RESEARCH AND GUIDANCE FROM HSE

UK perspectives on hydrogen and CO_2 pipelines

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Pipeline Transportation and Emerging Fuels Research and Development (R&D) Public Meeting and Forum, 30 November 2021

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
- Net Zero 2050 targets
- Research challenges
- Recent and ongoing UK research projects
- Remaining 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: research, 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 (Science Division: 400 staff and 550 acre test site)
  - £230M ($310M) budget: 60% from Government, 40% from external income

- Research and development
  - In-house R&D to support HSE policy, regulation etc.
  - Support to other Government departments
  - “Shared research” or joint-industry projects co-funded by HSE
  - Bespoke consultancy on a commercial basis

Net Zero 2050 targets

- Net Zero 2050
  - UK Government announced Ten Point plan[1] in November 2020
- Growth of low-carbon hydrogen and CCUS
  - Regional hydrogen and CCUS clusters
  - Hydrogen for heating: scaling up from neighbourhood trials to a potential hydrogen town by 2030
  - 5 GW of low carbon hydrogen production capacity by 2030
  - Capture 10 Mt of carbon dioxide a year by 2030
  - Working towards cross-government policy decision on hydrogen heating in 2025
- 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

Research Challenges: Hydrogen Properties

Property	Methane, CH_4	Hydrogen, H_2
Density (kg/m^3)	0.68	0.08
Dynamic viscosity (mPa.s)	11	8.7
Specific heat capacity at constant pressure (kJ/kg.K)	2.2	14
Ratio of specific heat capacities	1.31	1.41
Lower flammable limit (% v/v)	4.4	4.0
Upper flammable limit (% v/v)	15	75
Detonation cell size (mm)	250-310	15
Stoichiometric concentration (% v/v)	9.4	30
Auto-ignition temperature (°C)	595	560
Minimum ignition energy (mJ)	0.26	0.01
Minimum quenching distance (mm)	2.0	0.5
Burning velocity (m/s)	0.37	3.2
Maximum Experimental Safe Gap (mm)	1.12	0.29
Minimum Igniting Current ratio	1.0	0.25
Energy density per unit mass (MJ/kg)	56	142
Energy density per unit volume (MJ/m^3)	40	13
Temperature Class	T1	T1
Equipment Group	IIA	IIC

Limited or no effect	Some effect	Significant effect	Test does not differentiate

Generic property	Pipeline Steel Parameters	Effect of Hydrogen
Strength	Yield (0.2% or 0.5% proof stress)	Limited effect
	Ultimate tensile strength (UTS)	Limited effect
	YS/UTS ratio (Y/T)	Limited effect
	Young's Modulus (E)	No effect
	Poisson's ratio (n)	No effect
Ductility	Elongation (Total)	Significant reduction
	Elongation (Uniform)	Limited effect
Charpy impact	Charpy impact energy	Limited effect/ strain rate too high
	Specific transition temperature (T27J, T40J)	Limited effect/ strain rate too high
Crack propagation resistance	Drop weight tear test (DWTT) e.g. temperature for 85% shear fracture appearance	No data found on DWTT, but possibly limited effect due to high strain rate
Fracture toughness	K/J/CTOD initiation fracture toughness	Some reduction
	J/CTOD ductile tearing resistance	Significant reduction
Fatigue	Fatigue threshold stress intensity factor range (ΔKth)	slight reduction in some cases
	Fatigue Crack growth rate	Significant increase; many variables
	S-N fatigue line	Effect observed more strongly in high stress LCF region

