The LTS Futures Project – a UK Operator's (SGN) Experience of Assessing the Feasibility of Repurposing Their Natural Gas Transmission System to Transport Hydrogen

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Pipeline Pigging and Integrity Management Conference

February 12-16, 2024

Organized by

Clarion Technical Conferences

https://doi.org/10.52202/072781-0026

https://doi.org/10.52202/072781-0026

Abstract

The Local Transmission System (LTS) is the backbone of the United Kingdom (UK) energy network, delivering natural gas from the National Transmission System (NTS) to towns and cities across the country.

The four Gas Distribution Networks (GDNs) operate approximately 11,000 km of high-pressure pipelines, operating at pressures above 7 barg. The pipelines were originally designed to transport and store natural gas.

The UK Hydrogen Strategy states that: "Low carbon hydrogen will be critical for meeting the UK's legally binding commitment to achieve net zero by 2050". Hydrogen behaves differently to natural gas, therefore it is necessary to assess how it affects the existing LTS infrastructure.

The LTS Futures Project is a first of a kind, £30 million, joint funded project between SGN, the UK energy market regulator OFGEM, and the other UK GDNs. The project is led by SGN and looks to repurpose a 30 km natural gas transmission pipeline to hydrogen for a live demonstration trial, which will inform the development of a Blueprint methodology for repurposing the LTS. The LTS Futures Project is researching, testing and collating evidence to understand the compatibility of LTS assets, pipelines, associated plant and ancillary fittings in hydrogen, which will all be captured in the Blueprint.

The aim of the Blueprint is to provide a methodology to determine if a natural gas LTS asset is fit for hydrogen service and identify any data gaps, or further work needed for repurposing for hydrogen service.

Introduction

Hydrogen has a growing interest from a variety of sectors and stakeholders for blending / replacement of natural gas and so as a potentially valuable decarbonisation tool for governments, industries and consumers.

Hydrogen can be produced in several ways, both with fossil fuels and renewable energy. Currently, 95% of global hydrogen is produced through a process of steam methane reforming (SMR) of fossil fuels, either coal or natural gas – referred to as 'grey' hydrogen, or 'blue' hydrogen if the carbon emissions are captured and stored or reused. The most widely discussed and proposed alternative to SMR is to produce hydrogen through electrolysis – referred to as 'green' hydrogen, generally using renewable energy produced during off-peak times.

The move to decarbonisation in the UK has generated major interest in initiatives exploring the use of existing natural gas networks (pipelines and installations) for the transportation and distribution of hydrogen. SGN's 'Future of the LTS' project is one of the most advanced projects relating to above 7 barg pipelines. The project is investigating the requirements for repurposing the Local Transmission System, (LTS) to transport hydrogen. This project includes a live trial of the Grangemouth to Granton (GG) pipeline, which is currently decommissioned and held under low pressure nitrogen.

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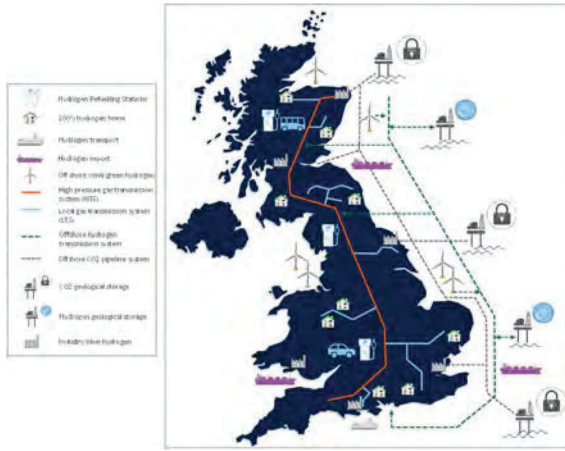

Figure 1. Potential future UK hydrogen system transformation

Pre project studies

SGN carried out pre project studies to consider the repurposing of the LTS for the transportation and storage of hydrogen or carbon dioxide. The Hytechnical project was a scientific and regulatory feasibility study which considered the requirements of standards to ensure compliance with safety legislation, the compatibility of the materials to ensure that the materials of existing natural gas networks are appropriate for safe transportation of hydrogen, and the risks posed to people by a pipeline failure. A detailed assessment of LTS pipelines confirmed that a significant percentage of the LTS network consists of relatively low-strength pipeline grades that operate at low stresses. Both factors are conducive to the pipeline's suitability for hydrogen transportation and storage as the use of higher strength steels and higher pressures leads to potential increased susceptibility to hydrogen degradation and an increased demand on the pipeline steels in terms of stresses.

Pipeline case studies were used to identify pipeline sections which were suitable to be repurposed for hydrogen use. These case studies included the decommissioned pipeline from Grangemouth to Granton, which was identified as having potential to be repurposed for hydrogen transportation. The requirements for LTS repurposing were considered in the Hytechnical programme, which comprised of:

1. Desktop exercises to understand the impact hydrogen has on:
    a. Inspection, Maintenance and Repair (IMR);
    b. Repurposing Pressure Reduction Installations (PRI); and,
    c. Building Proximity Distance (BPD) and separation distances to parallel pipelines.
2. Development of hydrogen supplements to gas industry standards (TD1, TD3, TD4 and TD13)
3. Updating of IGEM[1]/SR/25 hazardous area standard for hydrogen.

The Hytechnical programme concentrated on identifying the gaps that needed to be addressed in the development of approved industry standards and to ensure safe best practice. This work ensured consistency in repurposing existing natural gas networks and construction of new assets, which complied with legislation. The desktop studies carried out by Hytechnical aimed at closing gaps identified in studies addressing the inspection, maintenance and repair, requirements for pressure reduction installation performance and quantitative risk assessment (QRA) gaps. The results of the

[1] IGEM - Institution of Gas Engineers and Managers

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desktop studies provide the evidence-based research that will feed into the IGEM documents hydrogen supplements. Specifically, the IGEM TD document supplements were aimed at allowing new hydrogen pipelines to be installed (allowing industrial clusters to be decarbonised) and provide the re-qualification process (including material testing) for repurposing pipelines.

