

**RESEARCH AND
GUIDANCE FROM**



UK perspectives on hydrogen and CO₂ pipelines

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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 plan¹ 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

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
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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 (ΔK_{th})	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

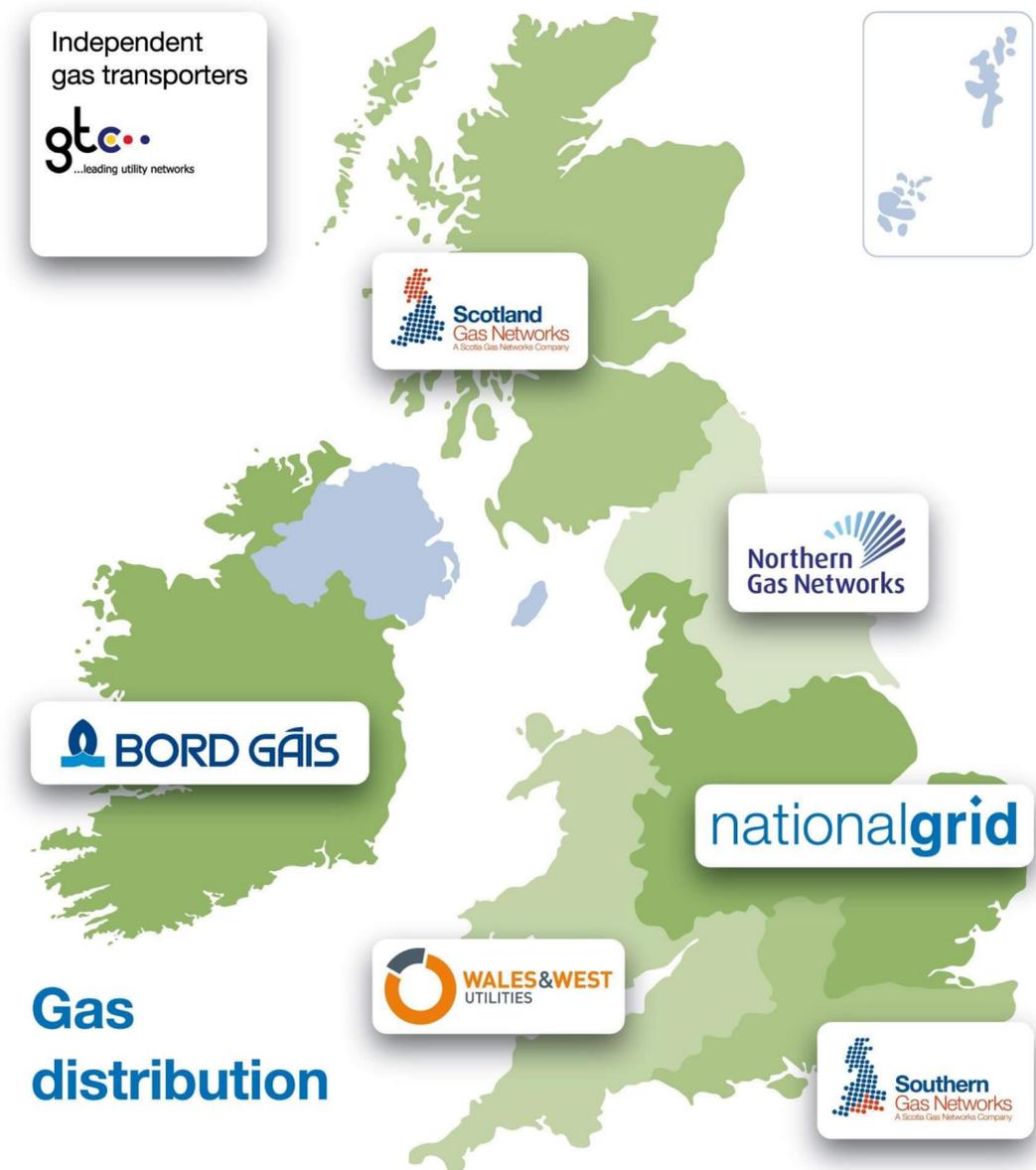
- **Equipment**

- 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



<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)