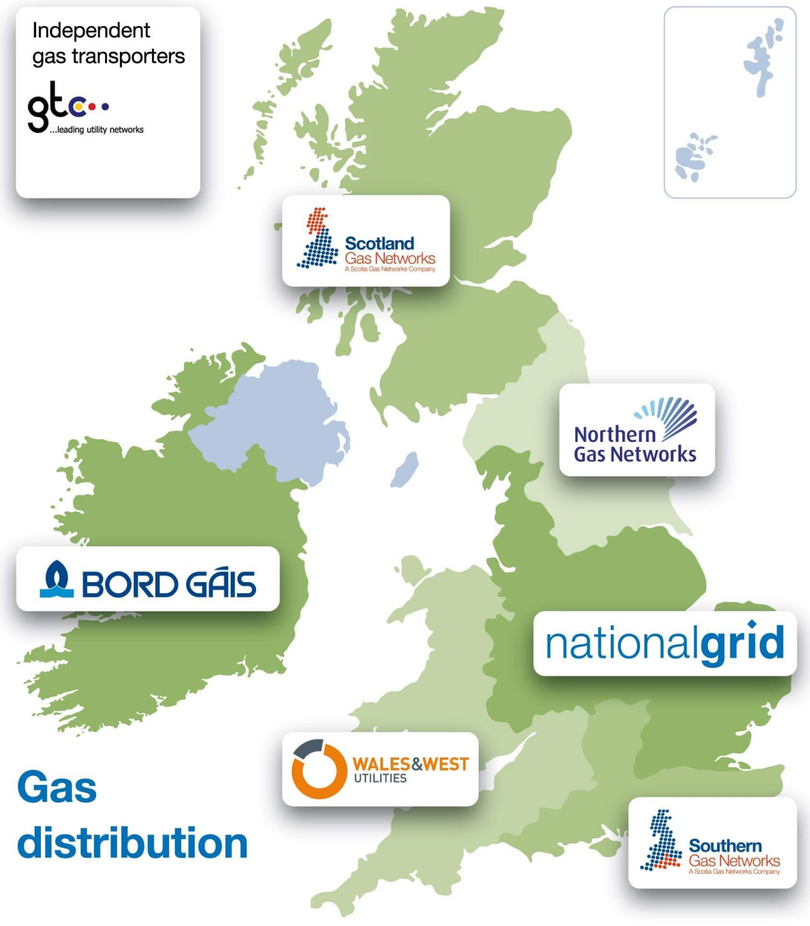
Research Challenges: Impact on Pipeline Network

Need to assess impact of hydrogen on transmission and distribution pipeline network (including AGIs)

- **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**

Overview of UK Gas Network

- Multiple gas companies operate across the UK
- UK gas network includes:
  - National Transmission System (up to 85 bar)
  - Local Transmission System (7 to 60+ bar)
  - Distribution network (< 7 bar)
  - Domestic installation (< 75 mbar)

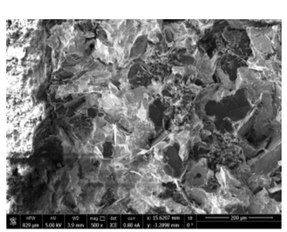
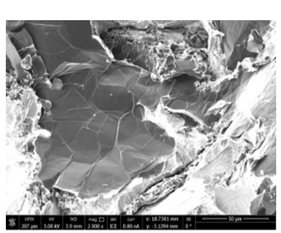


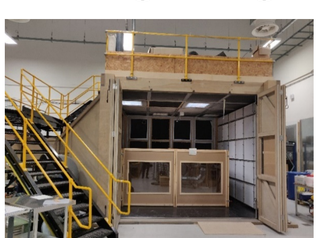
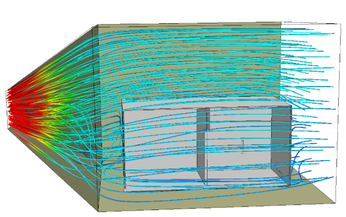
Ongoing hydrogen projects

HyDeploy

https://hydeploy.co.uk/

- **Blend of 20% hydrogen in natural gas**
- Scientific analysis and experiments to support QRA for 20% blend
- Community trials at Keele University and Winlaton village ongoing (668 homes)

h21

https://h21.green/

- **Repurposing of existing natural gas distribution network for 100% hydrogen**
- Leakage tests on recovered assets, gas migration through soil, dispersion, accumulation, ignition, fires, explosion severity, QRA, operational procedures



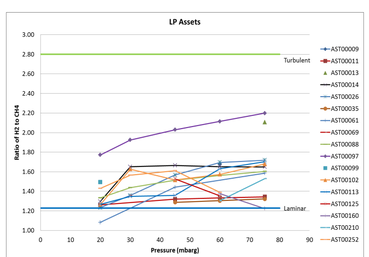
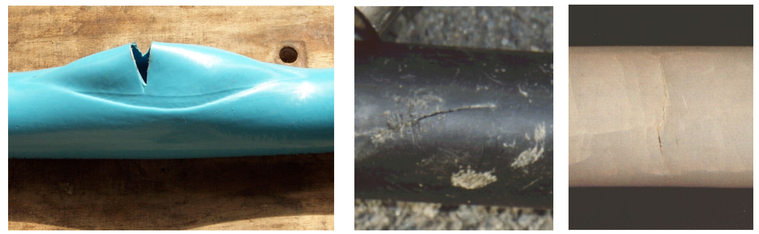