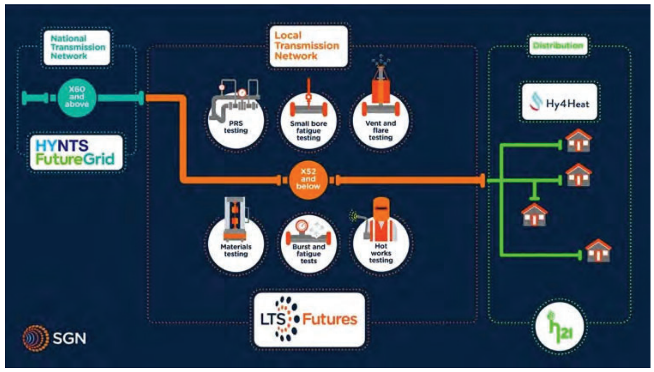

Figure 2. Interaction of LTS Futures project with other UK projects

In parallel with this, SGN shared the findings of the work to identify any further gaps, and chaired an IGEM group called 'LTS Futures' which comprised membership from all the gas distribution networks, HSE, BEIS and other industry bodies. This group worked collaboratively to identify knowledge gaps which were then addressed in the LTS Futures Research Programme. These included:

1. Evaluation and specification of materials requirements
2. A live trial to provide results for the development of a procedure, terms the Blueprint for repurposing LTS pipelines for hydrogen service.
3. Laboratory and offsite testing to ensure the performance of old or vintage materials is adequate for transporting hydrogen, that existing defects can be tolerated and that available modification and repair methods are acceptable, and the consequences of unplanned releases and failure are understood and can be evaluated.

The above knowledge gaps were developed into a research programme with 6 Elements, described in this paper.

Figure 3. LTS Futures project – six key Elements

Project scope and timeline

SGN are undertaking the LTS Futures Project, which forms part of the United Kingdom's (UK's) national hydrogen research programme to deliver a net zero decarbonisation solution for customers.

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The project seeks to research, develop, test and evidence the compatibility of the LTS assets, pipelines, associated plant and ancillary fittings for hydrogen service. The aim of the project is to demonstrate that the LTS can be repurposed to transport hydrogen, providing options for the decarbonisation of power, industry, heat and transport by delivering a safe supply of energy to all customers both during, and after, the energy transition.

The project was launched in April 2022 and will run until 2025 after the completion of the live trial of the LTS pipeline in 2024/25. Delivery of the LTS Futures project will support critical future heat policy decisions, providing understanding on the role of our extensive LTS in achieving net zero for the SGN networks in Scotland and the south of England, and beyond.

The pipeline includes:

- 25.163 km of 457 mm diameter x 6.35 mm wt x X52 grade spiral welded pipe
- 3.845 km of 457 mm dia x 9.52 mm wt x X52 grade seamless pipe
- Internal coating – epoxy resin
- 1 x 457 mm Class 300 ball valve in 610 mm x 610 mm concrete pit
- 2 x 150 mm Class 300 ball valves
- 762 mm dia sleeves (grouted and forged end seals)
- Cold bends, forges bends, sweepolet connection
- Local concrete protection
- 100% radiography of welds
- External coating – coal tar enamel
- Hydrotest pressures – 6.35 mm spiral weld section – 84.7 barg, 9.52 seamless sections 127 barg

A decommissioned pipeline section for the live trial was selected to avoid the need take an operational natural gas pipeline section out of service, which would require the construction and installation of a diversion to maintain security of supply. To identify a relevant pipeline section for the trial, sections of decommissioned LTS pipelines were assessed against a number of factors to determine whether they provide a reasonable representation of typical LTS pipelines. This assessment identified that the SGN decommissioned Grangemouth to Granton pipeline provided the best representation for the LTS Futures Live Trial. This pipeline represents a bounding case in terms of material grade (X52 is the bounding case above which material performance factors or material qualification is required), pipe type (spiral welded pipe presents the greatest technical challenge) and diameter and wall thickness, which represent respectively the maximum hazard and the highest probability of failure.

The pipeline has been mothballed since the 90s, so its use in the live trial requires a comprehensive assessment of the pipeline integrity and condition in order to bring it back into service, as well as to repurpose it from natural gas to hydrogen service.

The Grangemouth to Granton pipeline provides the upper bound case material for the LTS. The material (vintage X52) is upper bound case of 93% of the population of LTS pipeline assets, and the pipeline's construction includes key components which are typically included in LTS pipelines, such as block valves, cold bends, forged components and sleeves. The controlled demonstration will validate the interactions of these features together and with hydrogen.

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The route includes:
- 35 road crossings
- 11 crossings of other services
- 4 rail crossings
- 1 river (Almond) crossing

The route passes through rural and suburban areas. In the rural farm land areas, typical land drains are installed to maintain the quality of the land. In the suburban areas, the pipeline route passes close to occupied properties, which will require that the risk posed by the pipeline to people be assessed, and the need for risk mitigation measures, including the installation of slabbing over the pipeline to provide protection against potential damage caused by third parties working close to the pipeline. In addition, the route is close to Edinburgh airport, which will require operational and emergency procedures to take account of potential interference with flight paths.

