HSE ongoing activities
- Other recent UK hydrogen pipeline research publications
- Knowledge gaps

Introduction to HSE

- HSE is the UK regulator for health and safety
  - Includes onshore/offshore pipelines, chemical/oil/gas infrastructure, offshore platforms etc.
  - Activities: evidence gathering, policy development, consultation, regulation, incident investigation, enforcement
  - UK operates a risk based, goal setting regulatory regime
  - HSE acts as an enabling regulator, supporting the introduction of new technologies
  - 2,400 total staff
  - £230M ($310M) 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

- Net Zero 2050
  - UK Government announced Ten Point plan[1] in November 2020
- Growth of low-carbon hydrogen and CCUS based around
  1. Regional hydrogen and CCUS industrial clusters (next slide…)
  2. Hydrogen for heating:
     - Working towards cross-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

[1] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

Industrial hydrogen and CCUS clusters

- Track 1 (Phase 1) funding awarded 1 Nov 2021 to:
  1. **HyNet** https://hynet.co.uk new and repurposed hydrogen and CO_2 pipelines
  2. **East Coast Cluster** https://eastcoastcluster.co.uk two new offshore 100+ km CO_2 pipelines
  - Eligible to apply for £1bn CCS Infrastructure Fund (CIF) and £240M Net Zero Hydrogen Fund
  - Aim: two clusters operational by mid-2020s and four clusters by 2040
  - Store 20-30 $MtCO_2$ per year by 2030 = 8-12 million cars worth of emissions

Map data: © 2022 Google

- Track 1 (Phase 2) funding:
  - Proposal submission deadline Jan 2022, decision in Q2 2023
  - 20 projects associated with HyNet and ECC shortlisted[1], including:
    - 3 power stations with CCS
    - 4 hydrogen production plants
    - 13 industrial installations with CCS (e.g., refineries, cement)

1. https://www.gov.uk/government/publications/cluster-sequencing-phase-2-eligible-projects-power-ccus-hydrogen-and-icc/cluster-sequencing-phase-2-shortlisted-projects-power-ccus-hydrogen-and-icc-august-2022

Hydrogen Heating Programme

- Department for Business, Energy and Industrial Strategy (BEIS) is funding industry and regulators to deliver a range of research, development and testing projects to assess the feasibility, safety, costs and benefits of using 100% hydrogen for domestic, commercial and industrial heating, to support a policy decision in the mid-2020s

- HSE has convened 11 Evidence Review Groups to review safety evidence submitted by industry, each comprising roughly a dozen scientists, regulatory and policy specialists, covering:

1. Full system gas delivery and conversion strategy
2. Production and storage, network safety and storage
3. Materials and components
4. Risk assessment
5. Standards and procedures/capability and training
6. Domestic review (including public behaviours)
7. Complex domestic review
8. Industrial and commercial
9. Controls and costs
10. Trials (policy and regulatory group)
11. Regulatory framework group

(There is overlap between members of different ERGs)

- Desk-based safety review of evidence with Q&A logs

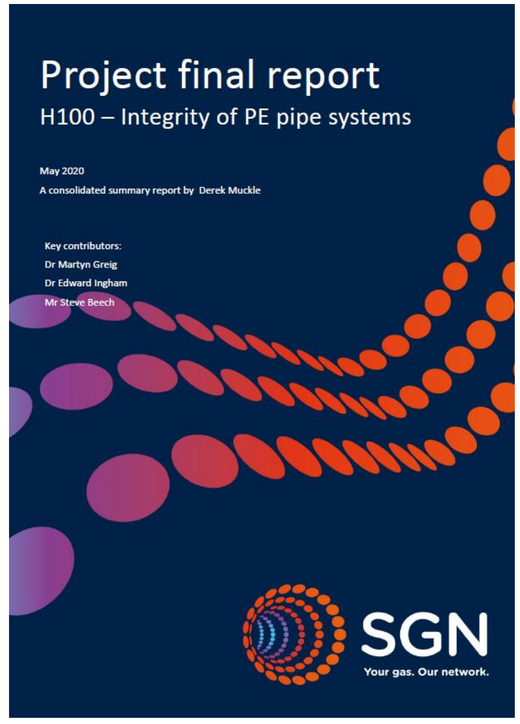
Technical topics covered in HSE's review of evidence