<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

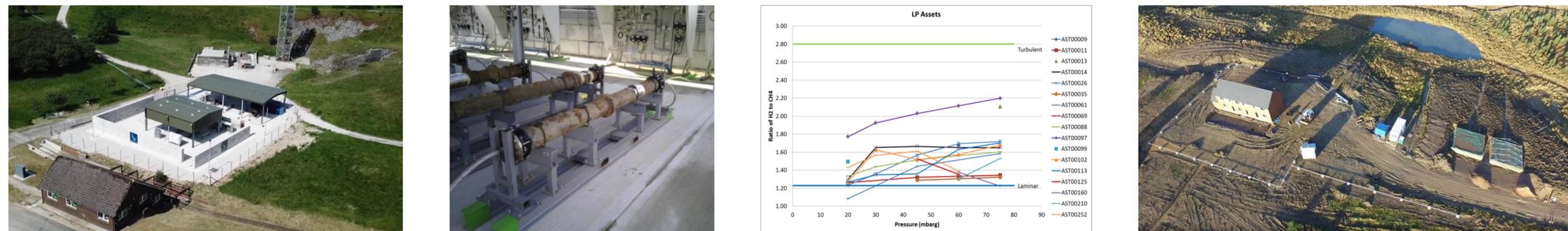


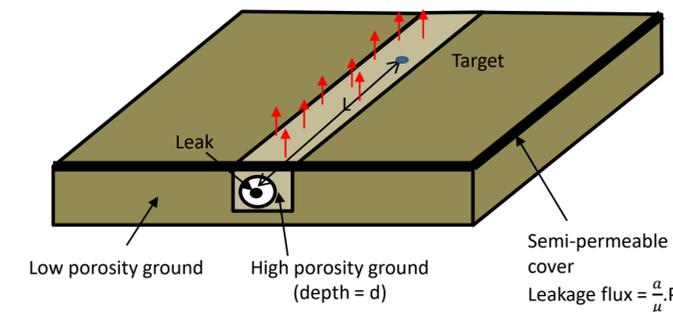
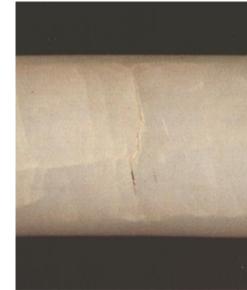
Image of H21 test site at Spadeadam courtesy of DNV (© DNV, 2021)

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



<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

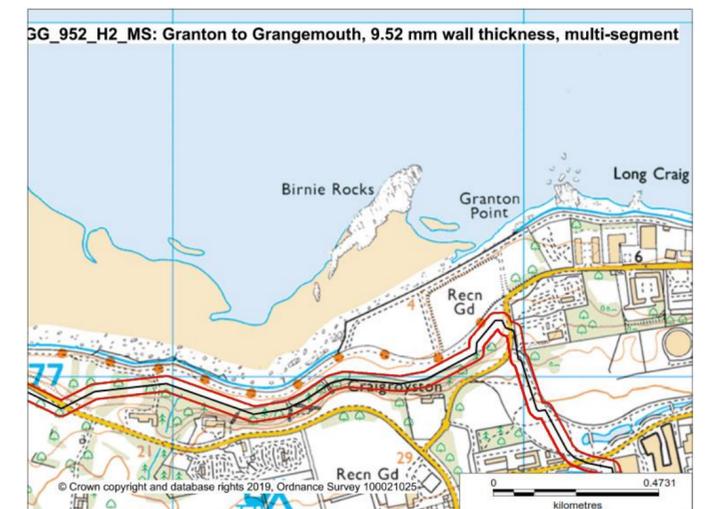
- 2021-2025, HSE funded by BEIS to provide support on:
 - Assessment of evidence on the safety of hydrogen heating
 - Identification of future safety regulation requirements
 - Support to hydrogen trials (HyDeploy, H100, H21 etc.)

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 CO₂ 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



Carbon Capture Utilisation and Storage (CCUS)



HSE » About HSE » HSE's work » Science & research » Resources » Research report series » Research reports 1101-1200 » RR1121

- Science, engineering and evidence
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- HSE: Innovation in Regulation

RR1121 - Overview of carbon capture and storage (CCS) projects at HSE's Buxton Laboratory

Over the last decade, the UK Government has supported innovation and growth in Carbon Capture and Storage (CCS) technology with the aim of commercial deployment. CCS research across the UK has reduced potential risks by helping to develop a thorough understanding of the operational hazards and by contributing to the design of safe plant and processes.

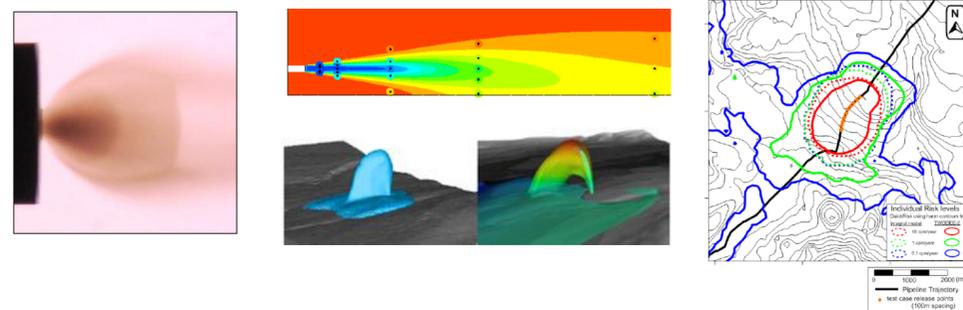
This report provides an overview of applied scientific work on CCS undertaken at HSE's Buxton Laboratory. The work includes laboratory-scale and field-scale experiments, evaluation of complex dispersion models for dense-phase carbon dioxide releases, development of decision support tools for pipeline risk assessment and publication of best practice guidelines. In particular, work has focussed on assessing the hazards posed by the accidental release of dense-phase carbon dioxide transported by pipeline. The research has been primarily funded by HSE and industry, with support from the European Union.