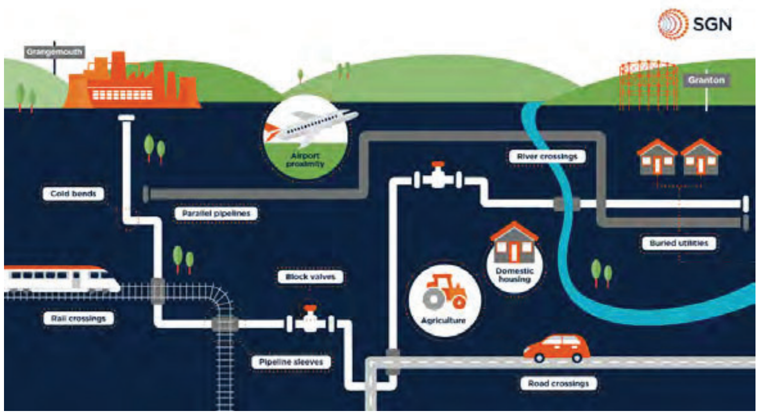

Figure 4. Schematic of the Grangemouth to Granton pipeline

The UK transmission system

The UK natural gas network is comprised of the National Transmission System (NTS) and the Local Transmission Systems (LTS) which are connected to the NTS. The NTS provides the capability for the transportation of natural gas from UK system entry points which are mainly located at coastal locations where gas arrives in the UK from offshore fields, interconnectors or by LNG ships. The NTS transports the gas from these location to the 8 distribution gas networks. The LTS is connected to the NTS network and transports the gas from the NTS Offtakes to the towns and cities within the distribution network where the pressure is reduced further to supply commercial and domestic users. The combination of the NTS and the LTS provides a fully integrated gas network for energy supply within the UK from the Entry Points to the medium and low pressure networks. The NTS comprises 7,600 kms and the LTS comprises over 11,000 kms of pipelines.

SGN owns and operates over 3,000 kms of HP (>7barg) pipelines, 75,000km of distribution main (<7 barg) and 8,000 pressure reduction installations (PRI's) - supplying 5.9 million homes and businesses.

The key parameters of the NTS and LTS pipeline populations have been analysed using the UKOPA (United Kingdom Operators' Pipeline Association) data which are summarised and compared in Table 1.

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Table 1. Comparison of NTS and LTS Pipeline Populations

Parameter	**NTS**	**LTS**
Diameter	95%≥ 610 mm	90% ≤ 610 mm
Material Grade	78% ≥equal to or greater than X52	89% equal to or lower than X52
Design Pressure	70 - 94 bar	49% ≤ 40 bar
Design Factor	≥ 0.68	49% ≤ 0.3
Commission Date	31% before 1973	71% before 1973
Hydrotest	High level (105% SMYS)	Typical - 1.5 x Design Pressure
Pressure cycling	Pressure cycled	Pressure cycled
Odour	Gas not odourised	Gas odourised

The NTS and LTS are maintained and operated to the UK standard IGEM/TD/1 [1]. The development of IGE/TD/1 commenced in 1964, with the construction of the UK NTS. The development of TD/1 was based on a detailed review of the ASME B31.8 standards, identification of the key principles and application of these to the UK environment, with particular attention to the higher population density. The development of gas industry specifications commenced with the development of the IGE/TD/1 standard.

A high level review of the UK pipeline population carried out for the HyTechnical Project confirmed that, on average, the LTS population is older than the NTS population. The LTS population is also a lower grade and operates at lower design factors. The chemistry and microstructure of older pipelines is likely to more susceptible to hydrogen embrittlement than that of newer pipelines of equivalent strength.

65% of the NTS and 81% of the LTS was designed and constructed during the development of IGE/TD/1 principles in Editions 1 and 2, and 35% of the NTS and 19% of the LTS meets the current design, construction and testing requirements in IGEM/TD/1 Edition 5 or 6. The LTS is constructed using older material and therefore incorporates a wider range of material manufacturing quality.

Risk

In the UK Pipeline Land Use Planning (LUP) zones are set by HSE based on calculated pipeline individual risk transects, and societal risk is used to carry out ALARP assessments when risk reduction must be considered. The risks posed by hydrogen pipelines depend upon the probability and consequences of failure. The probability of failure may be affected by the degradation of material properties, and the consequences of failure are influenced by the higher flame speed and flame temperature for hydrogen. The higher flame speed results in higher explosion overpressures for delayed ignition, the higher flame temperature affects objects engulfed in the flame, but as the radiative heat flux is lower the thermal hazard zone is not increased.

Risks posed are dominated by rupture, and so will increase if the rupture rate due to fatigue, external interference and/or ground movement is increased as a result of material degradation, and if the consequences are more severe because of the increase in overpressure due to delayed ignition.

Overpressure is a hydrogen specific consideration which could potentially affect the pipeline Building Proximity Distances (BPD). An initial evaluation of BPDs for hydrogen pipelines was carried out in the Hytechnical work programme. LTS Futures will use the results of delayed ignition rupture tests

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of a 6” pipeline section which are being carried out as part of the FutureGrid project to determine the overpressure and thermal consequences of a pipeline rupture. The results of these tests will allow validation of the LTS Futures BPD estimates and assess whether the overpressure hazard can be addressed within the thermal consequence distances.

The UK NTS and LTS

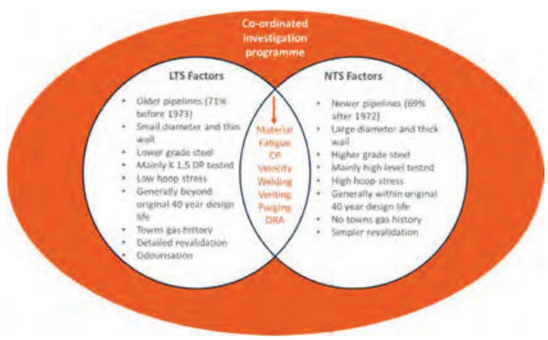

Figure 5. NTS vs LTS differences

UK Code requirements for hydrogen transmission pipelines (new build and repurposing)

UK pipelines are subject to legislative control under the Pipelines Safety Regulations 1996 (PSR 96) [2]. The Regulations cover general duties for the safe management of all pipelines in the UK relating to design, construction, operation, maintenance and decommissioning. In addition, the Regulations specifically define Major Accident Hazard Pipelines (MAHPs), which are pipelines that convey ‘dangerous fluids’ and for which the consequences of failure would present a major accident resulting in significant danger to people. Additional duties are defined for these pipelines, including notification, preparation of a Major Accident Prevention Document (MAPD), emergency procedures and arrangements, and provision of information to Local Planning Authorities for inclusion in the Emergency Response Plan for the area. High pressure gaseous hydrogen is classed as a dangerous fluid, as per natural gas.