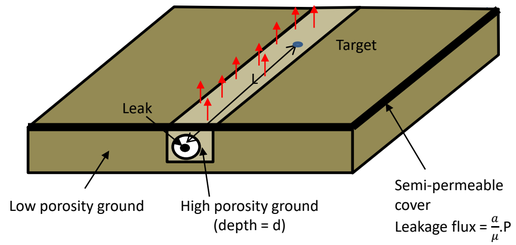
Image of H21 test site at Spadeadam courtesy of DNV (© DNV, 2021)

Ongoing hydrogen projects

https://www.sgn.co.uk/H100Fife

- **100% hydrogen in a new gas distribution network**
- Testing of PE pipe, experiments and analysis to support QRA
- Community trials in Scotland (300 homes) planned for 2023





FutureGrid

https://www.nationalgrid.com/FutureGrid

- **Repurposing of existing national gas transmission network for hydrogen**
- Analysis of 2% and 20% hydrogen blends plus 100% hydrogen
- Tests on different types, sizes, material grades of NTS assets, permeation, pipe coating and CP testing, fatigue, flange tests, leakage, rupture tests
- Phase 1: construction of hydrogen test facility at DNV Spadeadam using assets retrieved from the UK gas transmission network
- Build started in April 2021, testing to start in October 2022

Ongoing hydrogen projects

Hy4Heat

https://www.hy4heat.info/

- Hydrogen in residential and commercial buildings and gas appliances
  - Focus on downstream of the emergency control valve
  - Gas quality, metering, appliances, purging, tightness testing, trials
  - Two demonstration hydrogen homes

https://www.businessgreen.com/news/4034556/green-gas-uk-hydrogen-homes-open-public

Hydrogen Heating Programme

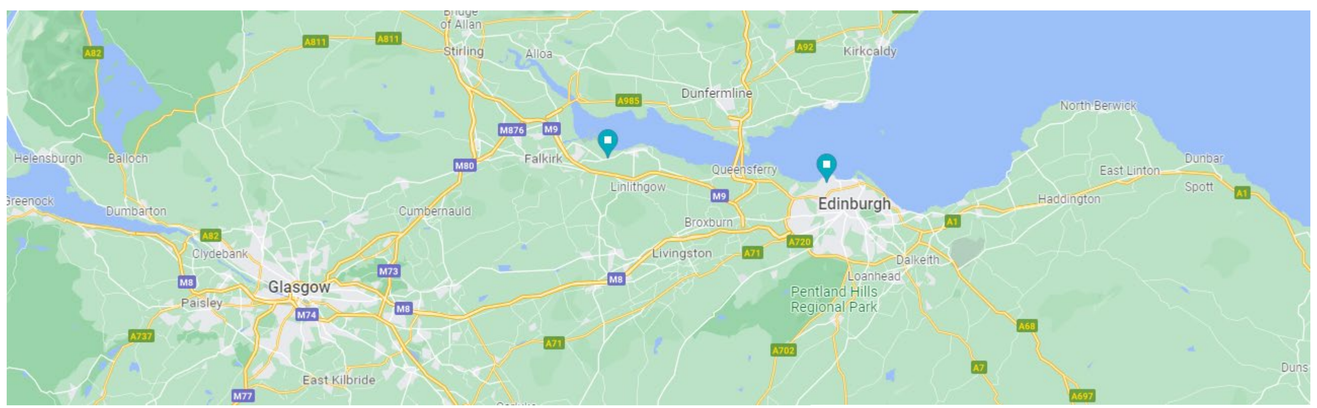
Department for Business, Energy & Industrial Strategy

- 2021-2025, HSE funded by BEIS to provide support on:
  - Assessment of evidence on the safety of hydrogen heating
  - Identification of future safety regulation requirements
  - Support to hydrogen trials (HyDeploy, H100, H21 etc.)