- **Materials performance**
  - Effect of hydrogen embrittlement and fatigue on design, construction, operation and maintenance
- **Risk assessment**
  - Change in failure frequencies, leakage, gas migration, dispersion, accumulation, ignition potential, fire and explosion effects, hazardous area classification
- **Operational procedures**
  - Pipeline purging, venting, inspection, maintenance, leak detection, repair
- **Equipment**
  - Gas detectors, regulators, heat exchangers, meters, kiosks, PPE, software
- **Training and Regulation**

Examples of Evidence Reviews Undertaken in 2022

1. Use of polyethylene distribution pipe systems for 100% hydrogen

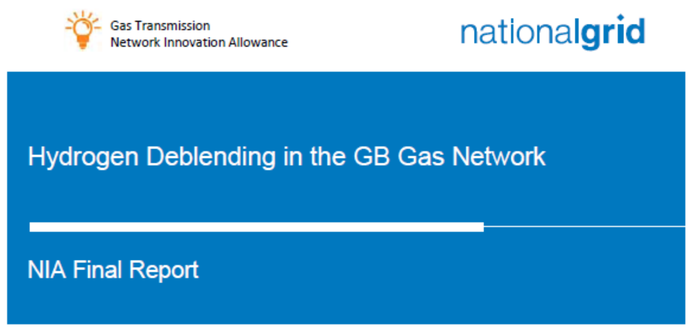
- Aim: to provide evidence to support the use of PE pipes, and data for use in QRA
- Scope:
  - Standards
  - Time-dependent failure modes
  - Fracture toughness
  - Rapid crack propagation
  - Leak tightness of elastomeric seals
  - Squeeze-off, saddle and socket fusion welding, repairs
- Included experiments: accelerated lifetime testing at elevated temperatures
- Work led by the UK gas distribution network company SGN
- 185-page report

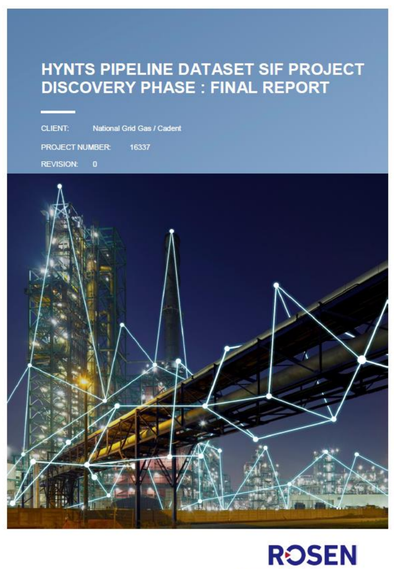


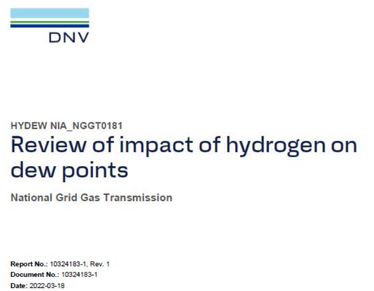
Examples of Evidence Reviews Undertaken in 2022

