Classified as External

LTS Futures

LTS Futures NZASP Submission

31st October 2021

SGN

Your gas. Our network.

Key Contacts:

Nancy Thomson, LTS Futures programme lead
Nancy.thomson@sgn.co.uk

Angus McIntosh, Director of Energy Futures
Angus.mcintosh@sgn.co.uk

David Handley, Head of Regulation
David.handley@sgn.co.uk

Document Control

Version	Status	Date	Author(s)	Summary of Changes
1	Final Draft	31/10/2021	Nancy Thomson Angus McIntosh Steven Howells Courtney West David Handley	
2	Final Draft	1/11/2021	Nancy Thomson	Amendments to typographical errors in finance tables

Reviewers

Name	Job Title	Email
Angus McIntosh	Director of Energy Futures	Angus.mcintosh@sgn.co.uk
David Handley	Head of Regulation	David.handley@sgn.co.uk

Management Approval

Name	Role	Signature
Angus McIntosh	Director of Energy Futures	Angus.mcintosh@sgn.co.uk
David Handley	Head of Regulation	David.handley@sgn.co.uk

Contents

1 Executive summary

The LTS Futures Project forms part of the UK's national hydrogen research programme to deliver a Net Zero decarbonisation solution for customers. The project seeks to research, develop, test and evidence the compatibility of the Local Transmission System Assets (LTS) assets, pipelines, associated plant and ancillary fittings, culminating in a 'first of a kind' repurposing trial and demonstration.

The aim of the project is to demonstrate that the LTS can be repurposed and potentially uprated to convey 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.

This is a critical part of the national hydrogen research programme. The LTS is currently fundamental to transferring hydrogen within a Local Distribution Zone (LDZ). If the LTS cannot be readily converted, then the LTS would require replacement, which we estimate will cost £19bn (for all GDNs). Alternatively, the consumption of hydrogen could remain localised to the points of production with associated storage facilities necessary to ensure security of supply on a local level. While the cost of LTS replacement is significant, the total system transformation costs for hydrogen are dominated by the production and downstream aspects.

Our current estimate is that if the LTS can be converted to transfer hydrogen then the cost of repurposing the LTS network will be between 15% and 30% of the costs of replacement, significantly reducing the costs of decarbonisation through the hydrogen pathway. The live trial will give us a much greater understanding of the actual cost and potential for repurposing and uprating the network, and in doing so, inform the system transformation.

The LTS Futures programme will provide critical and scalable understanding of the local transmission network's compatibility for transporting hydrogen, any design changes that would be required to enable safe operation, and the appropriate maintenance and inspection regimes to ensure it continues to operate in a safe manner.

This project intends to repurpose the [redacted] to [redacted] pipeline for the live demonstration. This pipeline runs from the [redacted] to [redacted] located on the outskirts of Edinburgh. This pipeline offers an ideal opportunity for the live trial due to its inherent characteristics and is an excellent proxy for the GB LTS. The trial aims to validate the research and provide a blueprint (methodology) for repurposing and uprating the 11,000km of pipelines in the GB LTS network.

A further important point of learning from the live trial is to understand the potential of line-pack when operating with hydrogen. Line-pack is the compression of gas within the network during periods of low demand to supply high demand periods. This is a critical point of energy storage within the current energy system. The 30 km [redacted] to [redacted] pipeline provides a sufficient length to enable the line-pack potential to be tested and the potential for storage through line-pack using hydrogen to be assessed.

A related and important point of learning is the assessment for potential uprating of the LTS system to increase both the delivery and linepack capacity. The project will investigate the potential of increasing the maximum operating pressure (uprating) of the pipeline and blueprint for doing so on a pipeline-by-pipeline and component basis. An assessment of the potential for uprating the entire GB LTS will be undertaken to identify the additional capacity and storage that could be achieved through this method.

By operating a live trial on a statistically representative LTS pipeline in a real-life environment with all the associated operational issues this project will give confidence to customers, policy makers and potential investors in the hydrogen.

The programme has an estimated cost of £28.15m over 3 years starting 1st April 2022 and will look to fully conclude in 2025 ahead of the UK Government heat policy decisions.

The project will consist of:

- **Element 1**: Live trial design [redacted]

- **Element 2**: Lab material testing [redacted]
- **Element 3**: Offsite testing [redacted]
- **Element 4**: Live trial (first of a kind repurposing trial and demonstration including uprating) [redacted]
- **Element 5**: QRA, Case for safety [redacted]
- **Element 6**: Knowledge dissemination [redacted]

By utilising a statistically representative pipeline for a live demonstration and combining this with trial data from laboratory testing results and offsite tests [redacted] we are able to achieve the greatest reach in terms of understanding how the LTS network will respond to hydrogen. This will enable the development of the commercial, regulatory and safety models for future operation of hydrogen network which will provide a blueprint (methodology) for repurposing and uprating the 11,000km of pipelines in the GB LTS network.

The overarching ambition is to develop the blueprint for repurposing and uprating by:

1. Providing 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;
2. Providing the technical foundation, political and investor confidence to support delivery of industrial cluster decarbonisation; and
3. Defining the role of LTS in a hydrogen system transformation.

2 Project description

The LTS Futures Project forms part of the UK's national hydrogen research programme to deliver a net zero decarbonisation solution for customers. The project seeks to research, develop, test and evidence the compatibility of the Local Transmission System (LTS) assets, pipelines, associated plant and ancillary fittings, culminating in a 'first of a kind' repurposing trial and demonstration.

The aim of the project is to demonstrate that the LTS can be repurposed to convey hydrogen, providing options for the decarbonisation of power, industry, heat and transport by delivering a safe supply of energy to all fcustomers both during, and after, the energy transition. The project will consist of:

- **Element 1**: Live trial design [redacted]
- **Element 2**: Lab material testing [redacted]
- **Element 3**: Offsite testing [redacted]
- **Element 4**: Live trial (first of a kind repurposing trial and demonstration including uprating) [redacted]
- **Element 5**: QRA, Case for safety [redacted]
- **Element 6**: Knowledge dissemination [redacted]

The total project cost will be £28.15m over a period of 3 years.

This project will build on the research already carried out, addressing the gaps identified and use this information to repurpose a statistically representative pipeline between [redacted] to [redacted] for the live demonstration. This will validate the research and provide a blueprint (methodology) for repurposing and uprating the 11,000km of pipelines in the GB LTS network providing the technical foundation, political and investor confidence to deliver industrial clusters and the system transformation.

3 Statement of needs

3.1 Problem definition

In June 2019, the UK became the world's first major economy to legally commit to cutting greenhouse gas (GHG) emissions to net zero by 2050[1]. The Scottish Government has committed to net zero GHG emissions by 2045[2]. A major system transition away from natural gas to hydrogen gas is required for these ambitious targets to be met.

It is widely recognised that hydrogen could offer a lower cost and lower disruption option for customers compared to other technologies (Appendix A and B). Decarbonisation of the gas network offers a credible least cost solution to support the transition to net zero.

It is necessary to understand compatibility across the spectrum of assets and operations, to what extent they can play a role in any system transformation and the cost.

The LTS is an essential network asset that delivers energy to towns and cities across GB. The processes, systems, facilities, technologies, assets, networks and services of the LTS are critical national infrastructure.

3.2 National and local transmission systems

The GB natural gas network is comprised of the National Transmission System (NTS) owned by National Grid, which currently connects the onshore terminals where natural gas currently enters the country with the Gas Distribution Networks (GDNs). The LTS operated by the GDNs currently takes the natural gas from the NTS and

[1] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law
[2] https://www.gov.scot/policies/climate-change/

transports it to the towns and cities where it supplies the lower pressure networks for the transportation of the gas to customers. As hydrogen becomes the preferred fuel, then a network of pipelines will be required to transport hydrogen from the major producers to the town and cities. With over 11,000km of LTS pipelines the current LTS is well placed to become that hydrogen network.

Figure 1 shows the NTS network of 7,600km of pipelines and the 11,000km of LTS pipelines, of which, SGN operates over 3,000km of pipelines in Scotland and Southern England.

Figure 1-Transmission systems in GB

In a system transformation, there are various potential end states, all of which require either entirely new transmission assets or a combination of repurposed and new. Although in any end state there will be a need for new pipelines to connect to new sources, the extent of repurposing will be determined by the SGN LTS Futures Programme and the National Grid FutureGrid Project[3]. Figure 2 illustrates how a potential future end state scenario for 100% hydrogen may look. This project seeks to provide a methodology blueprint to enable any LTS pipeline to be repurposed and uprated.

A safe, reliable demonstration of hydrogen in LTS pipelines is therefore a key evidentiary component of the role the LTS can play in the net zero solution and how the system can be transformed.

[3] https://www.nationalgrid.com/uk/gas-transmission/insight-and-innovation/transmission-innovation/futuregrid

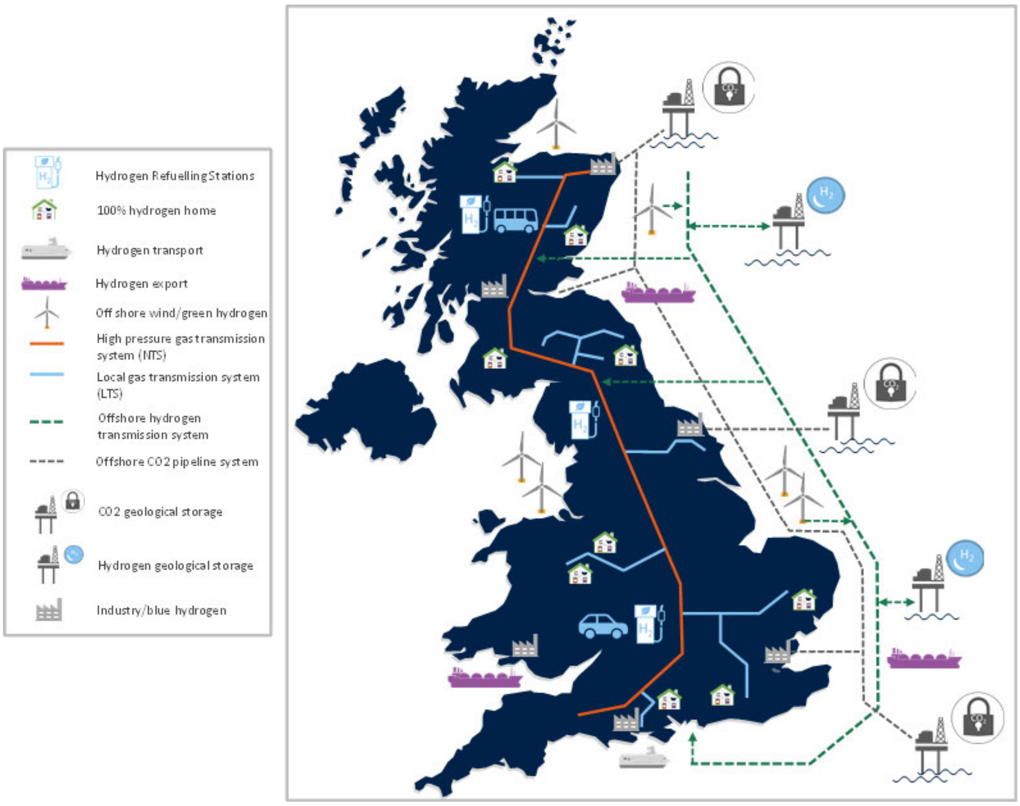

Figure 2-Potential future hydrogen system transformation

3.3 Development of programme to date

The LTS Futures Programme is the leading national endeavour investigating LTS suitability for conversion to hydrogen. The programme has been developed with input from a spectrum of industry experts, from pipeline operators to academia and is designed to develop the safety, technical and practical evidence to accommodate hydrogen in the LTS and deliver a blueprint for repurposing and uprating GB LTS infrastructure. The outcomes will provide the technical foundation and the political confidence to support delivery of industrial cluster decarbonisation[4] and attract the investors necessary to deliver.

The key outcome of the project will be a blueprint for how the GB LTS infrastructure can be repurposed and potentially uprated, with a refined cost estimate. This will define the role of LTS in system transformation in the longer term.