Pipeline design requirements for high pressure steel transmission pipelines are specified in the standard IGEM/TD/1 [1] for natural gas pipelines. The Hytechnical research programme has developed a supplement to TD/1 for hydrogen pipelines.

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The UK design requirements are integrity based in that design principles and requirements prescribe design parameters to be applied to ensure pipeline integrity and therefore consequently safety. However, where requirements are not definitive or conditions which fall outside the prescribed requirements are being addressed, the use of QRA as a decision tool is allowed. IGEM/TD/1 allows the use of individual and societal risk levels calculated using Quantified Risk Assessment (QRA) to be used to route pipelines and to carry out site specific risk assessments.

IGEM/TD/1 was originally developed by the UK gas industry to support the development of the National Transmission System (NTS) for natural gas. The principles of the American pipeline code ASME B31.8 were revised for application in the UK. The key principles identified were the requirement to assess the infrastructure within a fixed corridor along the proposed route of a pipeline, classify the area according to the infrastructure, and limit the pipeline operating stress in areas of high levels of infrastructure development. These principles were accepted and modified for application in the higher populated areas in the UK. The modifications involved replacing the fixed corridor width with a multiple of the building proximity distance (BPD), which defines the minimum required separation between the pipeline and existing normally occupied buildings, and limiting the operating stress in highly populated areas to 30% of the pipe material's Specified Minimum Yield Stress (SMYS).

The BPD is derived as the distance to a thermal radiation level of 32 kW/m^2 from a steady state fire, and its definition takes account of the low probability of pipeline failures and the possibility, due to the linear nature of the hazard, of escape or to take cover from the effects of thermal radiation. The BPD is calculated according to the diameter and pressure of the pipeline. The BPD is based on thermal consequences, and work to include the effects of overpressure were identified as a gap and are being carried out in LTS Futures.

Since the adoption of the ASME standard principles for application in the UK, major research programmes have been undertaken in the USA (Battelle Memorial Institute, Pipeline Research Council International (PRCI)), Europe (directed by the European Pipeline Research Group (EPRG)) and UK (Gas Council, British Gas) to evaluate the failure behaviour of and consequences of failure for high pressure gas pipelines. In addition, the USA experience of material manufacture and fabrication problems was accepted and applied in the UK IGEM standards, specifically in terms of design factor and wall thickness, proximity requirements, hydrotest requirements and fatigue. The aim of the ASME and IGEM standards are to minimise risks (posed by gas transmission pipelines) to the public, by:

- Recognising pipeline failure modes and consequences
- Minimising effects of consequences of failure (proximity distances)
- Minimising frequency of failure:
- resistance to damage (wall thickness requirements)
- control of failure mode (material properties, Design Factor)

The development of the IGEM UK standards for hydrogen pipelines builds on the history of the UK standards development through requirements to take account of:

- The physical, chemical, thermodynamic and energy properties of hydrogen compared to natural gas The impact of hydrogen on the properties of steel, including the impact on defect limits and repair techniques
- The hazards associated with releases of hydrogen, and the impact on safety management requirements

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- The increase in flowrate required to account for the reduced energy density, and the consequent increase in gas velocity on vibration, noise and acoustic fatigue
- Changes to inspection, maintenance and repair requirements

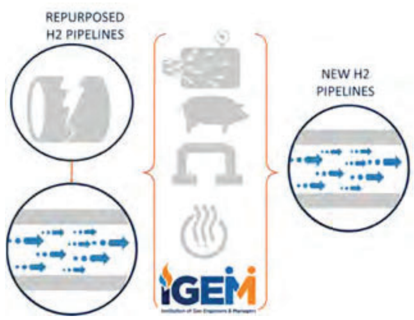

Figure 6. IGEM – Supplements for hydrogen (repurposing and new build)

Project Elements

There are six integrated elements of the project which are summarised below.

Element 1 - Design of live trial and pipeline modifications

Objective

Provide formal confirmation that the condition and integrity of the proposed pipeline are acceptable for safe operation, and that the risk posed by the pipeline are acceptable for hydrogen service.

Key aspects

To be able to repurpose the Grangemouth to Granton pipeline for hydrogen service in accordance with IGEM/TD/1, a design and operability assessment is required. This assessment includes an evaluation of the material properties and condition of the pipeline e.g.

- A hydrotest, an inline inspection or equivalent
- A cut out of a small section for material testing (not a pre-requisite for repurposing)
- Detailed line walks
- Above ground survey (e.g. Close Interval Potential Survey (CIPS))
- Building proximity surveys
- etc

The above activities require co-ordination and liaison with landowners. The results of these activities are analysed to identify modifications or repairs required for repurposing.