2. Hydrogen in Great Britain's national gas transmission system

- Review of potential impacts on materials (240-page report)
- Review of hydrogen impacts on dew points (32-page report)
- Hydrogen barrier coatings for gas network assets (17-page report)
- Feasibility study for hydrogen deblending in the Great Britain network (206-page report)
- Data requirements for hydrogen repurposing, in-line inspection technologies, pipeline repurposing feasibility ranking methodology (166-page report)
- Projects coordinated by National Grid







https://www.nationalgrid.com/FutureGrid

Examples of Evidence Reviews Undertaken in 2022

3. Industrial site surveys

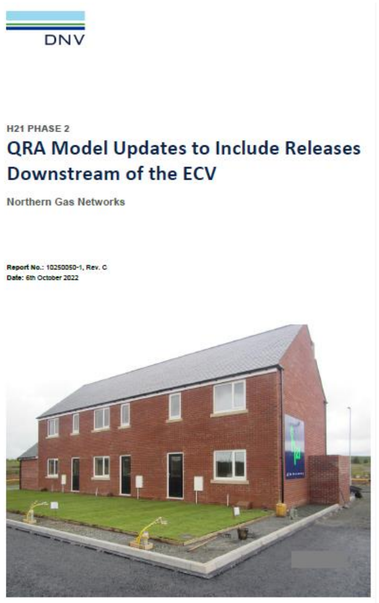
- Aim: to assess impact to industrial users of switching from natural gas to 100% hydrogen
- Includes site-specific technical, safety, environmental and implementation issues
- Survey and analysis work undertaken by the consultancy AECOM

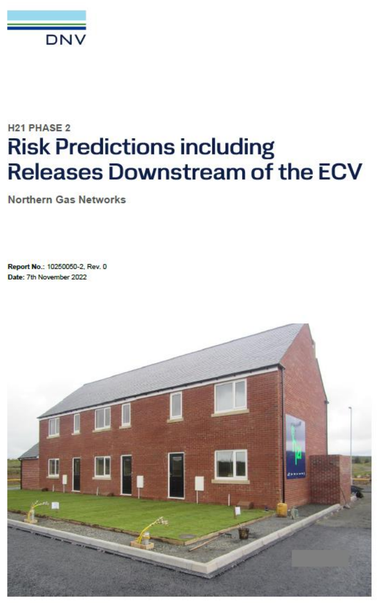
Industry	Facilities	Annual Gas Use
Petrochemicals	Industrial steam boilers, ovens, water heaters, space heaters, flare pilot & ignition packages	83 GWh
Food and drink	Industrial ovens, fryers, air handling units, water heaters	18 GWh
	Germination kilning vessels, roasters, grain dryers, thermal fluid heaters, water heaters, space heaters	42 GWh
Metals	Furnaces, gas torches, burners, water heaters and space heaters	28 GWh
	Industrial ovens, recuperative thermal oxidisers, water heaters and space heaters	6 GWh
Minerals	Aggregate dryer	35 GWh
Vehicles	Industrial ovens, air handling units, recuperative thermal oxidisers, water heaters and space heaters	29 GWh

Examples of Evidence Reviews Undertaken in 2022

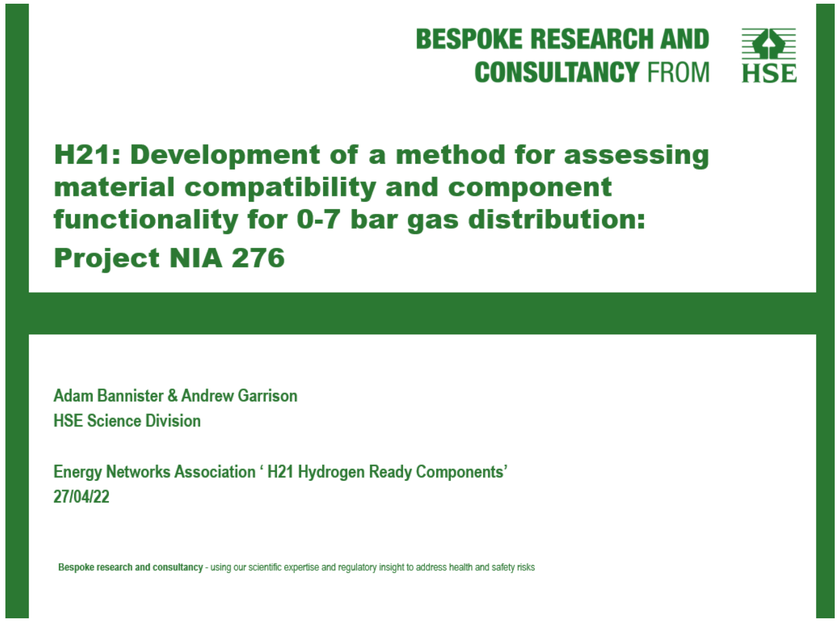
4. Quantified Risk Assessment (QRA) for hydrogen distribution and use