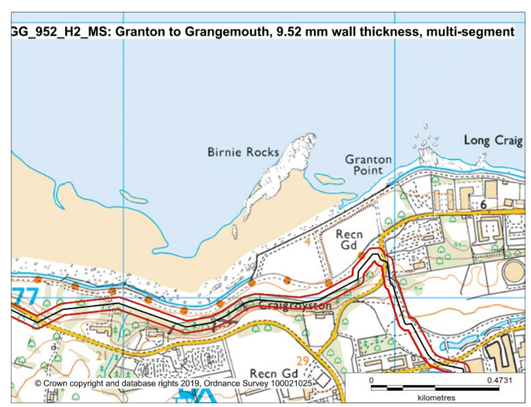
Future hydrogen projects

https://www.sgn.co.uk/about-us/future-of-gas/hydrogen/lts-futures

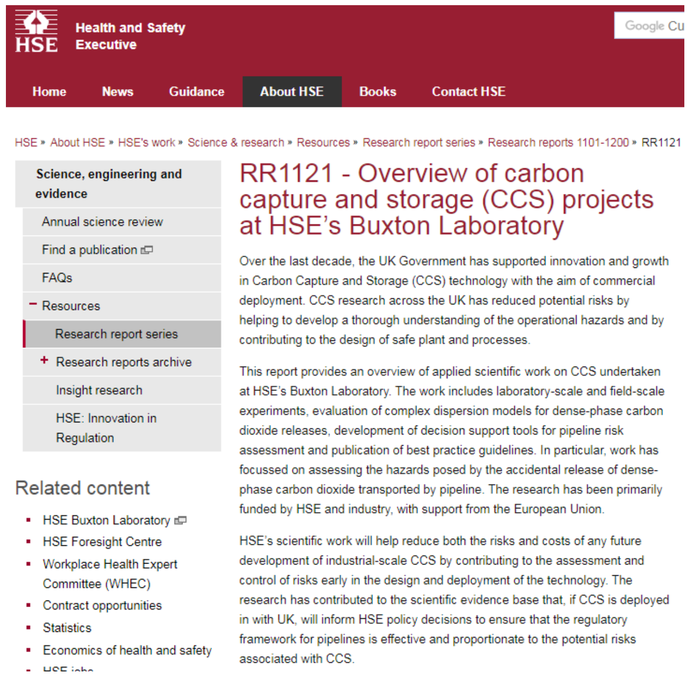
- Hydrogen in the Local Transmission System (LTS)
  - Initial desk-based feasibility study on repurposing the LTS for hydrogen and CO_2 transmission completed in 2020 by SGN and HSE https://hysafe.info/ichs2021/
  - New 3-year project proposed starting in April 2022
    1. Live trial design (Granton to Grangemouth pipeline)
    2. Lab material testing
    3. Offsite testing (at the DNV Spadeadam facility)
    4. Live trial (repurposing trial and demonstration including uprating)
    5. QRA, Case for safety
    6. Knowledge dissemination



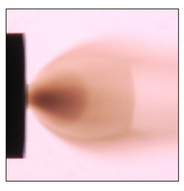
Map data © Google 2021

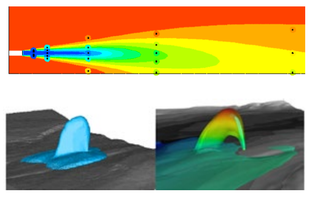


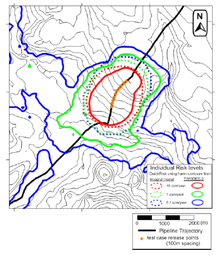
Carbon Capture Utilisation and Storage (CCUS)



http://www.hse.gov.uk/research/rrhtm/rr1121.htm







- Significant research in 2007-2017
- Renewed interest recently with regional hydrogen and CCUS clusters
- Initial regulatory review of some UK projects ongoing
  - Gas-phase CO_2 pipelines onshore
  - Dense-phase CO_2 pipelines offshore
- Repurposing of existing natural gas pipelines for transport of gaseous CO_2
- CO_2 pipelines regulatory policy under review

Remaining Knowledge Gaps

- **Transmission/distribution pipelines and associated infrastructure**
  - Engineering Critical Assessments for pipelines changing from NG to hydrogen service and impact on required inspection capabilities
  - Evaluation of repair techniques, e.g. preheat requirements for steels previously exposed to hydrogen service, hydrogen tightness of clamps and sleeves
  - Evaluation of potential beneficial effects of trace elements (e.g. oxygen) on hydrogen pipeline fatigue properties and fracture toughness
  - Investigation of materials issues on assets in the existing network (e.g. high tensile steel springs in valves, cast iron pipelines)
  - Improved crack growth models and failure rate models for both hydrogen and CO_2 pipelines
  - Dense-phase CO_2 pipelines: models for assessing fracture toughness to prevent running ductile fractures (Battelle two-curve method)

Remaining Knowledge Gaps

- Safety of operational procedures, e.g. detection, ignition, purging, repairs
- Safety of infrastructure, e.g. gas accumulation and explosion relief of governor kiosks
- Operation of components (e.g. regulators, meters) at higher flowrates (filters, noise issues, controls etc.)
- Background leakage modelling: effect of backfill on leakage rates across the network and overall shrinkage
- Use of hydrogen in multi-occupancy (high rise) buildings
- Human factors: training and competency, public acceptance and response

Many of the above issues are already being considered in ongoing and proposed projects, e.g. HyDeploy, H21

Acknowledgements

Thank you

- The projects mentioned here are funded and supported by HSE, the OFGEM Gas Network Innovation Competition, SGN, NGN, Cadent, WWU, National Grid, BEIS, DNV, Progressive Energy, ERM and IGEM.