Figure 3 below shows the LTS Futures programme road map which is detailed further in sections throughout the submission.

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

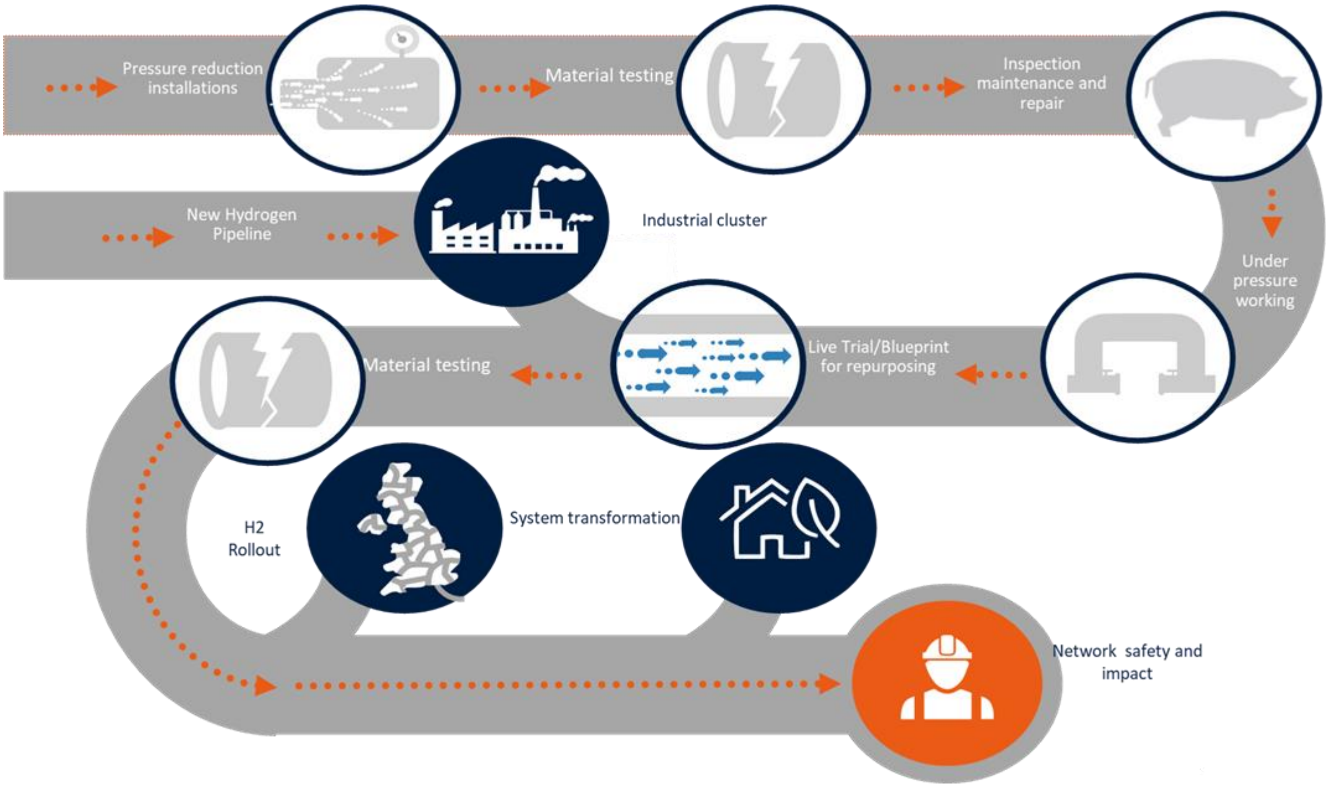

Figure 3-LTS Futures programme roadmap

Background

In May 2020 we completed the NIA funded Phase 1 of Future of the LTS project which considered repurposing the LTS for the transportation and storage of hydrogen or carbon dioxide. The scientific and regulatory feasibility study included a desktop assessment of both the compatibility of the materials and the risks posed to people by pipeline failure. The report concluded that a significant percentage of SGN's LTS network consists of relatively low-strength pipeline grades that operate at low stresses. Both factors are conducive to the pipelines' 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.

Case studies were used to test pipeline risk assessment methods and to bridge any gaps in existing knowledge. These case studies included the nitrogen filled [redacted] to [redacted] pipeline, which has been identified as having potential to be repurposed for hydrogen transportation.

We held a workshop in February 2020 to share the findings of the work and to identify any further gaps. An SGN chaired IGEM group called 'LTS Futures' has been established; this comprises membership from all the gas distribution networks, HSE, BEIS and other industry bodies.

The second phase of work, "HyTechnical", has recently concluded and 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.
    d. Venting, reviewing the SR/23 venting standard
2. Development of hydrogen supplements to gas industry standards (TD1, TD3, TD4 and TD13)

3. Updating of SR/25 hazardous area standard for hydrogen.

The HyTechnical project was a foundational feeder project for the programme led by SGN in collaboration with all gas network operators including NGGT, to develop the draft industry standards to design, build and construct new hydrogen pipelines and repurpose existing pipelines. LTS Futures Programme has, in collaboration with the GDNs, National Grid, IGEM, HSE, BEIS and industry experts, set out the further research required to support the transformation of the gas network and has been the foundation of the programme.

GB's LTS network dates from 1950's and over the year's pipelines have been manufactured to varying quality standards. Therefore, existing assets may not be manufactured and welded to the same quality as equivalent pipe today. To understand if these pipelines can be repurposed for hydrogen transportation, material testing and further analysis is required. Material testing of existing pipelines of this vintage is necessary to understand how they will behave when distributing hydrogen.

We are currently testing 1970 seamless X52 pipe from a recent SGN diversion project, in partnership with the University of Strathclyde. This pipeline sample is of similar material to the [redacted] to [redacted] pipeline. It is known that hydrogen embrittlement (a hydrogen failure mechanism) is more susceptible to cold worked areas such as dents, welds, cold bends therefore testing will be pre-strained areas. This will provide evidence towards the defect acceptance criteria that will be developed under Element 2 and 3 under the LTS Futures project. Figure 4 below encompasses the work completed by HyTechnical as well as the material testing completed in the laboratories.

The LTS Futures project was identified within the SGN RIIO-GD2 plan[5], formed through wide ranging engagement with customers and stakeholders. The project is identified as a critical evidentiary project within the BEIS Hydrogen R&D Programme (see Figure 5) and is supported by National Grid Gas Transmission (NGGT) and all (GDNs).

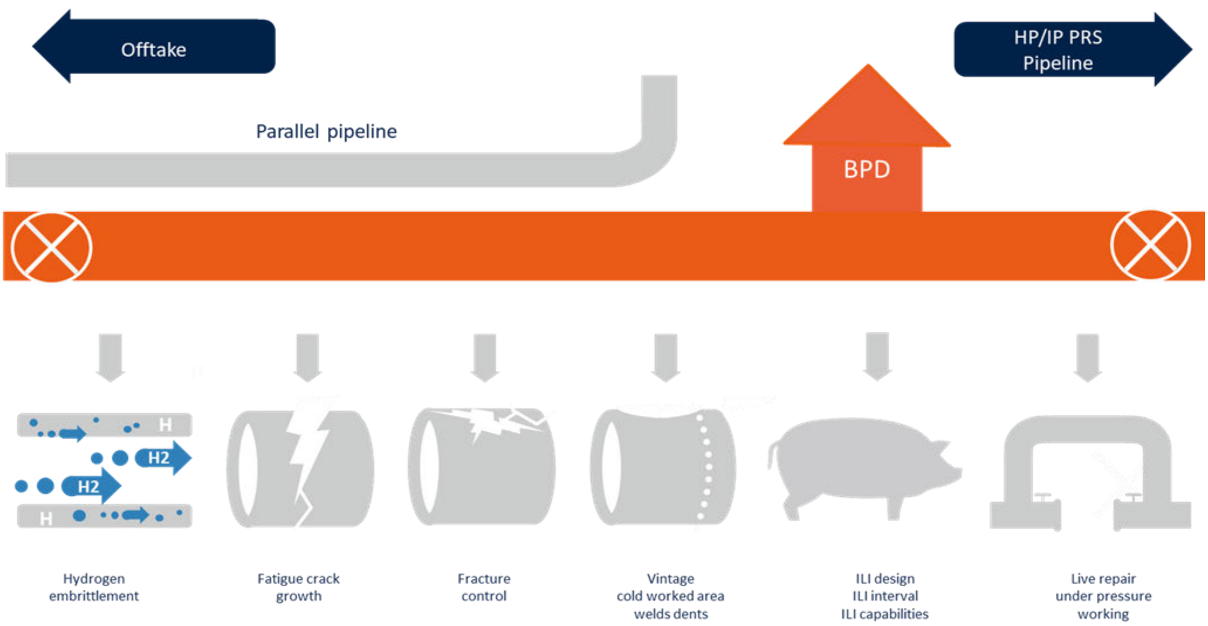

Figure 4-LTS Futures HyTechnical and Material Testing NIA

[5] https://www.sgnfuture.co.uk/wp-content/uploads/2019/12/SGN-RIIO-GD2-Business-Plan.pdf

or

https://www.sgnfuture.co.uk/wp-content/uploads/2019/12/Appendix-006-SGN-Energy-Systems-Transition.pdf

[redacted]

Figure 5-UK's national hydrogen research programme

The LTS Futures programme has been developed with HSE, BEIS and Subject Matter Experts (SME's) to ensure all known gaps have been identified and incorporated into the scope. We aim to close these gaps through a combination of laboratory testing, offsite testing and the live trial of the [redacted] to [redacted] pipeline. Figure 6 illustrates testing feeding into full system transformation of the network to 100% hydrogen, in addition to key learnings from the FutureGrid project assessing NTS assets and pipelines for hydrogen.

This 'first of a kind' demonstration project will deliver a LTS repurposing and potential uprating blueprint methodology that can be replicated and used to mobilise hydrogen market growth.

[redacted]

Figure 6-Key stakeholders and groups developing LTS Futures testing feeding system transformation of the network

The safe operation of future transmission and distribution networks is of paramount importance when aiming for public acceptance of this low carbon energy vector for decarbonisation of heat and other critical sectors. The Health and Safety Executive (HSE) has completed a gap analysis and review of the National Hydrogen programme, at the request of the Department of Business, Energy and Industrial Strategy (BEIS). HSE findings were published in the report Safety Assurance Protocol & Gap Analysis in November 2020, identifying a number of key considerations that must be explored in order to develop the Hydrogen Grid Research and Development programme prior to significant decisions on future Heat Policy decisions due in 2025.

The project team were keys stakeholders in HSE Gap Analysis and provided input. 65 safety considerations were identified by HSE across all asset categories/activities. These have been assessed to determine if and how they are addressed in the LTS Futures Programme. 31 of the 65 considerations are addressed in the scope of the LTS Futures project, and a further 8 are partially addressed. The considerations which are not considered are not within the scope of LTS Futures, i.e. they are outside network scope, or relate to lower pressure tiers, new technologies and materials and network conversion.

3.4 LTS pipeline life transporting hydrogen

The life of LTS pipelines transporting hydrogen is dependent on the fatigue damage caused by cyclic stress due to cyclic pressure. Current research has shown that the fatigue life in hydrogen service is expected to be lower than that in natural gas service.

The LTS Futures project will carry out further research to determine the potential reduction in fatigue life for pipelines in hydrogen service. A more detailed explanation is given in Appendix C.

3.5 Increasing capacity/uprating hydrogen

Pipeline capacity pertains to both energy delivery capacity (volumetric) and linepack capacity (stored energy). Both are dependent on the pressure and flowrate within the pipeline. The LTS Futures project includes an uprating study applied to both the offsite testing [redacted] and the [redacted] to [redacted] pipeline trial to investigate the potential improvement in energy delivery and linepack capacity from increased pressure and flowrate, and how this will impact on the pipeline and associated LTS components (such as PRS). Further details are given in Appendix D.

3.6 Project technical description

The aim of the project is to demonstrate that the LTS can be repurposed to convey hydrogen and potentially uprated, 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.