- Aim: to compare risks from hydrogen to natural gas and assess mitigation measures
- Includes consideration of: pipeline release frequencies, hole sizes, tracking through ground, gas ingress into buildings, gas releases in buildings, gas accumulation, explosion, fire, vulnerability
- Mitigation options included in the analysis: excess flow valves, gas detection, increased ventilation, replacement of metallic mains and services with PE, relocation of gas meters
- Analysis of existing data plus new experiments
- Work carried out for www.h21.green by DNV
- Phase 2 reports:
  - Methodology (245 pages)
  - Results (121 pages)





Example of HSE Science and Research Centre Work



Presented by Adam Bannister (HSE) to Energy Networks Association in April 2022

Aims

- Develop a methodology for assessing materials and component suitability (gas facing) for hydrogen service at 100% hydrogen at up to 7 bar
  - Applicable to fixed gas-facing assets
  - Excludes temporary assets
- Demonstration of the methodology through a series of case studies
- Allow individual manufacturers currently unfamiliar with hydrogen to make their own assessments and to understand the role of materials

Concept of HSE risk ranking method

- Utilise existing network information (assets, materials, standards)
- Overall net risk level concept: Existing risk (NG) + New risk (Hydrogen)
  - Existing risk evaluated at ‘asset assembly’ level
  - New risk evaluated at ‘component’ level
  - Definition of a threshold
- Quantitative method based on combination of:
  - Sensitivity of a material to hydrogen degradation
  - How it is loaded
  - Potential consequences of failure
- Mitigation options for cases not achieving ‘pass’ on first assessment
  - 1: Improve data quality on material, operation or loading
  - 2: Testing of material or additional analyses
  - 3: Asset protection, monitoring or secondary controls
- Provide a spreadsheet tool for carrying out the assessments in a consistent manner

Example Output No. 1: Single band repair clamp

Natural Gas Asset Assessment			Score	Comments
Age and model number and relevant GIS year	A	Not known, generic, or multiple locations/ages exist	5	
Operating Pressure Tier	P	Medium Pressure (75mbar-2 bar)	3	
Function (Consequence of loss of)	F	Gas transport	0	
Location	L	R, S and T locations and less than 30m from property but external to it (use for worst-case location for external assets)	11	
Failure History	FH	Known to be not susceptible to failures and failures are rare: Supporting data available or absence of data as rate too low to record	0	
Inspection and Maintenance	IM	Usually fit-and-forget with no inspection required due to asset reliability	0	
Sum of individual score ratings in NG		Low	19	

Hydrogen Component Assessment

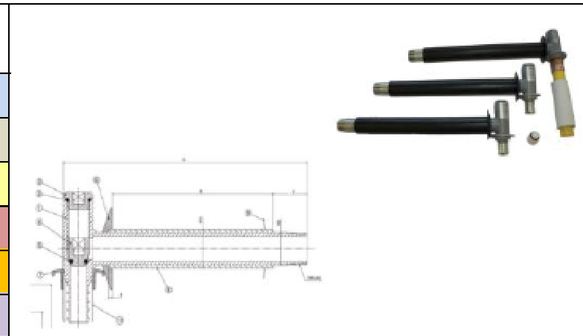
	Component No.	1y Gas facing Y/N	Material	DL score	CL: consequence level	CL score	LL score	Total H2 score	Pass/ Fail in H2 (1y)	2y gas facing Y/N (If Y, complete DL & CL)	Red list material and High CL score Y/N (If Y, complete LL Score)	Pass/ Fail in H2 (2y)
1	Body	N	Stainless steels, Austenitic SS, Gr 304 (1.4301, X5CrNi18-10)	8.3			0	8	-	N	-	Pass
2	Lugs	N	Cast irons, SG (ductile) iron, EN-GJS-350-22-LT; EN-GJS-400-18-LT	14.6			0	15	-	N	-	Pass
3	Gasket Mat	Y	Rubbers/ Elastomers, Nitrile (NBR) rubber (or N Buna),	2.8	Loss of asset integrity only	6	4	13	Pass	-	-	-
4	Bolts	N					0	0	-	N	-	Pass
5	Nuts and washers	N	Carbon steels, Flange nuts, Nuts: 2H (Q&T); Grades 5, 6, 8, 9, 10, 12	18.8			0	19	-	N	-	Pass