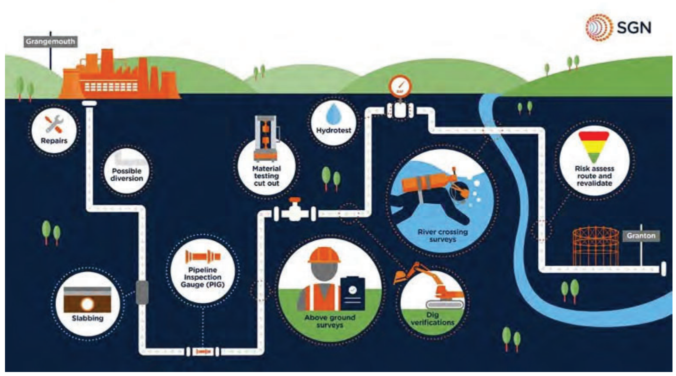

Figure 7. Live trial design considerations

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Key learnings to date

- Demonstration of pipeline integrity by a successful hydrotest to a minimum pressure of x1.5 MOP
- CIPS and DCVG surveys completed and follow up digs as required
- Completion of IGEM/TD/1 report, acting as a technical audit of the pipeline
- Development of an outline blueprint for repurposing the LTS
- Defining pipeline integrity management requirements (IMR) prior and during live trial
- Drafting Major Accident Prevention Document (MAPD) for hydrogen operation
- Development of project specific welding procedures for hydrogen pipeline / pipework
- Design feasibility study completed for hydrogen supply
- Purging requirements analysed by modelling
- Pipeline section removed for material testing (Element 2) and full scale testing (Element 3)

Figure 8. Marker Posts

Looking forward

- Detailed design of hydrogen supply / entry unit / flare stack
- Conduct all construction works for hydrogen supply / entry unit / flare stack
- Update blueprint
- Update MAPD

Element 2 - Laboratory material testing

Objective

To determine the effect of pressurized, gaseous hydrogen on the material properties of vintage steel currently used to transport natural gas.

Key aspects

The material properties (such as strength, ductility and toughness) of the pipeline are key characteristics that affect how the pipeline responds to loads and its tolerance to defects. Coupon scale testing provides an opportunity to perform a large volume of testing to evaluate the effect of hydrogen on such material properties.

Material tests will provide a comparison between failure in air and hydrogen. This will influence the acceptability of defects (acceptable, or repair, or replace) and will inform the QRA and Blueprint.

The Grangemouth to Granton pipeline is considered a good example of pipelines in the LTS due to its vintage, grade, and geometry. Line pipe from the Grangemouth to Granton pipeline and from other pipelines in the LTS will be tested to provide a risk profile of all the LTS materials to understand the likely extent to which LTS pipelines can be repurposed and an assessment of cost. This will include options for intervention, ranging from increased inspection and survey to repair and replacement. The outcome of the testing will also inform industry standards.

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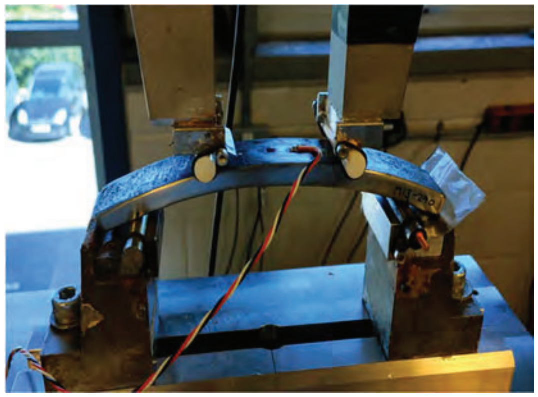

Figure 9. Fatigue Endurance Testing in Air

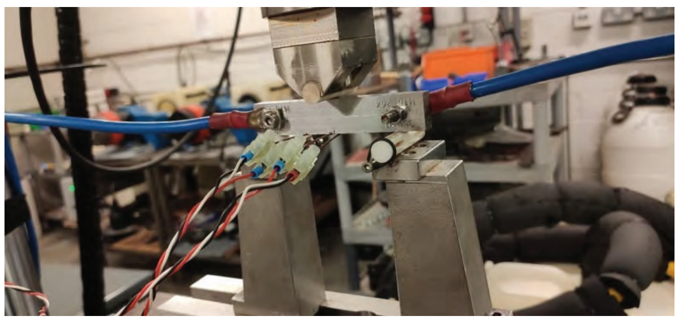

Figure 10. Fracture Toughness Testing in Air (SENB Specimen)

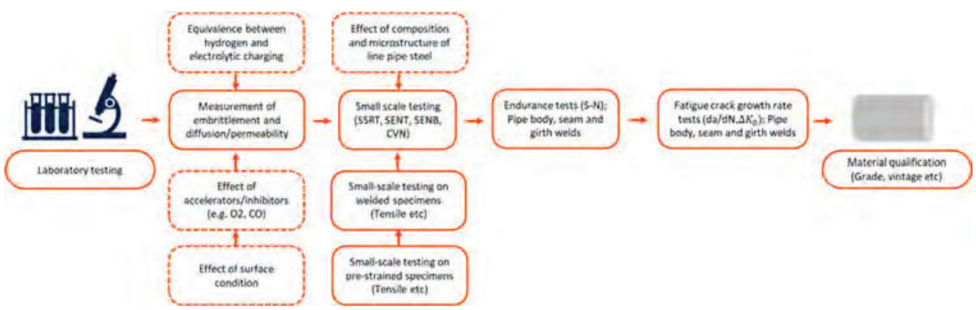

Figure 11. Material testing flow chart

Key learnings to date

- The pipe body, girth welds and seam welds have been characterised through microscopy, hardness and chemical composition testing to inform on the baseline properties.
- Transverse strip tensile and Charpy V-notch Impact tests have been performed on the material as would typically be carried out as a quality control test on line pipe for a new pipeline.
- Tensile tests and Slow Strain Rate Tensile (SSRT) tests have been carried out in air and gaseous pressurised hydrogen. Tests on the pipe body, girth welds and seam welds have been conducted. The testing demonstrates a consistent, reduction in the ductility in hydrogen.

Looking forward

- Constant load, threshold stress intensity factor (K1H) tests are to be performed in a gaseous hydrogen environment, as per Option 2 of ASME B31.12.