One key aspect of the programme involves repurposing the [redacted] to [redacted] LTS pipeline to hydrogen. The live trial will intend to validate laboratory and offsite testing element outputs and develop a blueprint methodology for repurposing and uprating existing LTS pipelines to hydrogen. Further technical description of why [redacted] to [redacted] pipeline is the optimal pipeline for testing can be found in Appendix E.

Project design

The project has been designed around 6 elements; these elements are considered separately for project planning purposes but are highly interlinked in-terms of delivery. The project will consist of:

- **Element 1**: Live trial design
- **Element 2**: Lab material testing
- **Element 3**: Offsite testing [redacted]
- **Element 4**: Live trial (first of a kind repurposing trial and demonstration)
- **Element 5**: QRA, Case for safety
- **Element 6**: Knowledge dissemination

Element 1: Live trial design

The Live Trial Design element consists of two parts:

a. Design of the hydrogen supply pipeline and components
b. Preparatory works and design of the repurposing the [redacted] to [redacted] pipeline

Hydrogen supply

Several options to supply hydrogen for the [redacted] to [redacted] live trial have been identified, each with its own challenges and complexities as detailed in Appendix F.

Following comprehensive analysis, the best value for money and most practical solution is to supply hydrogen via a direct pipeline connection [redacted]. A supply of hydrogen via pipeline would consist of:

This option would include:

- A <3” steel pipeline from the supply point [redacted] to the entry equipment site. [redacted]
- Land and planning consents
- Steel high pressure pipework to connect the incoming 3” supply pipeline to the metering and odorization skid and the whole site to the [redacted] to [redacted] pipeline.
- Concrete hardstanding and road to [redacted] emergency gate and security fencing.
- Site office and welfare facilities. An E&I kiosk containing the flow computer for the metering and all other instrumentation and electrical equipment required.
- An incoming power supply kiosk.
- Ducting for E&I cabling.
- an entry unit will be installed at a suitable point along the new 3” pipeline. The entry unit will include inter alia:
  - **a pressure control system** to reduce the pressure of hydrogen from the [redacted] tie in to [redacted] to [redacted] pipeline. [redacted] pressure control will be required to reduce hydrogen pressure below [redacted] to [redacted] MOP.
  - **a temporary flare and/or connection to the refinery fuel gas system** to dispose of hydrogen after the completion of live trial operations on the [redacted] to [redacted] pipeline. The connection to temporary flare and/or connection to the refinery fuel gas systems also provides a flow within the pipeline to support hot working demonstration and line pack validation calculations.
  - **instrumentation and control system** to carefully monitor pipeline filling and control linepack/uprating assessments on the [redacted] to [redacted] pipeline.
  - Hydrogen measurement unit which will include

    c. flow meter,
    d. chromatograph,
    e. flow computer,
    f. odorisation unit

Under Element 1 we will design all aspects of the hydrogen supply and the live trial

[redacted]

Preparatory works and design for repurposing and uprating the [redacted] to [redacted] pipeline

Repurposing and uprating the [redacted] to [redacted] pipeline will require an integrity and condition assessment and remediation of the [redacted] to [redacted] pipeline to support the design of the trial in accordance with the requirements of the IGEM/TD/1 and Supplement 2 for Hydrogen (developed under HyTechnical). These preparatory works are necessary to demonstrate the case for safety prior to repressurising, repurposing and uprating the pipeline to hydrogen service under the live trial element. A number of preparatory works required on the pipeline are illustrated in Figure 8 below.

[redacted]

Figure 8 [redacted] to [redacted] remediation works for repurposing

Repurposing/Uprating works required involve inter alia:

- Specification and completion of modifications to enable in line inspection of the pipeline
- In-line inspection of the pipeline;
- Hydrotest;
- Assessment of inspection and condition results to confirm the pipeline operating pressure can be reinstated;
- Cut out of the material to be tested in the lab (Element 2);
- the development of the primary blueprint requirements for repurposing LTS pipelines taking account of material degradation factors and the pipeline hydrogen hazard zone as identified in the HyTechnical project;
- Determine intervention for any damage or defects in the pipeline identified by the inspection for fitness for purpose in hydrogen service;
- Specify and complete any repairs and/or remedial works required;
- identify any population infringements [redacted] within the hydrogen hazard zone of the pipeline;
- Specify and install risk reduction measures required at infringements in order to satisfy land use planning requirements;
- Assessment of the potential to uprate the [redacted] to [redacted] pipeline, and assessment of the impact this may have on linepack storage and downstream supply.
- Specification, design and installation of pipeline modifications for repurposing and uprating,

- Notification of the intended repurposing of the [redacted] to [redacted] pipeline to the HSE as required under the Pipelines Safety Regulations (PSR);
- Preparation of the Major Accident Prevention Document (MAPD) and case for safety.
- Policies and procedures will be developed for the trail to ensure safe operation and activities undertaken as part of the trial, for example: commission, purging, venting, live welding, maintenance, inspection etc
- Develop supporting operative training requirements
- Training of all involved in the live trial.

The above activities are required for compliance with Pipeline Safety Regulations (PSR) and requirements will be fully detailed in the repurposing and uprating blueprint.

Element 2: Laboratory material testing

The material properties (such as fracture toughness and ductility) of the pipeline are key characteristics that affect how pipelines' respond to external loads and tolerance to defects. Material testing is required to confirm that any degradation of material properties is acceptable for future service. The limits are set by the values of fracture toughness and ductility at failure, so destructive testing of small-scale material samples is essential.

Material tests will determine the failure point with hydrogen. This in turn will influence the acceptability of defects (acceptable, or repair, or replace) and provide the relationship between the two parameters and associated tolerance, which will be incorporated into the QRA and blueprint.
The safety margin of the live trial pipeline will be determined and demonstrated using the material failure limits measured in the laboratory testing.

As discussed above, the [redacted] to [redacted] pipeline is considered to be of excellent baseline material due to its vintage, X52, and large diameter/thin wall combination. Other LTS material types (seamless, seam welded) and grades (B, X24 & X46) are less susceptible to issues with hydrogen service, however, other material types (seamless and seam welded) will be tested to ensure correlation and tolerances of acceptability within the QRA and blueprint. The results will 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.

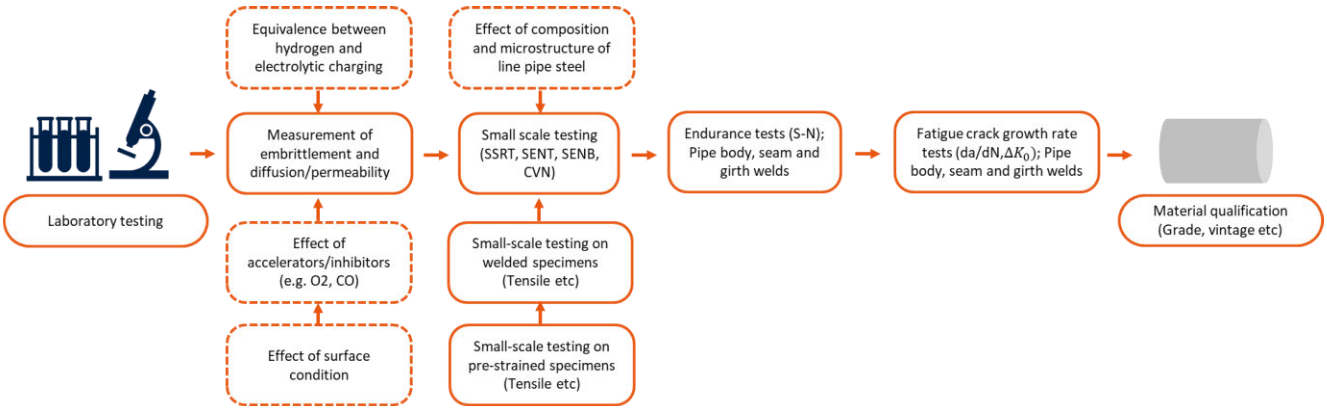

Figure 9-Laboratory material testing

Element 3: Offsite testing

Offsite tests are carried out in an environment remote from the public to investigate events which may cause failure and to understand the consequences of these. Following testing, operational, maintenance and emergency procedures will be developed to: i) ensure dangerous events are avoided, ii) if they occur the consequences are managed, and iii) identify essential mitigations. The offsite testing will require validation through a controlled and safety assessed demonstration at the live trial. It is important to note that the live trial will not be a test of safety at failure conditions.

[redacted]

A programme of specific hydrogen hot working tests, hydrogen release tests and equipment operability and functionality tests will be carried out [redacted] Existing infrastructure will be used to minimise the cost of construction, with the site already [redacted] utilised test rigs. The addition of the LTS component and ancillary fittings completes the site from system entry to end user. How these fit with the existing site is illustrated in Figure 11 below.

[redacted]

Figure 11-Offsite testing

All the offsite testing will be validated through the live trial in a controlled environment. Offsite testing will include the following:

- Hot work testing
- Delayed ignition causing potential overpressure from hydrogen vent stack testing
- Stabbings and auxiliary fitting vibration testing
- PRS operability and functionality testing
- Burst and fatigue tests of defects
- Hydrogen measurement unit

Further details of testing technical description can be found in Appendix G.

Element 4: The live trial
The live trial will be in a controlled environment where the security of supply and customer risk in relation to security of supply (no customer will require interruption) has been removed.

The Live Trial will:

- Construct, lay and test the new hydrogen supply pipeline and entry unit, designed under the Live trial design (Element 1).
- The new hydrogen measurement unit will be transported and installed after being tested and calibrated at the offsite testing (Element 3)
- Install temporary pig traps for commissioning and returning the pipeline back to filled with nitrogen;
- Commission the new 3" supply pipeline as designed, initially with nitrogen, before purging with hydrogen and venting (learnings taken from the offsite testing Element 3).
- Commission the [redacted] to [redacted] with hydrogen from the new supply pipeline;
- Meet the operation and maintenance requirements for the pipeline in hydrogen service (learning takes from offsite testing Element 3);
- Measure the quality and volume of hydrogen required to pressurise the pipeline to support validation of the network analysis model and the prediction of linepack storage;
- If earlier phases are successful in demonstrating the potential for safe uprating of the [redacted] pipeline, increase the operating pressure to the derived Maximum operating pressure (MOP).
- Uprate the [redacted] to [redacted] pipeline to validate the capacity studies, measuring flow, volume and gas quality to understand increased capacity and linepack effect at higher pressure
- Carry out a hot work trial on the pipeline to validate the hot work procedure results obtained in Element 3;
- Carry out an emergency incident response simulation involving all internal and external stakeholders:

Once all the required tests have been completed the [redacted] and [redacted] pipeline the pipelines will be purged, vented and filled with nitrogen and temporary flare will be removed. The hydrogen measurement unit will be decommissioned and removed. Figure 13 shows the end of project infrastructure.