HSE's scientific work will help reduce both the risks and costs of any future development of industrial-scale CCS by contributing to the assessment and control of risks early in the design and deployment of the technology. The research has contributed to the scientific evidence base that, if CCS is deployed in with UK, will inform HSE policy decisions to ensure that the regulatory framework for pipelines is effective and proportionate to the potential risks associated with CCS.

Related content

- HSE Buxton Laboratory
- HSE Foresight Centre
- Workplace Health Expert Committee (WHEC)
- Contract opportunities
- Statistics
- Economics of health and safety
- HSE iStock

<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 CO₂ pipelines onshore
 - Dense-phase CO₂ pipelines offshore
- Repurposing of existing natural gas pipelines for transport of gaseous CO₂
- CO₂ 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 CO₂ pipelines
 - Dense-phase CO₂ 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



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- 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

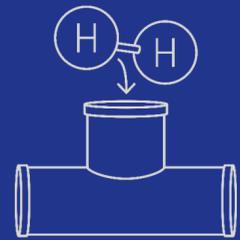


An ambitious programme to build a hydrogen test facility from decommissioned assets at DNV's facility in Cumbria to demonstrate the National Transmission System (NTS) can transport hydrogen. Testing will be completed in two parts:



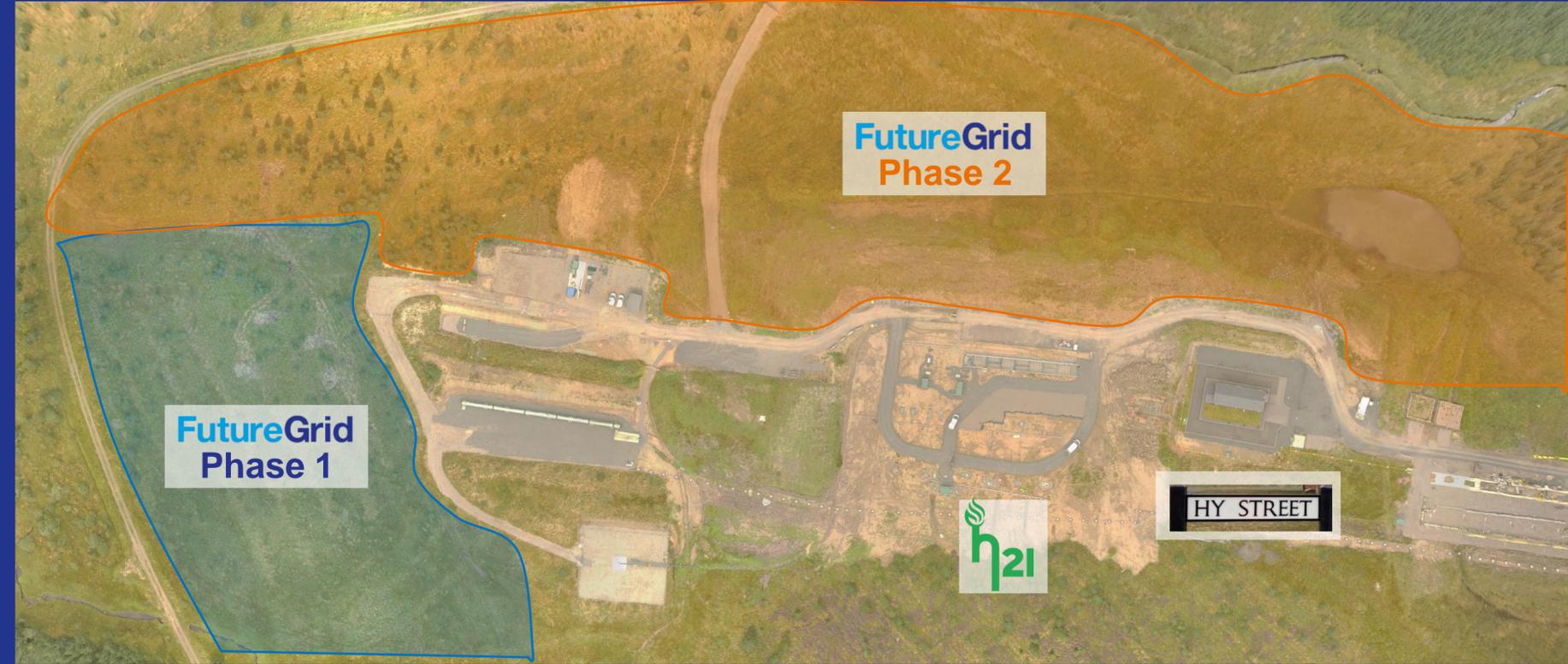
Offline Hydrogen Test Facility

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: (1) 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.