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- Fracture toughness testing is to be conducted using both Single Edge Notch Bend (SENB) and Single Edge Notch Tension (SENT) specimens in both air and pressurised, gaseous hydrogen. Initial results will inform if there is a favoured specimen type for testing material used in pipeline applications.
- Fatigue Crack Growth Rate (FCGR) tests and Endurance tests are to be conducted in both air and pressurised, gaseous hydrogen. Frequency Scanning tests are also to be conducted to determine the effect of loading frequency on crack growth rate within a hydrogen environment.

Element 3 - Off-site testing

Six work packages are to be undertaken by DNV at their Spadeadam Test Facility, Cumbria. The testing programme includes: hot work testing, ignited releases with overpressure and thermal radiation measurements, fatigue testing of branch connections in hydrogen service, pressure reduction station performance testing, and burst tests and fatigue tests of pipeline defects.

Work Package 1 – Hot works

Objective

To investigate whether it is possible to safely carry out live welding on a hydrogen pipeline and determine whether the weld properties and fatigue performance are degraded because of hydrogen.

Key aspects

The aim of the hot works package is to demonstrate the following:

- That live welding can be conducted on a hydrogen pipeline safely under a defined procedure.
- Determine if standard SGN welding specifications are applicable to hydrogen pipelines.
- Develop a weld procedure qualification record (WPQR) and establish weld quality.
- Heat decay trials
- Investigate weld fatigue performance in a hydrogen environment.

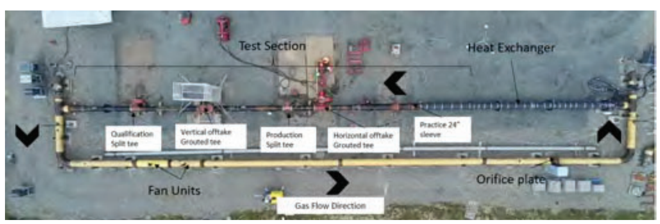

Figure 12. Test loop at DNV Spadeadam

Figure 13. Test loop at DNV Spadeadam

Figure 14. Setting up slit tee for welding at DNV Spadeadam

Key learnings to date

- Heat decay trials under flowing hydrogen conditions to understand heat transfer rates
- Successful welding x3 split tees under flowing hydrogen conditions
- Successful grouting of an epoxy tee under flowing hydrogen conditions
- Drill x4 split tees under flowing hydrogen conditions
- Development of Welding Procedure Specifications (WPS's) for live welding to a hydrogen pipeline

Looking forward

- To weld an 18in split to the Grangemouth to Granton pipeline whilst under hydrogen operation (Element 4)

Work Package 2 – Burst and Fatigue Tests

Objective

The aim of the burst and fatigue tests is to provide data which can be compared to baseline tests which also form part of the programme to see if the effect of hydrogen exposure reduces the burst pressure and fatigue life of pipeline defects. This information can then further inform hydrogen pipeline defect assessments.

Key aspects

The burst and fatigue work package will produce data on the effects of hydrogen exposure on pipeline defects. Nine burst tests will be carried out on samples with dents, dent and gouges and crack-like defects. Fourteen fatigue tests will be carried out on samples with crack like defects, dents in the pipe wall, dents on the seam welds, and dents on the girth welds. An epoxy tee and split welded tee will also be fatigue tested as part of WP1. The vessels to be tested in hydrogen will be soaked in hydrogen for approximately 90 days prior to the start of the tests.

Figure 15. Hydrostatic Burst Test

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Figure 16. Heating of defect on hydrogen burst test vessel

Figure 17. Hydrostatic Burst Test Defects (before and after test)

Figure 18. WP1 Tee Fatigue Test Vessel

https://doi.org/10.52202/072781-0026

Key learnings to date

- Finite element analysis conducted during the design of the tests has provided information on the minimum length of a test vessel, to avoid interaction between the defect and the domed ends.
- Hydrostatic burst testing completed and provided baseline values for defect failure pressures.
- Pre-heating of defects on hydrogen burst vessels to attempt the break down surface oxide layer.
- Hydrostatic fatigue pre-test to evaluate instrumentation suitability and cycle time.

Looking forward

- Hydrogen burst testing of five vessels currently undergoing extended soaking period.
- Hydrostatic fatigue testing of purpose made defects and vintage welds.
- Hydrogen fatigue testing of purpose made defects and vintage welds.
- Hydrogen fatigue testing of grouted epoxy and welded tee from live application in WP1.
- The effect of hydrogen on the burst and fatigue strength of defects in pipelines.
- The relevance of material properties (fracture toughness, etc.) measured in small-scale tests to the behaviour of defects observed in full-scale tests.

Work Package 3 – Fatigue testing of small-bore branch connections

Objective

To determine the fatigue performance (vibration-induced) of small-bore attachments and to obtain data to assess if the performance is reduced as a result of hydrogen exposure.

Key aspects

The work package will produce data on the effects of hydrogen exposure on small-bore branch connections when subject to a high frequency excitation force to simulate pipework vibration loading. A 610mm OD x 11m long test vessel will be fabricated. The test vessel will include ten welded attachments with a range of sizes, onto which a typical pipe configuration.

When the test vessel has been hydrogen saturated the internal hydrogen pressure will be increased to test pressure and then vibration generators attached to each branch connection to produce the required high frequency vibration loading. By monitoring strain gauges attached to the branch pipes the frequency and amplitude of the vibration will be measured.

The test will run until a branch connection fails, this will then be repaired, and the test continued until all the branches have failed or representative number of cycles have been achieved.