Overall rating of asset assembly for service in hydrogen	Pass

Example Output No.2: Building entry tee

Version: 4.0

Natural Gas Asset Assessment			Score	Comments
Age and model number and relevant GIS year	A	Known or assumed for a family of locations	3	
Operating Pressure Tier	P	Low Pressure (19-75 mbar)	0	
Function (Consequence of loss of)	F	Emergency isolation	10	
Location	L	R, S and T locations and within property (use for all internal assets)	15	
Failure History	FH	Failures known to occur and/or occur at a frequency high enough to be recorded	5	
Inspection and Maintenance	IM	Usually fit-and-forget with no inspection required due to asset reliability	0	
Sum of individual score ratings in NG		High	33	



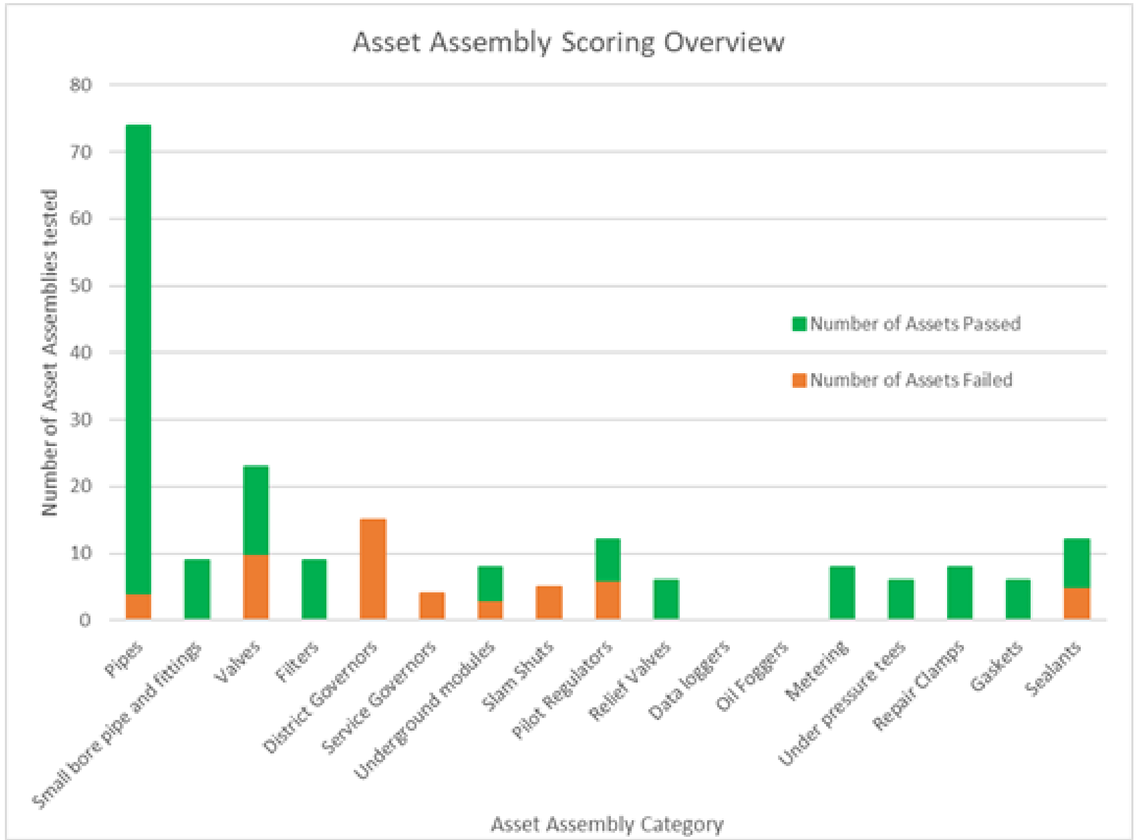
Hydrogen Component Assessment

	Component No.	1y Gas facing Y/N	Material	DL score	CL: consequence level	CL score	LL score	Total H2 score	Pass/ Fail in H2 (1y)	2y gas facing Y/N (If Y, complete DL & CL)	Red list material and High CL score Y/N (If Y, complete LL Score)	Pass/ Fail in H2 (2y)
1	Body	Y	Carbon steels, Pipeline and generic steel, A106 B and generic low strength	10.4	Loss of asset integrity and control function	10	8	28	Fail		-	-
2	Anti Tamper Top Cap	Y	Carbon steels, Pipeline and generic steel, A106 B and generic low strength	10.4	Loss of asset integrity and control function	10	0	20	Pass		-	-
3	O-ring	Y	Rubbers/ Elastomers, Nitrile (NBR) rubber (or N Buna),	2.8	Loss of asset integrity only	6	4	13	Pass		-	-
4	Internal Plug	Y	Nylons, Glass-filled nylon,	5.6	Loss of control function only	4	0	10	Pass		-	-
5	O-ring	Y	Rubbers/ Elastomers, Nitrile (NBR) rubber (or N Buna),	2.8	Loss of asset integrity only	6	4	13	Pass		-	-
6	Wall Plate	N	Rubbers/ Elastomers, Viton Fluorocarbon rubber,	13.9			0	14	-	N	-	Pass