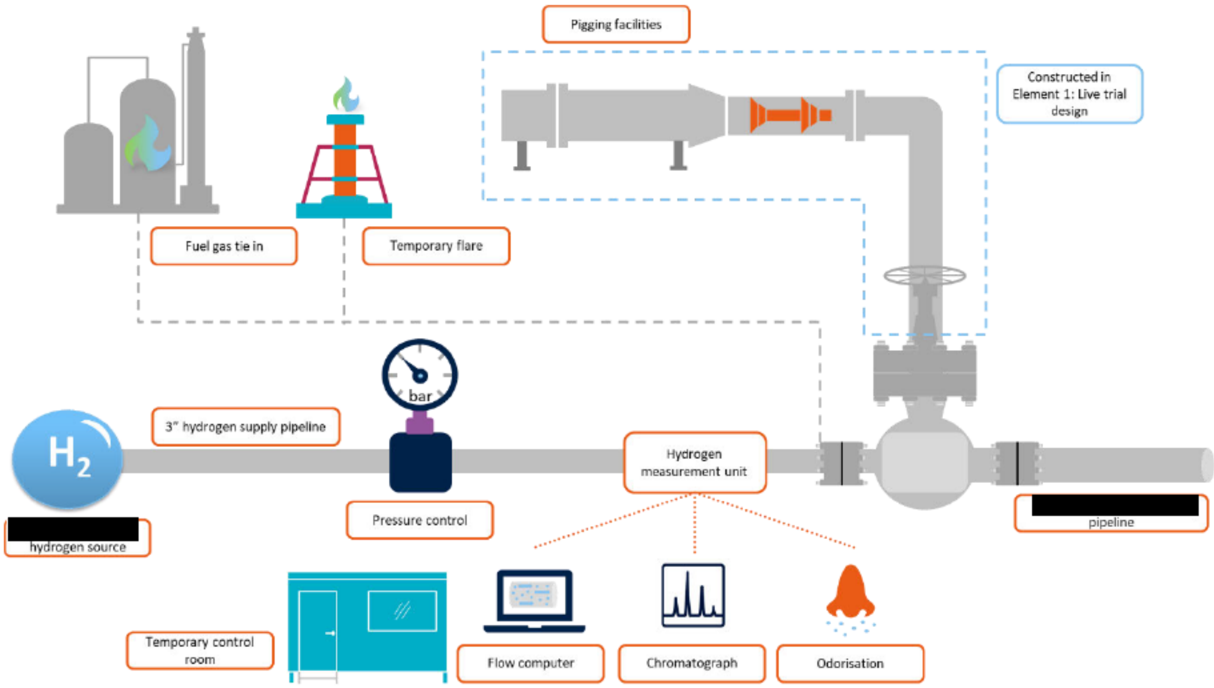

Figure 12-Hydrogen supply and entry unit components for [redacted] to [redacted] live trial operations

Once all the required tests have been completed the [redacted] and [redacted] pipeline the pipelines will be purged, vented and filled with nitrogen and temporary flare will be removed. The hydrogen measurement unit will be decommissioned and removed. Figure 13 shows the end of project infrastructure.

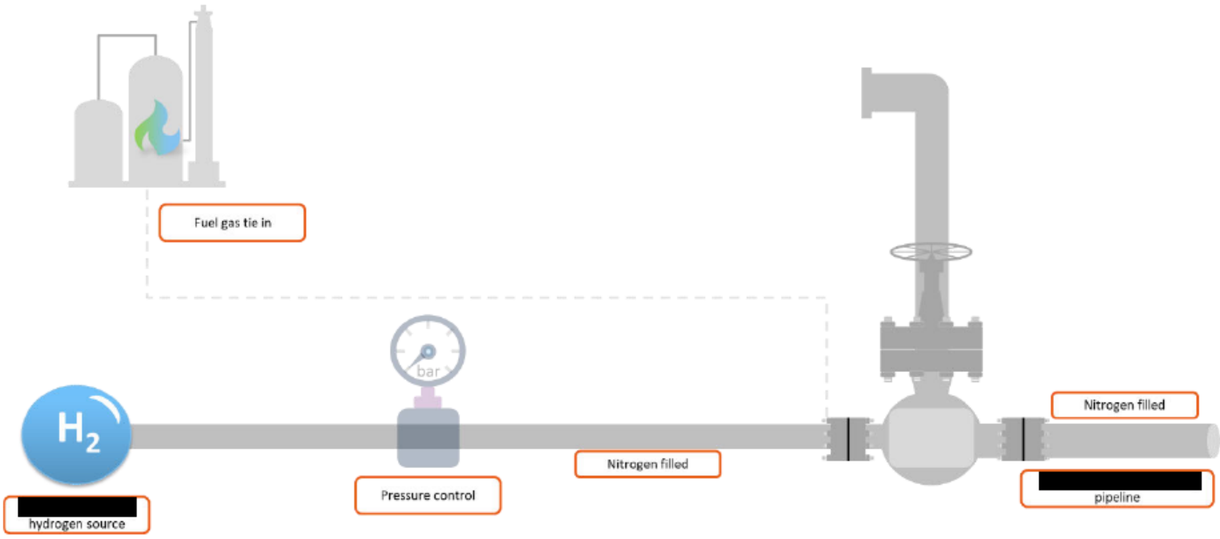

Figure 13-End of project infrastructure after live trial of the [redacted] to [redacted] pipeline is completed

The outcomes of the live trial will be incorporated into the repurposing and uprating blueprint, which will be applied to specific LTS case studies (including capacity assessment, uprating and repurposing), and a full cost analysis will be carried out. Figure 14 illustrates the key characteristics and deliverables of the live trial.

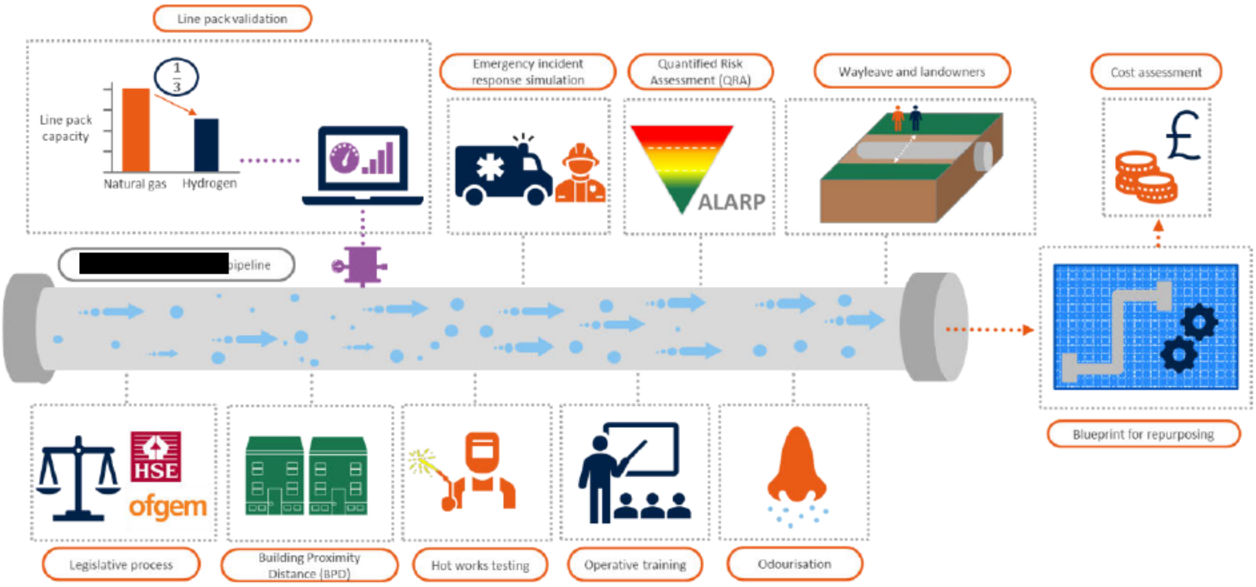

Figure 14-The live trial

The live trial will validate a number of the previous findings and conduct various simulations, training and exercises. The four main exercises carried out on the demonstration pipeline will include:

- emergency response simulation
- line pack assessment
- hot working exercise
- uprating and capacity assessment

Further detailed technical description of main operations for the live trial can be found in Appendix G.

Other learnings from the live trial include:

- Operational, maintenance and emergency procedures and how these link to 3rd parties
- Training and competence of operational staff
- Legislative process (notification, permission etc)
- Determining wayleaves/landowners and engagement process
- Validation of odorisation in transmission pipelines

The overall outcome is the blueprint methodology of how to repurpose and potentially uprate an LTS pipeline for hydrogen service.

Element 5: Quantified Risk Assessment (QRA) and Case for Safety

Pipeline Safety Regulations (PSR 1996) & Gas Safety and Management Regulations (GSMR 2015) 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 EN, 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.

The safety evaluation is a systematic study of the major hazard potential of a pipeline, and must assess the design, construction and operation. The purpose is to demonstrate that all necessary measures are taken to prevent a major accident and limit any potential consequences. The evaluation shall include a full Quantified

Risk Assessment (QRA) and specific consideration of material requirements, pressure boundaries and the control regime, additional maintenance and risk management requirements.

The QRA involves the calculation of the risk of fatalities which may occur as a result of a failure of the pipeline. This process involves the calculation of individual risk to a person present at distances from the pipeline 100% of the time, and the calculation of the societal risk to number of people in occupied buildings within the hazard zone of a pipeline failure. The results are compared with the risk levels in the HSE safety framework, to assess whether risk reduction measures are required. The HSE use the results of QRA to determine the Land Use Planning (LUP) consultation zones around pipelines, so the QRA results will be required to ensure a "no objection" to the [redacted] to [redacted] live trial.

[redacted] All methods, data and assumptions shall be recorded in the documented safety evaluation. The safety evaluation will be fully documented in the Case for Safety, which will include the QRA results.

This developed 'Case for Safety' is the proposed operational application of the QRA to be assessed under the [redacted] to [redacted] pipeline trial project, once tested this will further define a set of tested operational and engineering instructions defined as 'safe and applicable' for hydrogen pipelines. The trial outputs will define a quantified safe set of operational procedures, these procedures once approved will become part of the safe standard operating parameters for LTS pipelines. These procedures will ultimately become part of the GBs safety case as an activity defined as safe for the conveyance of hydrogen through an LTS pipeline.

Element 6: Knowledge dissemination

Knowledge dissemination is detailed in Section 4 in addition the hydrogen awareness courses will be available [redacted] ensure that the project team is aware of the differences between working with natural gas and working with hydrogen.

[redacted] the following training courses in preparation for technical resources carrying out the project. These will include the following:

- Hydrogen general awareness course [redacted].
- Hydrogen detection training course.
- Hydrogen Emergency Preparedness/emergency response.
- Hydrogen Operational training course – operating valves,
- Hydrogen Maintenance activities training course.
- Hydrogen gas entry facility training course.

The elements described above play a critical role in understanding how to operate, maintain, inspect and repair hydrogen pipelines in a real-life setting. The elements of the programme will validate existing research and provide a methodology to determine the proportion of the LTS which can be efficiently repurposed. The programme will develop material acceptance standards (Element 2) for the legacy pipelines required for repurposing of the LTS. To ensure hydrogen pipelines are safe and cost effective, it is essential the requirements for their safe operation and maintenance is fully understood and operational procedures are developed and validated (Element 3, 4 and 5). Issues such as servitudes, easements, landowner engagement and legal issues will be understood (Element 1), all of which will feed into the regulatory requirements for operating hydrogen pipelines. This work will enable the options and costs of repurposing the LTS to be determined and understood by carrying out a live trial utilising an existing pipeline that has previously operated under natural gas service.

All aspects of the case for safety will be peer reviewed [redacted]. SGN will also prepare a minimum of two papers for publication in academic journals.

3.7 Project delivery

The project comprises a series of parallel workstream, referred to as elements, each with its own delivery milestones, go/no-go project stage gates and staged payments to reflect critical path items. Below is a list of project elements and timelines, illustrated in the high-level plan in Figure 15 and a detailed Gantt chart in Appendix H.