Figure 19. WP1 Tee Fatigue Test Vessel

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Key learnings to date

- Natural frequency calculations for different connection types / geometries
- Design of complex external loading system

Looking forward

- Completion of fatigue testing programme

Work Package 4 – Vent and flaring trials

Figure 20. Venting / flaring trials

Objective

The vent and flaring work package will investigate the thermal radiation, noise and overpressures generated when hydrogen is vented and flared under pressure. This data will enable direct comparisons to be made with natural gas venting and flaring data and provide information for QRA's.

Key aspects

The aim of the vent and flaring work package is to collect data on the following:

- The noise spectrum and noise level at 100 m distance for hydrogen vent and flaring operations.
- The overpressure generated when delayed ignition is experienced with venting and flaring operations.
- The thermal radiation generated from hydrogen flaring operations.
- Good quality normal and high speed video of unignited and ignited plumes.

Key learnings to date

- Noise and overpressure measurements were recorded and subsequently analysed

Looking forward

- Technical reporting of tests conducted

Work Package 5 – Performance testing of pressure regulator equipment

Objective

The aim of this work package is to establish if existing pressure reduction units can function correctly when operating with hydrogen and if the units can accommodate the higher flow / velocity required

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to transmit the same amount of energy as natural gas. The testing will establish if there are any instabilities in the sensing instrumentation and whether the units experience vibration or noise issues as a result.

Key aspects

To perform these tests an experimental arrangement is currently being designed, which though not finalised, will be based on the following:

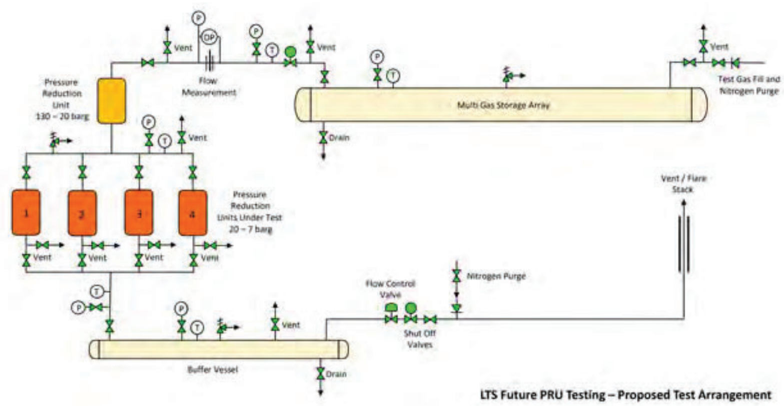

Figure 21. Example of pressure regulator experimental arrangement

Key learnings to date

- Design feasibility for test rig complete.

Looking forward

- Detailed design of test rig, then construction and commissioning
- Implement test programme

Element 4 - Live trial

The key characteristics and deliverables of the live trial are illustrated in the diagram below:

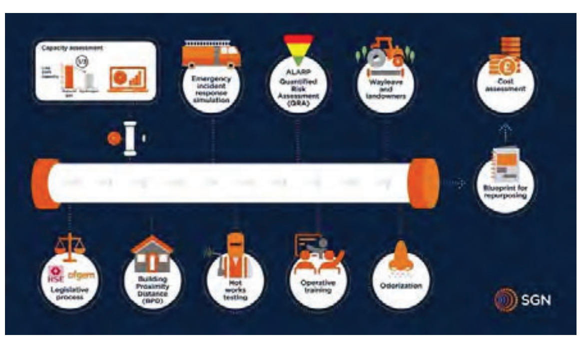

Figure 22. Live trial – key characteristics

Objective

To address the following:

- Purging / Commissioning

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- Venting/Flaring,
- Maintenance/Operations (i.e. split tee and drilling / stoppling)
- Emergency Response
- Decommissioning.

Key aspects
In order to carry out the live trial, the capability, competence and resilience of the systems, organisation and people involved in the proposed repurposing must be confirmed as acceptable. Operational, maintenance and emergency procedures are required to ensure safe management. These procedures must be applied to actual features on real pipelines by people who need to be trained.

The live trial will validate a number of the previous findings and conduct various simulations, training and exercises. The three main exercises carried out on the demonstration pipeline will be: an emergency response simulation, line pack tests and hot working onto the live hydrogen pipeline.

Key learnings to date
- Not yet commenced.

Looking forward
- Live trial to be conducted Q4 2024 / Q1 2025

Element 5 - QRA and Case for Safety

Objective
To develop a quantified risk assessment (QRA) and Case for Safety, for regulatory review.

Key aspects
Pipeline Safety Regulations (PSR 1996) & Gas Safety and Management Regulations (GSMR 2015) [3] require gas transporters have a fully defined 'safety case' to ensure the safe operations of pipelines that are kept well maintained and good state of repair. These regulations set the required principles for safe operation of pipelines which filter down into a hierarchy of further detailed and defined sets of standards and specifications (such as BS, ASME, IGEM etc.) which cover a wide range of engineering and safety parameters to be compliant with. These standards fundamentally require that any change in service or operating conditions of high pressure pipelines must have a safety evaluation carried out.

Key learnings to date
- QRA of the 3" supply line and the 3 most populated locations along the Grangemouth to Granton pipeline has shown that risk levels are broadly acceptable despite using conservative factors on failure frequency and conservative assumptions on ignition probability.
- A draft Case for Safety has been developed in accordance with the framework agreed with the UK safety regulator (HSE) that incorporates key information from the other elements of the project.

Looking forward
- The QRA conservatisms are expected to be reduced following the conclusion of material and full-scale test programs.
- The Case for Safety is a living document that will be updated as required.

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- Any existing procedures referred to in the Case for Safety will be reviewed and amended for hydrogen use as required prior to the live trial.

Element 6 – Knowledge dissemination

Objective
Sharing knowledge with stakeholders, e.g. other operators, government agencies and wider industry.