7	GRP Retention Washer	N	Miscell. Polymers, Polycarbonate,	18.1			0	18	-	N	-	Pass
8	Through Wall Sleeve	N	Polyethylene, PE80, PE80	6.0			0	6	-	Y	N	Pass
9	Spring Washer	N	Carbon steels, Spring steels, SL, SM, SH, DM, DH	20.1			4	24	-	N	-	Pass
10	Crimp Sleeve < 63mm	N	Copper, Castings, Grade CR004, 99.90 % pure Cu	9.7			0	10	-	N	-	Pass
11	PE Pipe	Y	Polyethylene, PE80, PE80	6.0	Loss of asset integrity only	6	4	16	Pass		-	-
12	Sleeve	N	Carbon steels, Threaded pipe fittings, BS EN 10241 ; BS 3799	13.6			0	14	-	N	-	Pass
13	GRP Pipe	N					0	0	-	N	-	Pass
14							0	0	-		-	-

Overall rating of asset assembly for service in hydrogen	Fail

Output from Gas Distribution Network Operator

Asset assembly scoring overview



Based on evaluation of 214 gas network assets

Cast Iron Gas Network Assets

- HSE will review any evidence submitted by networks on the suitability of cast iron components
- HSE consider that this safety demonstration requires the quality and breadth of evidence, and the wider industry and technical community consultation, which is currently required to establish a standard
- UK gas networks likely to fund further materials testing on cast iron
- HSE is interested to learn about any work ongoing in the USA (or elsewhere) on suitability of cast iron for hydrogen service
- Background info on iron mains replacement programme:
- – https://www.hse.gov.uk/gas/supply/mainsreplacement/index.htm
- Aim: to replace all iron mains (≤ 8” diameter) within 30 m of buildings by 2032

Hydrogen Committee

- **Recently published reports**
  - Literature review of asset integrity in repurposing existing natural gas infrastructure for hydrogen
  - Application of life cycle assessment methodology to the understanding of the energy balance and efficiency of hydrogen value chain building blocks