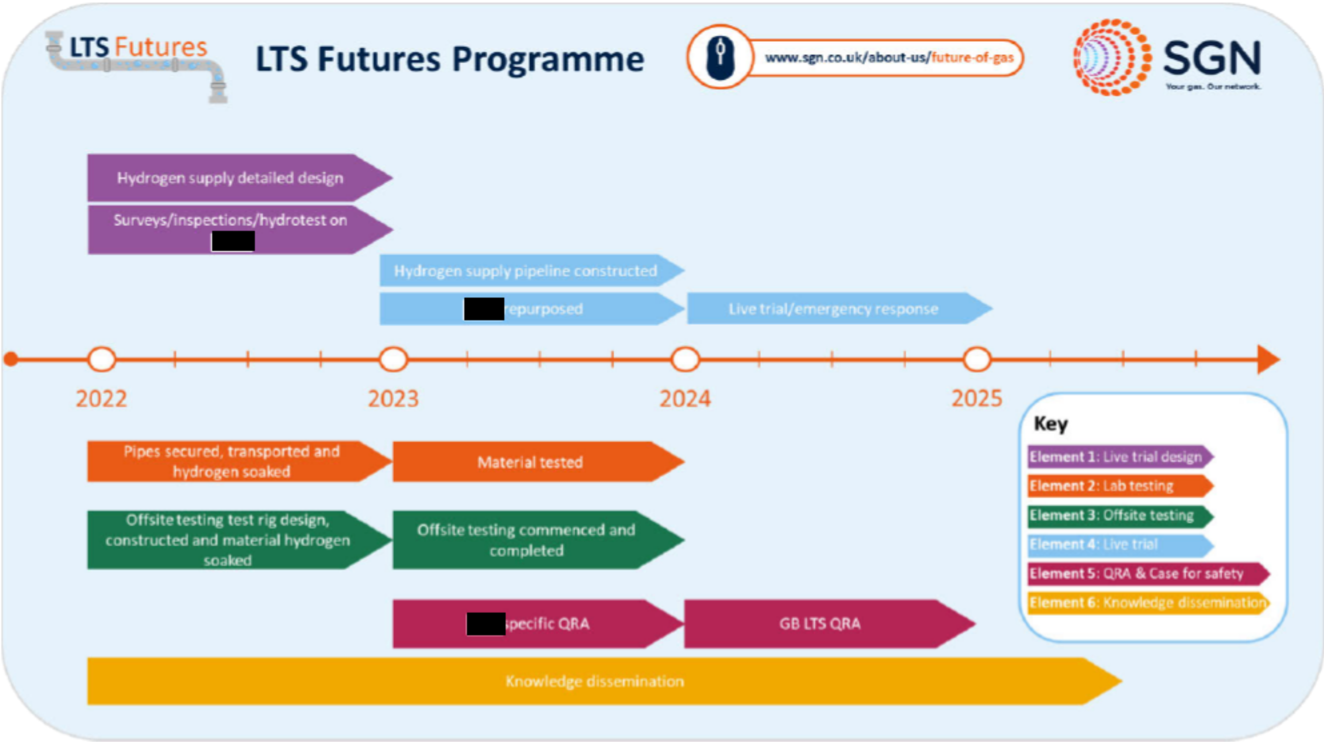

Figure 15-Indicative high level project plan

Requirements pre-Project commencement 1st April 2022

- Feasibility for pigging, uprating and hydrogen supply reports
- [redacted]
- Contracts with key suppliers
- Preparation of procurement event for lab testing

Stagegates

A series of go / no go stagegates has been built into the programme to ensure that the LTS Futures project has a suitable number of decision points to manage key uncertainties, which are largely related to the live trial design and the live trial elements. The contracting strategy also ensures that wherever possible contracts entered into for the project have suitable milestone structures with payment on deliverables and termination provisions to provide the project with appropriate cost control. The 8 key Go/No-go stagegates and associated evidence required for acceptance is detailed below.

Table 1-Project deliverables at stagegates

Ref.	Element	Deliverable	Deadline	Evidence
1	Element 1: Live Trial Design H2 supply	Pre-Feed and Detailed Design of H2 supply pipeline	01/12/2022	Approved and appraised design packs [redacted] Signed off versions of Tender Documentation including detailed specifications and award criteria. Land lease/purchase Planning consents
1	Element 1: Live Trial Design [redacted] to [redacted]	Recommendations, QRA and cost assessment	01/12/2022	Above ground surveys, in-line inspection (ILI), hydrotest reports. TD1 report. Material testing preliminary report for [redacted] to [redacted] Peer review report.
1	Element 2: Lab Testing	Materials specimens have been secured	01/12/2022	Confirmation of receipt of material at test house
1	Element 3: Offsite Testing	Preparation works for Offsite testing.	01/12/2022	Burst and Fatigue, venting, stabbing rigs as built drawings. Report on material soaked in hydrogen (3months). Order confirmation for compressor ordered for PRS testing. [redacted]
1	Element 5: QRA and Safety Case	[redacted] to [redacted] Interim QRA for repurposing and uprating	01/12/2022	Interim QRA report for the [redacted] to [redacted] pipeline
2	Element 2: Lab Testing	Material is tested and demonstrated fit for hydrogen for [redacted] to [redacted] pipeline	31/03/2023	[redacted] to [redacted] pipeline cut out tested in accordance with material requalification provided in ASME B31.12 Hydrogen pipeline standard. Material testing report. Peer review report.
2	Element 3: Offsite Testing	Early offsite test reports	31/03/2023	Burst analysis report. Fatigue tests on defects analysis and report Vibration tests on stabbings analysis and report PRS testing commence report Measurement unit test commence report
2	Element 4: Live Trial	Order placed for materials	31/03/2023	Confirmation order of materials

3	Element 1: Live Trial Design	MAPD for supply pipeline and repurposed pipeline	01/06/2023	Identification and specification of modifications to the [redacted] to [redacted] pipeline. Dig verifications, repairs and slabbing works completed. Design of the H2 supply pipeline and entry unit. MAPD draft report. Emergency Response desktop exercise report Design inputs to blueprint report. Peer review report.
3	Element 3: Offsite Testing	Hot work testing begins	01/06/2023	Hot work testing commence report
4	Element 2: Lab Testing	Vintage seamless and seam weld pipe material testing	30/07/2023	Lab testing report confirming the vintage GB LTS pipelines are acceptable for hydrogen service and supporting data and analysis to feed into the GB LTS QRA and blueprint. Peer review report.
5	Element 3: Offsite Testing	Hot working, uprating and venting	31/10/2023	Hot working report determining the suitability to hot works on live hydrogen assets. Draft hot work procedure for hydrogen pipelines. Increased flow tests through the PRS Vent tests at a range of sizes and pressures analysis and report Data and analysis supporting info report for the QRA. Peer review report.
6	Element 4: Live Trial	Assessment against the Blueprint	28/02/2024	Application of repurposing blueprint to [redacted] to [redacted] pipeline report. Application of uprating blueprint to [redacted] to [redacted] report. Peer review report.
7	Element 4: Live Trial Element 6: Knowledge dissemination	Training complete and Commission pipelines	01/04/2024	SGN personnel training certificates QRA and ALARP studies complete As build drawings and commissioning certification
7	Element 4: Live Trial Element 6: Knowledge dissemination	Cost Analysis	01/04/2024	Cost analysis report for [redacted] to [redacted] Cost analysis report for Case studies. Refined cost analysis report for repurposing and uprating the LTS assets for hydrogen.

				Peer review report.
8	Element 5: QRA and Case for Safety	QRA for GB LTS assets	01/10/2024	Report detailing all relevant evidence gathered across all elements for the overarching QRA for repurposing and uprating the LTS assets to hydrogen Peer review report.
8	Element 4: Live Trial	Line pack assessment	01/10/2024	Linepack assessment report including uprating potential. Peer review report.

Project cost commitment showing Go/No-go stagegates

[redacted]

A comprehensive project reporting structure will be implemented to monitor and control the project. We will monitor cost and time progress against the project plan and carry out acceptance tests as each stage gate is reached. Only when we are satisfied that the acceptance tests have been met at each of these key steps will we progress through each stage gate and continue the project. Similarly, the project team can halt or terminate the project (within the principles of the NIC governance) should the project cease to be able to deliver the key outcomes.

Procurement and Contract

A comprehensive, fair and competitive strategy is essential to drive innovation, improve efficiency and ensure we provide value for money in all its activities. SGN Procurement and Contract (P&C) have been involved since the very early stages of the project in establishing the sourcing strategy for all key workstreams which require third party engagement and, working with the project team, have established timelines and high-level approach to market for each.

Our procurement activities are driven by competition, compliance with Utilities Contract Regulations 2016 (UCR) and Internal Governance Processes. This approach is geared towards ensuring value for the end consumer and interested parties, in addition, to ensuring we act responsibly and ethically in our procurement activities.

P&C activity relating to all third party workstreams of the LTS Futures' project are closely aligned with SGN's Procurement Mandate, which follows six best practice principles:

- **Comprehensive Procurement**: Utilisation of competitive processes for all projects and procurements. Processes to deal with any necessary deviation from this;
- **Robust Competition**: The competitive process must be robust, transparent and ensure equal treatment for potential bidders and protect information appropriately;
- **Efficient Operating Model**: The complexity of the competitive process used should be proportionate to the value and technical complexity of the works, goods or services in question;
- **Transparency:** All information must be provided equally to all parties and any conflicts of interest must be appropriately managed. Licensees should be agnostic to technology and bidder type;
- **Fairness**: We seek to ensure that the supply chain does the right thing through fair and reasonable processes, along with mandated evaluation criteria where appropriate; and
- **Customer Outcomes**: Competitions should be structured to generate outcomes in the interests of existing and future customers.

Further to what is planned and being developed in terms of strategy for the procurement of goods, works and services for the project, P&C and the project team have engaged current framework contractors/providers to establish high-confidence in proposed costs and quality of work by obtaining budgetary quotations for the high-level scopes developed to date for key goods, works and services – ensuring that costs submitted in the submission are not all historical, but indeed forward-facing and based on anticipated build/supply windows. It should be noted however, that these budgetary quotations are not binding at this stage as such there is a high risk that prices will change between now and the point of contract award. In Section 6.3 we have set out our approach to delivery cost risk.

Go-no-go stage gates will be utilised to ensure the project is structured to manage risk and uncertainty of success as far as practicable. This allows the project to manage investment risk and ensure valuable learning is achieved throughout.

Project team

The project is being led by a dedicated team within SGN Energy Futures' Directorate with an approved resource plan for delivery. This team performs all necessary project management functions to include regular reporting, risk monitoring and management, cost control and programme management.

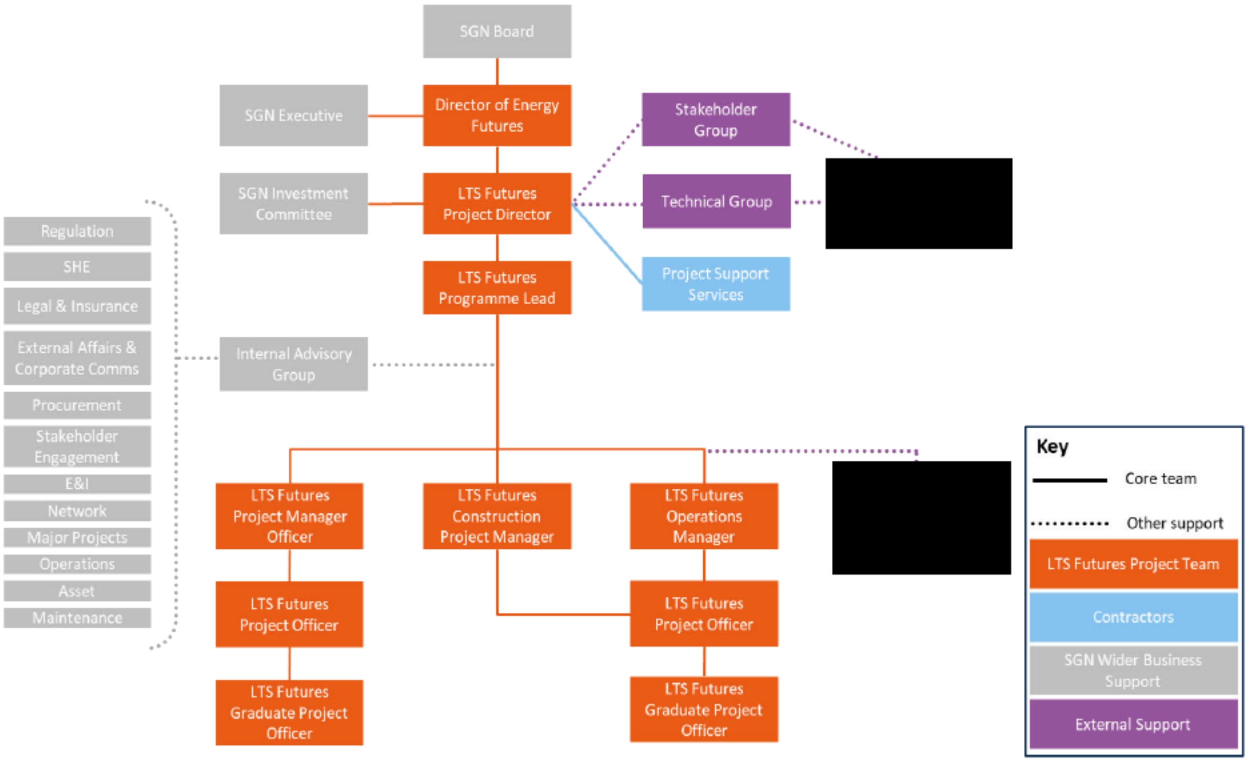

Figure 17-LTS Futures project team

The project is structured as per Figure 17 with the appropriate governance processes in place. The overarching Advisory Group will meet monthly and the focused business area working groups that sit under this have been mobilised. We also plan to set up a project steering group with attendance from critical decision makers across the interfaces.