Key aspects
LTS Futures will liaise with associated projects including FutureGrid, H100 Fife, H21 and Hy-Deploy, ensuring that knowledge dissemination, continuity of learning, complementary scopes and co-ordinated timelines are achieved across the projects. Engagement with key stakeholders on a site-specific, regional and national level will cover disciplines of statutory consultees, local authority, political, industry, regulatory bodies, local community, public and customers, and other project stakeholders.

Key learnings to date
- Several stakeholder (internal and external) engagement exercises have been conducted which have encouraged a two-way communication process, giving SGN the opportunity to explain the project purpose and its objectives, whilst enabling feedback and challenge / review
- Several conference papers are being prepared to provide shared learning.

Looking forward
- Further stakeholder engagement exercises are to be conducted prior and post the live trial.

Development of the LTS Futures Blueprint
The key requirements for the Blueprint are:
1. Capacity Assessment – Determine whether the required capacity for future energy delivery is sufficient at the current pipeline maximum operating pressure (MOP).
2. Data Assessment – Identify the data required to complete the application of the Blueprint, including route survey, availability of original design and construction records and operations and maintenance records required by pipeline standards. In particular, the records which are essential to completing the assessment.
3. Integrity Assessment – Perform fitness for service assessments for the impact of hydrogen on materials, based on material test results (to be developed under LTS Futures Elements 2 and 3); and for all existing damage and defects, taking account of degradation of material parameters due to hydrogen embrittlement.
4. Quantified Risk Assessment – Calculate the individual and societal risks posed by operation in hydrogen service, and confirmation that the risk levels are As Low As Reasonably Practicable (ALARP). Where risks are not ALARP, identify the required mitigation actions to reduce risk levels.
5. Safety Justification – Taking into account the outcome of previous steps, detail all modifications required to justify that the assets will be acceptable for future operation in hydrogen service from a safety perspective.
6. HSE Liaison – Follow the notification procedure required by HSE, develop and agree the Blueprint methodology with the HSE, and HSE review and comment on documentation produced as part of the Blueprint application process.

Key learnings to date

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- The majority of the data required for pipeline repurposing should be referenced in the TD/1 MOP Affirmation audit. Availability and accessibility of records has been variable.
- There is not a requirement for installations to be formally audited and assessed under IGEM/TD/13 (as it is for pipelines under IGEM/TD/1). This can result in fragmented records.
- Good quality TD/1 reports are an important element in demonstrating that a pipeline can be repurposed.

Looking forward

- The LTS Futures Blueprint will be further updated at key project stages.

Conclusions and final remarks

The key outcome of the LTS Futures programme will be the development of a Blueprint for repurposing, and in developing the Blueprint the project will demonstrate the safety, technical, commercial, regulatory and operational requirements for repurposing an LTS transmission pipeline. These outcomes are essential for demonstrating the compatibility of the LTS in a hydrogen environment and provide political and investor confidence in decarbonising industrial clusters and the potential for LTS networks to play a role in the future energy systems.

This project aims to generate learning for industry, government, regulatory bodies, stakeholders and the public, on both a national and international level to help inform the UK energy transition. While the LTS Futures project is not exhaustive, the programme covers an extensive (breadth and depth) scope of works that will be transformational in validating the evidence base for hydrogen in the UK gas networks. Of primary importance will be the demonstration that the Grangemouth to Granton pipeline can be repurposed safely, securely and cost effectively to transport 100% hydrogen in the same way that natural gas is transported in the LTS by gas distribution networks today.

The live trial of the Grangemouth to Granton pipeline will provide the majority of this learning, as this trial represents typical LTS operating conditions in terms of the route, and operation and maintenance activities.

The programme seeks to:

1 Provide evidence to determine the safety and suitability of LTS network assets for hydrogen culminating in a live trial to prove the practical and operational aspects.

   a. Develop a methodology (blueprint) for future repurposing projects, ensuring safety, efficiency and applicability throughout the Great Britain
   b. Determine the suitability of LTS materials for 100% hydrogen
   c. Validate the operational strategy for operating a hydrogen network, identifying any differences from operating a natural gas network
   d. Develop the skills and competencies for managing, operating and maintaining assets in the hydrogen economy, with the procedures required to support it

2 Provide the technical foundation and investor confidence to support delivery of industrial cluster decarbonisation in:

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a. Development of knowledge and acceptance of hydrogen within the public, industry, standards bodies and regulatory agencies
b. Development of an optimised and validated cost model for future repurposing projects
c. Provision of visibility of the commercial and regulatory aspects for future operation of repurposing hydrogen networks, this insight will support future regulatory models
d. Commencing the understanding of the interface and commercial arrangements with hydrogen suppliers

3 Defining the role of LTS in system transformation and facilitate industrial clusters by:
a. Identifying the requirements the regulatory (safety, commercial and environmental) framework required for the GB Hydrogen network in terms of
  i. Compliance with Pipelines Safety Regulations
  ii. Compliance with Pressure Systems Safety Regulations
  iii. Identify any modifications required to the Gas Safety (Management) Regulations or other legislation
  iv. The Land Use Planning and Planning consent process

b. Confirming whether a repurposed LTS will deliver the required operating pressures, flowrates and linepack to facilitate the green recovery

Acknowledgements
The authors would like to acknowledge the contribution of the following to this complex project:-

SGN: Antony Green, Max Koronka, Sophie Bladon, David Wylie, Craig Henderson, Craig Keating, Steve Howells
PIE: Nikki Barker, Tony Stonehewer, Graham Goodfellow, Chris Lyons, Chris Hughes, Peter Boothby
DNV: Clara Huéscar Medina, Adam Robinson, David Hall, Sarah Kimpton
ROSEN: Mark Atkinson
TWI: Jonathan Wilson
NGS: Ashley Burnhope
TDW: Jamie Bull
Stats Group: Neil Mackay
Steer Energy: Nick Ryan
Premtech; Martin Nicholson

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