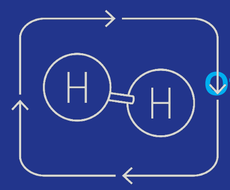
- The contents of this presentation, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy

FutureGrid

www.nationalgrid.com/FutureGrid

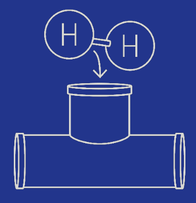
DNV nationalgrid

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 completed in two parts:



Offline Hydrogen Test Facility

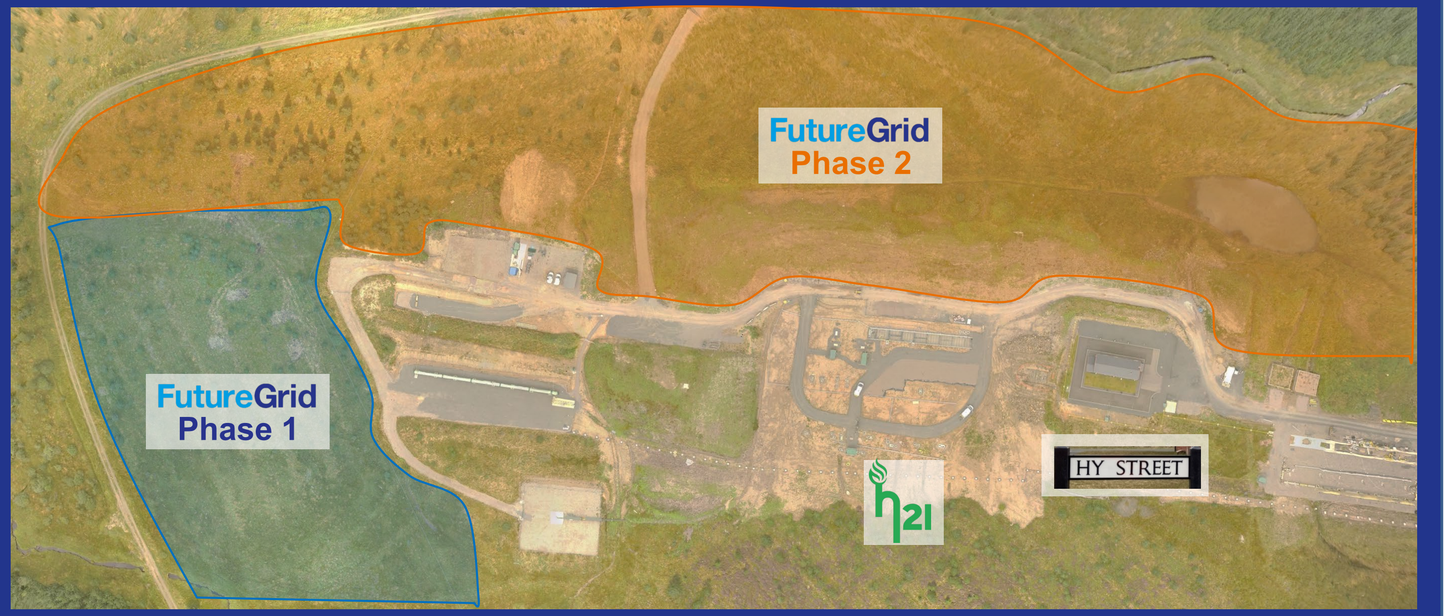
NTS assets of different types, sizes, and material grades will be tested with 2, 20 & 100% hydrogen. The facility will initially run on 100% natural gas to collect baseline data for the equipment and then move through 2%, 10% and 20% hydrogen / natural gas mixtures and then 100% hydrogen.



Standalone Hydrogen Test Modules

Standalone hydrogen test modules will provide key data required to feed into the main facility including:) Material Permeation Testing (2) Pipe Coating & CP Testing (3) Fatigue Testing (4) Flange Testing (5) Asset Leak Testing (6) Rupture Testing

This will help us understand how hydrogen interacts with our assets, so that we can develop the appropriate safety standards required to operate our network. Construction is now underway with testing on the main Offline Hydrogen Test Facility set to begin mid 2022.



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