As a complex, high value and multi-discipline project, the internal Advisory Group will draw on the expertise and guidance from across the key business areas within SGN. This has been depicted in the organogram provided above, which lists the various teams involved. As the project develops, different business areas will be invited to join the Advisory Group. This regular engagement will help to ensure that all of the key departments are up to date and aware of the project progress, which will subsequently facilitate the smooth and coordinated roll out of LTS Futures. This will subsequently allow our stakeholders and customers to be informed and prepared for the necessary transition to net zero.

LTS Futures is supported at all levels within SGN, as indicated in the organogram above, where there has been full support demonstrated from the SGN Investment Committee, the SGN Executive and the SGN Board, which will continue throughout the life of the project.

In addition to the Advisory Group, the LTS Futures programme will be communicated internally across various channels and platforms such as internal reporting, SGN intranet updates through 'Digital Hub' blogs and news stories, as well as a dedicated LTS Futures page.

The project will benefit throughout from our wider business, which will support the project delivery through to operation. This will build on the hydrogen awareness component that is already being integrated into internal training programme across the business, ensuring that the appropriate resources and training are provided to upskill critical teams such as SGN Operations, Maintenance, Major Projects and Emergency Response.

Contracting structure

Across all aspects of the project and its development, we have ensured a fair, compliant and competitive approach has been followed with regards to the project contracting structure. The proposed contracting structure for LTS Futures is designed to ensure close control of the project and its success, while ensuring it is fully supported by the appropriate resources required to deliver the project safely, on time and in budget. The high-level indicative contracting structure is provided below.

[redacted]

The Network Licensees Partners are Cadent, NGN, WWU and NGGT. We recognise and actively respond to opportunities for collaboration between the UK Network Licensees and as such embrace the opportunity to share knowledge and outcomes of LTS Futures with the other networks as Project Partners and Supporters, as we have done in previous projects.

All Project Suppliers are yet to be defined, which will be delivered through a robust procurement process. However, there are various key suppliers involved in the project that are already identified based on their previous project participation. [redacted]

During Element 1, prior to construction of the hydrogen supply pipeline and the repurposing of the [redacted] to [redacted] pipeline, we will agree an approach with the duty holders of all aspects of LTS Futures hydrogen supply pipeline and repurposed pipeline in relation to design assurance and compliance with legislation such as PSSR. Regulation 4 of PSSR covers the design, construction, repair and modification of pressure systems and puts a duty on all concerned to ensure that the pressure system is fit for purpose. HSE guidance on PSSR advises that designs are independently verified and approved. Robust controls are therefore required to manage new works, modifications and repairs on a gas network. The purpose is to ensure that planned and executed 'design and repurposed activity (Element 1)' is properly appraised, approved and determined as fit for purpose by fully qualified and competent people, where possible designs will be assured against SGN existing standards and specifications [redacted] When this is not possible (for example, SGN procedures and specifications do not cover hydrogen), designs will undergo an approval and appraisal process to evidence compliance with required legislation.

HSE is a key stakeholder for the programme. Appendix I details engagement with the HSE on the LTS Futures programme. HSE and [redacted] have been engaged since the inception of the project in January 2019.

A roadmap has been developed to identify key HSE engagement. [redacted]

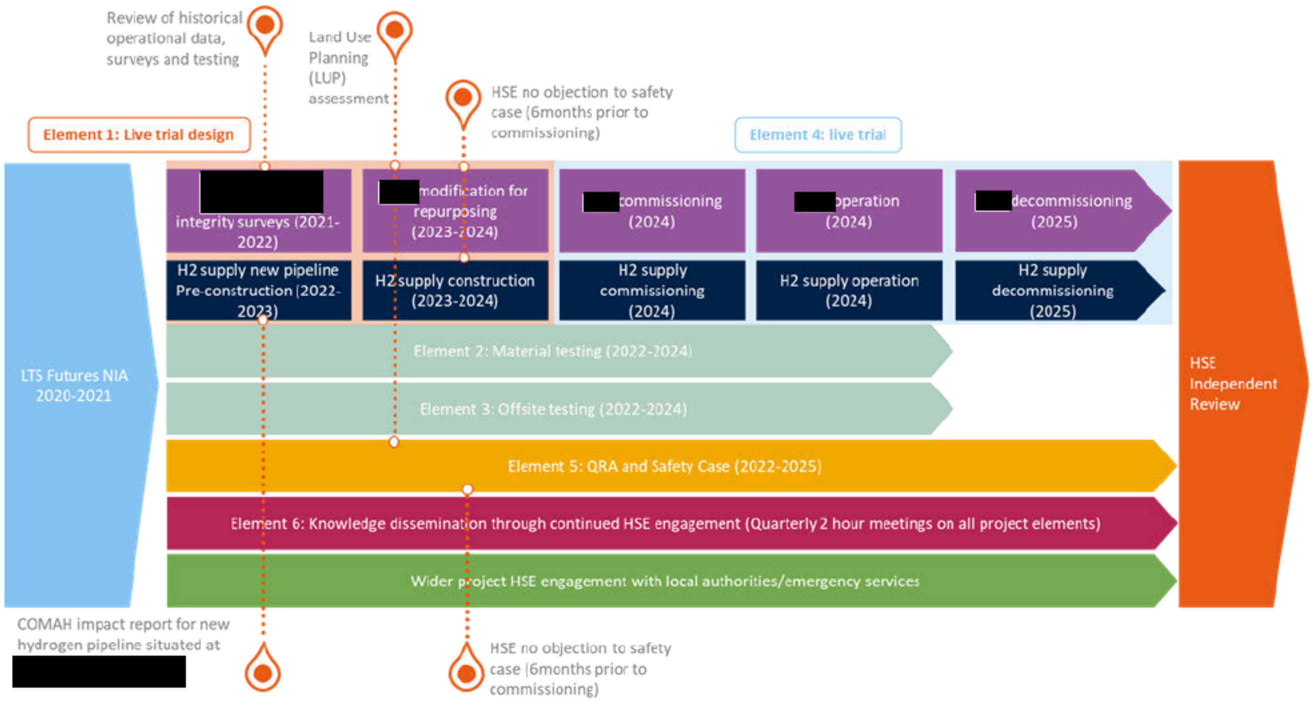

Figure 19-High level timeline of HSE engagement

Regulatory interfaces

In undertaking the development of this project, we have assessed the regulatory interfaces that would be required for SGN Scotland to undertake the project under its current licence arrangements. Whilst this review is not exhaustive our assessment would suggest that:

- **Supply of gas.** As a transporter SGN are not permitted to own the gas within the pipeline (section 7a of the gas act) and a licence is required to arrange for the introduction, conveyance and removal of gas from a pipeline system operated by a transporter. As such, we would be looking to contract with a shipper to provide hydrogen to the system, to maintain ownership of the hydrogen within the system and following its extraction.
- **Standard Licence Condition 4B (Connection Charging Methodology).** Due to the requirements this condition places on relevant gas mains, in line with Clause 13 of the condition we will need to register this gas main as a 'non-relevant main'.
- **Standard Licence Condition 4E (Requirement to Enter into transportation Arrangements in Conformity with Network Code).** This licence condition requires us to maintain membership of the UNC. We believe that it is important to be clear that certain requirements of the UNC do not apply to this specific pipeline as such we would support the derogation modification currently being introduced by Northern Gas Networks (see below).
- **Uniform Network Code (UNC).** A derogation from the UNC framework will be required, the pipeline used as part of this project will not be conveying gas to customers, nor will it be conveying methane. Northern

Gas Networks have recently introduced a modification (0760)[6] to support with future derogations from the UNC (much like Ofgem can approve with licences). This is designed to support innovative projects, particularly those with a net zero benefit from being held up, or unduly prohibited, due to UNC requirements. We would look to apply derogations where necessary, should Ofgem approve the change.

Managing risk

LTS Futures maintains a project risk register that captures the readily identifiable risks in relation to the project. This allows us to oversee current risks to project delivery and ensure appropriate control actions and mitigations are in place. The top risks for each element can be found in Appendix J. At this time no risks have been identified that indicate the project cannot start in a timely manner or will be unable to progress to completion in line with the programme. The LTS Futures risk register is reviewed every week by the project team and appropriate mitigations are identified with corresponding actions.

Faced with the unprecedented circumstances of the Covid-19 pandemic, we have developed our comprehensive project plan to ensure the impact of this is being continually monitored and safety is maintained at all times. Working with our Partners and Participants, we continue to review associated risk with Covid-19 and are confident that we can deliver the project to the plan proposed. This has been included within our project risk register and we have assigned control actions and mitigation measures that will allow us to continue to progress with work in accordance with the project schedule.

We recognise that we can only identify a selective range of risks and that we are not able to identify and accurately quantify the impact of all risks that may arise with a major project such as LTS Futures. This is discussed in more detail in Section 6.2 . In the last year we have seen the price of natural gas increase seven-fold in some instances, this will be monitored and assessed as the programme develops.

4 Knowledge dissemination

Understanding the suitability of the LTS network is critical for any hydrogen transformation. If successful, this project will validate the technical, safety and operational ability to transport and store 100% hydrogen in the LTS network, offering a route for decarbonisation of the gas network. With the project programme concluding in 2025, vital learning and validation of the hydrogen evidence base will be available to support both Scottish and UK Government decarbonisation policy, including UK Government heat policy decisions.

We recognise the importance of collaboration and effective learning dissemination. The project has been designed to provide transparent critical evidence for the decarbonisation of heat, but also detailed validation of the safety and technical aspects specific to network operation. All Network Licensees have been invited to support the LTS Futures Reopener submission. This commitment is demonstrated in the letters of support received (Appendix K). We also recognise the important contribution the LTS Futures programme can make to future industry skills diversification and future STEM career opportunities. We will lead an external Technical Group, with representatives from the other Network Licensees, Project Partners, Project Suppliers and other Industry, Consumer and Skills bodies. There will also be a complementary Stakeholder Group to ensure the project stakeholders are kept well informed on the project progression, to share emerging outcomes and next steps. The positioning of these groups within the project is shown in the organogram above. The groups will meet quarterly to be updated on the project's progress and ensure coordination with related projects on the integrated hydrogen trial pathway as well as any other relevant projects in the hydrogen space.

[redacted]
https://www.gasgovernance.co.uk/sites/default/files/ggf/book/2021-10/Final%20Modification%20Report%200760%20v2.0.pdf

The LTS Futures programme and potential expansion opportunities form a key part of the national hydrogen programme and is recognised under the Gas Goes Green programme. We already have key members updating and participating in groups illustrated in Appendix I.

We will continue to participate proactively and commit to sharing the project learning effectively to inform the wider strategy for decarbonisation. A detailed stakeholder communication plan and hierarchy is provided in Appendix I.

4.1 LTS and NTS collaboration

We have worked closely and iteratively with subject matter experts, consultants, policy decision makers, legislation, regulation and the Health and Safety Executive (HSE) to challenge and review the project scope and strategy. We have incorporated the appropriate testing to deliver evidentiary outcomes to support the safe and efficient repurposing of the existing LTS to hydrogen service. Current knowledge gaps have been identified and prioritised for investigation. Further details provided in Appendix L.