- **Ongoing Projects**
  - **Hy2003** Environmental impacts of the large-scale deployment of hydrogen
  - **Hy2001** Development of competence, skills and training for the transition to hydrogen
  - **Hy2004** Guidance on the development of a safety case for hydrogen across the value-chain
  - **Hy2005** Infrastructure integration for existing natural gas infrastructure
  - **Hy2201** Export/import of hydrogen and liquid ferivatives (LH2, NH3, LOHC, MCH)
  - **Hy2202** Large Scale Storage of Hydrogen (and its derivatives)
  - **Hy2203** Incident data management for QRAs and HAZOPs in the context of hydrogen safety cases

Recent UK hydrogen emissions-related publications

Atmospheric implications of increased Hydrogen use

Nicola Warwick, Paul Griffiths, James Keeble, Alexander Archibald, John Pyle, University of Cambridge and NCAS
and Keith Shine, University of Reading

April 2022

"*Our estimate of the hydrogen Global Warming Potential for a 100 year time horizon is 11 ± 5, which is more than 100% larger than previously published calculations*"

https://www.gov.uk/government/publications/atmospheric-implications-of-increased-hydrogen-use

Fugitive Hydrogen Emissions in a Future Hydrogen Economy

Frazer-Nash Consultancy

https://www.gov.uk/government/publications/fugitive-hydrogen-emissions-in-a-future-hydrogen-economy

March 2022

Emissions from Individual Elements

The hydrogen emissions from the individual elements are summarised as follows. These are given as a percentage of the hydrogen produced, transported or used within that element.

Sector	Specific Area		Predicted Emission Confidence level	
			50 %	99 %
Production	Electrolytic	With venting and purging	3.32 %	9.20 %
		With full recombination of hydrogen from purging and crossover venting	0.24 %	0.52 %
	CCUS-enabled		0.25 %	0.50 %
Transport and Storage	National Transmission System		0.04 %	0.48 %
	Distribution Network		0.26 %	0.53 %
	Underground Storage		0.02 %	0.06 %
	Above Ground Storage (gas)		2.77 %	6.52 %
	Road Trailering (gas)		0.30 %	0.66 %
	Road Trailering (liquid)		3.76 %	13.20 %
End-uses	Residential		0.30 %	0.69 %
	Gas Turbines		0.01 %	0.01 %
	Refuelling Stations		0.25 %	0.89 %
	Fuel Cells	With venting and purging	1.36 %	2.64 %
		With full recombination of hydrogen from purging and crossover venting	0.56 %	1.02 %
	Combustion Engines		0.30 %	0.66 %
	Process Industry		0.25 %	0.50 %

Knowledge Gaps and Technological Innovation Needs

- Development of procedures and remote repair technologies for dealing with low pressure hydrogen gas escapes on large-diameter hydrogen pipelines
- Hydrogen specific flow stopping equipment for distribution pipelines (75 mbar – 7 bar)
- For hydrogen pipeline purging:
  - Development of optimum methods and equipment for indirect purging
  - Analysis of the effect of hydrogen's high diffusivity on flow stratification during pipeline purging
- Hydrogen gas detection for homes, including networked options and auto shut-off
- Smart excess flow valves for homes, designed to operate at the flows around the end-user requirements rather than at a set limit (also self-testing devices for pipework leaks)
- Experiments on ignition of hydrogen pipeline releases (immediate/delayed, consequences)
- Experiments on response of buildings to internal hydrogen explosions
- Development of explosion relief systems for enclosures with hydrogen blends and 100% hydrogen (e.g., governor kiosks, compressor buildings)

Knowledge Gaps and Technological Innovation Needs

- Further analysis of:
  - Compatibility of gas network assets for hydrogen service (lifetime testing)
  - Hydrogen gas network asset performance (e.g., regulators)
- Analysis of erosion in pipeline systems for blends and 100% hydrogen

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