5 Project outcomes

5.1 Primary deliverables and learning points

The LTS Futures programme overarching ambition is to develop the blueprint for repurposing and uprating of LTS Assets. There are many safety, technical, commercial, regulatory and operational aspects to this project which are being demonstrated. LTS Futures will deliver many important outcomes and learnings that are further detailed in Appendix M. 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 energy transition. An example list of the outcomes from LTS Futures is in Appendix M of this document. While this is not an exhaustive list the LTS Futures programme covers an extensive scope of works that will be transformational in validating the evidence base for hydrogen in the gas networks. As such, it is paramount that the dissemination of this learning is effective and timely.

A successful outcome will be to demonstrate whether the [redacted] to [redacted] pipeline can be repurposed and uprated, safely, securely and cost effectively.

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 and uprating projects, ensuring safety, efficiency and applicability throughout the GB.
   b. Determine wayleave suitability, access and landowner engagement requirements
   c. Determine the suitability of LTS materials for 100% hydrogen
   d. Validate the operational strategy for operating a hydrogen network, identifying any differences from operating a natural gas network
   e. 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.
   a. Develop knowledge and acceptance of hydrogen within the public, industry, standards bodies and regulatory agencies

b. Optimise and validate the cost model for future repurposing projects
c. Provide visibility of the commercial and regulatory aspects for future operation of conversion hydrogen networks, this insight will support future regulatory models
d. Understanding interface and commercial arrangements with hydrogen suppliers

3. Define the role of LTS in system transformation and facilitate industrial clusters.
   a. Develop and test the regulatory (safety, commercial and environmental) framework required for the GB Hydrogen network
      i. Compliance with Pipelines Safety Regulations
      ii. Identify any modifications required to the Gas Safety (Management) Regulations or other legislation
      iii. Land Use Planning and Planning consent
   b. Confirm a repurposed LTS will deliver the required operating pressures, flowrates and linepack to facilitate the green recovery

This programme will establish the UK as a world leader in repurposing ageing assets for hydrogen transportation.

The majority of this learning will be via a live trial to repurpose and uprate the [redacted] to [redacted] pipeline, which represents typical LTS operating conditions in terms of the route and inspection, maintenance and repair activities.

6 Value for money

6.1 Project costs

The LTS Futures cost estimate is presented below by element, the full cost plan is provided in Appendix N. The table below sets out the total cost expenditure, and then subdivides this into two components a RAV component and an R&D component. The regulatory funding consideration is discussed further in Section 6.5

Table 2-Cost estimate summary table

[redacted]

It should be noted that for this table the capital cost proposal (RAV) has been presented in 2021/22 prices as these will have inflation applied through the PCFM. The Innovation cost proposal (R&D) has been presented in nominal prices which is in line with the treatment of NIC projects that do not have inflation applied through the PCFM. [redacted]

The project expenditure will span over three financial years being 2022/23 to 2024/24 as is presented in the tables below. For the Capital project (RAV) component, it is important that these costs are adjusted appropriately for both CPI, and Labour and material RPEs (real price effects) as explained further in Section 6.2 For the innovation cost proposal (R&D) component, CPI inflation has been included within the funding request however it is important that the potential impact of RPEs is still considered. [redacted]

Table 3-RAV yearly cost estimate summary

[redacted]

Table 4-R&D yearly cost estimate summary

[redacted]

[7] https://www.ofgem.gov.uk/publications/version-31-gas-network-innovation-competition-governance-document Gas NIC Governance v.3.1 Paragraph 8.50

[redacted]

Reducing cost uncertainty
Providing accurate information on which to base cost estimates helps to minimise the risk of overspend against each individual cost line.

To this end the LTS Futures project cost estimate has been informed by early market engagement as well as drawing on internal and external expertise from similar projects.

The project cost has been calculated using detailed knowledge of the LTS pipelines, site surveys and engagement [redacted] and other suppliers. Costs of civil engineering work for installations at locations that have yet to be excavated have been derived from previous works of a similar scale.

To develop the funding estimate, a number of sources were used to derive aspects of the price. These were:

1. **Indicative estimate of the cost from a supplier of the activity**. While this cost estimate was being provided by a service provider or supplier relevant to the activity or item it is being done prior to any tender documentation, specifications or design work having been undertaken. This was the method by which the following were estimated:
    a. Design costs
    b. Materials whenever possible but this also includes consideration of previous projects.
2. **Previous project experience** Based on previous costs incurred during RIIO-GD1 and this year. There have been many projects delivered offering a wide variety of interventions during GD1 which provide a selection of similar costs to draw from when estimating LTS Futures live trial design (Element 1) costs. This was the method by which the following were estimated:
    a. Cost control, covering tender preparation and evaluation, quantity surveying and post construction evaluation.
    b. Specialist Services such as construction supervisor, CDM management, Pipeline Inspector, hydrostatic pressure testing and radiographic inspection of all welds.
    c. Main Works Contractor (MWC).
    d. E&I costs. These are the costs other than those already covered within the design and MWC for a specialist E&I contractor and materials.
    e. Miscellaneous other costs such as records collection, planning permission, land purchase, direct labour and removal of redundant equipment.
3. **Reducing cost uncertainty.** A full programme of work with the single aim of reducing cost uncertainty has been undertaken in the development of the cost plan. This was structured in systematic way that ensured the higher value cost items were prioritised for refinement and to ensure that key strategy and project delivery methods were mapped out in advance of refining the budget costs associated with them and their successors.
4. **Direct communication with expected contractors.** The costs from the needs case have been refined in preparation of the final cost estimates presented in this submission by means of market engagement,

securing costs via agreements in principle (such as MOUs for example) and discussions with various third parties that will either interface with the project or provide advise that can feed into the build-up of cost estimates.

5. **Independent assurance.** An independent quantity surveyor has reviewed and challenged LTS Futures programme costs. The quantity surveyors have significant experience in handling commercial and contractual aspects of major projects. The quantity surveyor has ensured we have obtained the best market price and quality of materials and trades to deliver the project.

This approach enables us to develop detailed costs breakdown and, where possible, gather a level of agreement or memorandum of understanding on the costs that are likely to occur. But it should be noted that many costs will only be able to be defined with confidence once the design work has been fully completed.

For each data point we have then made two adjustments, an adjustment according to the confidence in the underlying data point, and an adjustment for the time of the data was received.

- Adjustment for the time of the quotation, where relevant and following guidance from the QS, we have adjusted the original sources data to bring it into line with 2021/22 prices taking into account both general inflation and specific material price increases that have been experienced over the last year. Where a data point is a recent quote, provided within the 2021/22 financial year, we have worked on the basis that the original quote will include up-to-date known costs.
- Adjust for confidence in the underlying data point. We have applied an 80th percentile approach to the underlying cost data in recognition that there is a likelihood that the costs will change between an informal quotation and actual contract definition.
    - Where the quote is a confirmed fixed cost and high confidence we have assume a +/-10% variance applied to the maximum and minimum range on a normal distribution and assumed the 80th percentile cost. This has been applied to the following cost type:
        i. SGN labour costs; and,
        ii. fixed cost proposal associated with a desktop exercise
    - Where the quote is a recent quote and reviewed by a quantity surveyor we have assumed a +/-20% variance and assumed the 80th percentile cost. This has been applied to the following cost type:
        i. Cost reviewed by QS and quote from October 2021
        ii. fixed cost proposal associated with testing work and work on new h2 pipeline and repurposed pipeline
    - Where a quote is an old quote, or a new works contract, we have assumed a +/-30% variance and assumed the 80th percentile cost. This has been applied to the following cost type:
        i. Quote from March 2021
        ii. New hydrogen pipeline route still TBC
    - Where the quote is an irregular contract or we are currently unable to get a quote due to unknown quantities we have assumed a +/-40% variance and assumed the 80th percentile cost.

These adjustments make appropriate allowance for normal variation in the contracts assuming that the contract is as described at the point of the quotation. It is important to note that these adjustments do not take into account broader project risks such as further changes in material costs or significant design or scope of work changes.

6.2 Allowing for inflation and RPE’s

As set out above the figures provide for the RAV component are stated in 2021/22 prices and will need to be inflated accordingly for the year in which the expenditure is incurred. In calculating this inflation, we think that it is important that appropriate indices should be used for both material cost and labour costs to account for the difference in general CPI inflation and the real price effects (RPEs) of these cost categories. The R&D component has been presented in nominal prices based on forecasted CPI inflation.

As with the RIIO- GD2 final determination we would propose that RPEs are applied to labour costs and material. With Labour costs being a composite of three indices - AWE: Private Sector Index (K45V), AWE: Construction Index (K553) and BCIS PAFI civil engineering (4/CE/01). Whilst the materials index is a composite of – BCIS 4/CE/24 Plastic products, BCIS 3/S3 Structural Steel work, and BCIS FOCOS infrastructure resource cost index of infrastructure: Materials. All other costs we would expect to be inflated by CPI in line with the final determination.

In the table below we have separated expected expenditure into each of these categories for each project element. [redacted]

Table 5-Expected RAV project expenditure

[redacted]

Table 6-Expected R&D project expenditure

[redacted]

[redacted]

[redacted]

6.3 Allowing for project risk

With major construction projects it is widely recognised that there is a tendency to under-estimate the cost at the early stages of a project due to the lack of knowledge about the costs that the project will be required to incur in order to deliver a successful outcome. This has been referred to optimism bias and is defined as:

"Optimism bias is the tendency for a project's costs and duration to be underestimated and/or benefits to be overestimated. It is expressed as the percentage difference between the estimate at appraisal and the final outturn."[8] .

In an evaluation of 80 large public procurement projects that was carried out for the HRMC, it was identified that a works duration optimism bias of 3% - 25% and a capital expenditure optimism bias of between 6 and 66%. It should be noted that this bias is additional to established project management and risk management techniques. As a result, in supplementary guidance[9] the treasury green book recommends non-standard engineering civil engineering projects, a category that includes innovative utility projects, should make allowance for this.

In line with the guidance, we think that the early stakeholder engagement, project and risk management practices that we have in place and the efforts we have entered into to engage with contractors has reduced but not eliminated the optimism bias. For example, we note that we are in a particular volatile period for UK and global economy as it emerges from the economic shock of COVID and Brexit, and the impact that this is having and will continue to have for both prices and supply chain delivery.

[redacted]

---

[8] Report completed by Mott MacDonald for HRMC 'Review of Large Public Procurement in the UK' 2002 https://www.parliament.vic.gov.au/images/stories/committees/paec/2010-11_Budget_Estimates/Extra_bits/Mott_McDonald_Flyvberg_Blake_Dawson_Waldron_studies.pdf

[9] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191507/Optimism_bias.pdf

[redacted]

[11] RIIO-T1 reopener: One off asset health costs (feeder 9). Ofgem 28th Sept 2018, pg 29, Para 3.30, "The evidence from comparator projects suggested that risk/contingency allowances for similar projects typically range from 5%-15%, with an average of around 10% [see Appendix 1]. We acknowledged that the Feeder 9 project is unique, and that we would be willing to accept a risk allowance at the higher end of this range, i.e. 15% of the total project value"

[12] https://www.ofgem.gov.uk/system/files/docs/2020/05/decision_on_our_project_assessment_for_the_hinkley-seabank_electricity_transmission_project_0.pdf

[13] https://www.ofgem.gov.uk/ofgem-publications/88909/poyrytneireport.pdf

Given that the LTS Future project has a high level of risk associated with it, in terms of the status of the buried pipe work, the proposed connection to the supply of hydrogen and the recent raw material price[14] volatility and supply chain volatility. [redacted]

6.4 Cost benefit analysis

As this project proposes to carry out work of critical importance to the success of the gas industry's collective and collaborative efforts to prove and demonstrate the practical, safe and affordable energy system transition from natural gas to hydrogen, the indirect cost savings, may by applied, of pursuing a transition to hydrogen as a means of heat decarbonisation, therefore avoiding the higher costs and disruption to gas customers of installing electrified heating technologies.

The direct cost benefit of carrying out this project is the potential saving from proving the existing assets can be repurposed, therefore avoiding the more expensive option of decommissioning the existing LTS and installing a new LTS to facilitate hydrogen.

Due to the lower volumetric energy density of hydrogen compared to natural gas, there will be a requirement for new LTS pipelines to be constructed for the future hydrogen LTS network to be able to deliver the equivalent energy flowrate and linepack as the natural gas LTS network does now. The energy throughput capacity of the LTS and its energy storage capacity through linepack are dependent directly on the gas properties of the transported gas (i.e. the gas pressure and velocity)

Additional cost savings can be achieved by carrying out additional works to increase the capacity of the repurposed LTS and to prove the safe upgrading of PRS's to permit higher flowrates. These works will reduce the required length of new LTS pipelines to account for the reduced capacity for energy flow and linepack.

Table 7 below summaries the scenarios used in the cost benefit analysis of this project.

Table 7-Scenario summary-all GB LTS assets

Scenario	Summary	Licensee Scale (SGN LTS Pipelines only)		GB Rollout Scale (All LTS Pipelines in GB)	
		Existing LTS Repurposed	*New LTS Constructed*	*Existing LTS Repurposed*	*New LTS Constructed*
Base Scenario	LTS across GB is fully decommissioned with a new LTS installed in its place.	0 km	3,030 km	0 km	11,000 km
Scenario 1	LTS across GB is repurposed to current gas pressures and velocities (30% capacity with hydrogen). New LTS pipelines constructed to restore capacity	3,030 km	2,103 km	11,000 km	7,635 km
Scenario 2	LTS across GB is repurposed and uprated to permit higher gas pressures and velocities, with additional work carried out to enable the upgrading of PRS installations to permit increased gas velocities. New	3,030 km	1,030 km	11,000 km	3,740 km

[14] Regarding particular materials - imported plywood saw the highest price increase of 78.4% year-on-year followed by fabricated structured steel (74.8%) and imported sawn or planed wood (74%).

	LTS pipelines constructed to restore capacity

For the Licensee scale (SGN LTS only), the total NPV savings of each scenario compared to the base scenario are presented in Table 8.

Table 8-NPV-Licensee scale

Total Saving (Net Present Value) compared to base scenario	Scenario 1	Scenario 2
2030	£74,144,322	£102,761,560
2040	£690,773,386	£957,388,900
2050	£1,163,915,657	£1,613,148,324

The total NPV Saving of each scenario at the GB Scale (all GB LTS pipelines) are similarly presented in Table 9.

Table 9-NPV-GB rollout scale

Total Saving (Net Present Value) compared to base scenario	Scenario 1	Scenario 2
2030	£269,154,147	£373,034,682
2040	£2,507,602,958	£3,475,416,901
2050	£4,225,174,857	£5,855,888,811

The CBA methodology is outlined in Appendix A.

6.5 Regulatory funding consideration

Following the initial submission, we have considered the most appropriate manner in which to fund the LTS futures project given the impact on the consumer bills, the type of project and the anticipated accountancy treatment (please note that the accountancy treatment is not clearly defined and our understanding will be developed as we progress through the project).

Our proposal recognises that the LTS is a hybrid of both innovation and asset intervention. It is reasonable to assume that the unique location of the [redacted] to [redacted] pipeline from the refinery and source of hydrogen production to the outskirts of Edinburgh that the pipeline will have an enduring value once the project is completed.

Secondly it recognises that there is a significant R&D component of the project, where the focus is on assessing the capacity, and the key deliverable is a blueprint which can then be applied to other networks. As a result, the majority of R&D expenditure is material testing, offsite testing, and the combining of this to formulate and disseminate the safety case.

On this basis we propose to split the funding into two components. The first component is identified by expenditure to recommission and connect the network asset, which we think is appropriate to put onto the RAV in full and recover from Scottish consumers as with any other asset. The second component is identified by research and development and captures the knowledge that is disseminated, and the costs would be recovered from GB consumers as a whole by recovering the costs through the transmission charging mechanism as used by the SIF and used by the NIC during GD1.

As set out in the table below there is a clear delineation between the two approaches, the only point to note is that lab testing, where the cost of the hydrogen entry unit will be tested prior to deployment on site, is included in the RAV component.

Table 10-RAV/Innovation delineation

[redacted]

It is our view that this approach would provide an appropriate basis on which to fund future hydrogen pilot projects which combine delivery and innovation R&D.

Network contribution

We consider it appropriate to maintain the 10% company contribution on the innovation R&D component of the project and that this would be made up of financial contribution from networks, contribution in kind from network companies and contribution in kind from third parties. [redacted]

This will be made up of provisional commitments in kind from network [redacted] based on the networks' own evaluations and provisional commitments in kind from LTS project participants [redacted] In addition to the pipe we are supplying we have contributed significant time and resource to all previous and current aspects of LTS Futures and are providing the [redacted] to [redacted] pipeline for the trial which removes the cost of diversion of a similar pipe for the trial (detailed in Appendix A). The remaining total will be made up from financial commitment from networks.

Table 11 details the Benefit in Kind.

Table 11-Benefit in kind contributions

[redacted]

6.6 Value for money

At all stages of the project design, we have looked to maximise learning and minimise cost. In addition to the measures taken to ensure selection of partners, competitive procurement and management of uncertainty, there are a number of key design features that maximise value for money. These are summarised below, with further detail in Appendix E, 'why [redacted] to [redacted]

Table 12-Programme value for money

Key Features	Key value for money
Pipeline selection	Repurposing a mothballed pipeline removes the diversion cost to ensure security of supply.
	Repurposing a pipeline statistically representative of GB LTS pipelines removes the potential requirement to undertake further live trials, removing further diversionary costs.
Hydrogen supply	Proximity to an existing hydrogen production facility in [redacted] offers a lower cost hydrogen supply connection and reduces risks associated with hydrogen supply availability, logistics and planning.
Linepack validation, uprating and flow tests	The pipeline length and diameter provide sufficient volume for testing linepack storage and uprating potential. Connecting to [redacted] hydrogen supply provides the opportunity to run multiple tests without a substantial increase in cost. [redacted]

Component selection and representativeness of GB LTS	Extraction and retention of redundant pipe and fittings from across GB has removed the cost of diversionary work for us to test vintage LTS components, whilst ensuring representativeness.
	The material testing severity analysis concluded that the [redacted] to [redacted] pipeline could provide a worst-case material example for repurposing and uprating. Therefore, testing the upper bound case material in conjunction with the other pipe type will cover all the GB LTS pipeline assets.
	Using an abandoned PRS that has been in live service for testing removes the cost of a new PRS and provides a representative vintage asset for testing
Maximising existing investments in test facilities.	[redacted]
	Significant costs avoided for development, planning and construction of the test facility. Re-use of existing and now redundant test rigs for hot work testing, for example, removes cost for building a new rig.
Emergency response simulation	The [redacted] to [redacted] pipeline is a GB representative Major Accident hazard LTS pipeline that crosses rivers, rail tracks, roads, 3 local authorities and is close to a main GB airport. All these environmental factors impact the emergency response procedures. Having all these factors included on the pipeline will reduce the requirement for further analysis and maximise learning for the blueprint.
Future use of pipeline	The [redacted] to [redacted] asset could be an important strategic asset for distributing hydrogen to the Edinburgh region at least cost. [redacted] is one of the largest industrial clusters in GB and would be a key location for hydrogen production both for own use and regional deployment.
	Under the live trial, we will be undertaking a hot work validation, this will consist of welding on a split tee. This tee connection will be located at the most optimal location to support future connections.

7 Changes since initial submission

There have been a number of changes since the Needs Case submitted on 6th August 2021, the key changes are:

- the inclusion of uprating option Section 3.5 and Appendix D
- the proposed regulatory treatment, Section 6.5
- cost refinement following independent QS review

Other changes or additions include:

- restructure of submission to include greater detail and previous detail moved to appendices.
- the confirmation of benefit in kind (BIK) support from the other GDNs and their letters of support

Increasing capacity, inclusion of uprating blueprint

One of the priorities identified in the HSE gap analysis set out above was analysis of safety implications on methods to increase system capacity, through increasing pressures, on larger diameter pipelines or parallel pipelines and the potential to uprate capacity. As a result of this gap analysis and the complementarity with the original LTS Future proposal, as set out in the pre-submission document, we have extended the LTS project to cover this gap. [redacted]
The inclusion of uprating option allows identification of where and how capacity can be increased.

Proposed regulatory treatment

Proposals for regulatory treatment have been updated to reflect a RAV/R&D split.

Appendix A - LTS Futures CBA & NPV analysis

Hydrogen-a lower cost, lower disruption option

Transitioning the whole energy system of the UK to net zero greenhouse gas emissions, in line with legally binding net zero legislation, presents perhaps the most significant challenge the UK has ever faced.

To successfully transition every sector of the economy to net zero;

- All appliances, processes and technologies must be adapted/replaced and transitioned to a point where overall energy demand at the point of final use produces net zero greenhouse gas emissions. Demands must be for net zero fuels, electricity and bio-energy sources, with any residual fossil fuel use linked to CCS technologies or addressed through negative emission processes/technologies elsewhere.
- The upstream energy supply chain of net zero energy sources must be able to supply current and future demand in a secure and affordable way.
- The utility infrastructure designed and built to link energy supply chains to energy demands, must be converted and reinforced to enable the supply of net zero energy to all current and future demands in a safe, practical and equitable way.
- Energy security, storage and flexibility infrastructure to support a net zero economy must be developed to the same capability/capacity of the current energy system.

The decarbonisation of the energy delivered through the gas networks through the system transition from natural gas to 100% hydrogen potentially presents to policy makers and the wider gas industry a practical, low cost and low disruption strategy to enable the decarbonisation of heat and industry whilst retaining the use and benefits of the UK's extensive gas network infrastructure (critical to the overall energy storage and security of the UK whole system) and allowing for the most like for like net zero replacement for the present natural gas dominated heating sector, which customers are used to and accepting of.

A system transformation to 100% hydrogen networks in GB requires all key technical and safety evidence to be in place. All pressure tiers of the gas industry must be evidenced to be practically and operationally capable of transporting 100% hydrogen, with no compromise on safety or whole system security of supply. The repurposing and possible uprating of the LTS is critical in evidencing the end-to-end suitability of the gas industry's transition to hydrogen as a means of decarbonisation.

Heat demand is intra-seasonally mismatched and therefore requires a highly flexible, reactive and easily stored energy source to supply its complex and unpredictable demand profile.

Supplying heat demand with electricity alone presents several practical challenges and would incur maximum cost and disruption to customers. Supplying complex demand profile of heat the electricity would result in significant redundant generation capacity in periods of low heating demand (summer months), mitigated only by the build out of significant energy storage (the majority of the UK's energy storage and flexibility provision is provided by gas storage and line pack in the NTS).

Heat demand is most practically supplied by chemical potential energy. Natural gas, biomethane and hydrogen gas are all forms of chemical potential energy. Gas boilers provide the majority of space heating in the UK. The high temperature output of the combustion of natural gas (due to its high energy density) provides a low disruption, low-cost and familiar heating solution to over 23 million customers across the UK.

The continued use of natural gas for space heating is not compatible with achieving net zero. To decarbonise heat, a major system transition must take place to enable low carbon energy to supply heat demand.

There are a number of financial and practical benefits for customers in decarbonising heat through repurposing the gas networks to hydrogen.

At a high level, the gas networks would be transitioned to transport hydrogen through the construction of new networks or the conversion of existing networks, the only demand side change required would be appliance changes and any additional safety measures identified by H100 and H21. Hydrogen production would be required at scale and gas storage would be required to be repurposed.

At a GB scale, the only alternative option available to policy makers to decarbonise heat would be to electrify it. In practice, this would require the widespread installation and retrofit of heat pump and/or resistive heating technologies across all 23.2 million properties currently connected to the gas networks, the reinforcement of the power networks, significant measures to improve the thermal efficiency of the GB housing stock and the significant build out of renewable energy generation and non-gas storage technologies.

The most recent cost comparison of note carried out was National Grid's Future Energy Scenarios 2020, which considers each year, the different pathways to net zero for the UK economy as a whole and each individual sector.

National Grid's consumer transformation scenario, which envisaged a predominantly electrified heating sector, was estimated to cost £303 billion more than the system transformation scenario, which envisaged the majority of heat achieving net zero through the rollout of hydrogen networks.

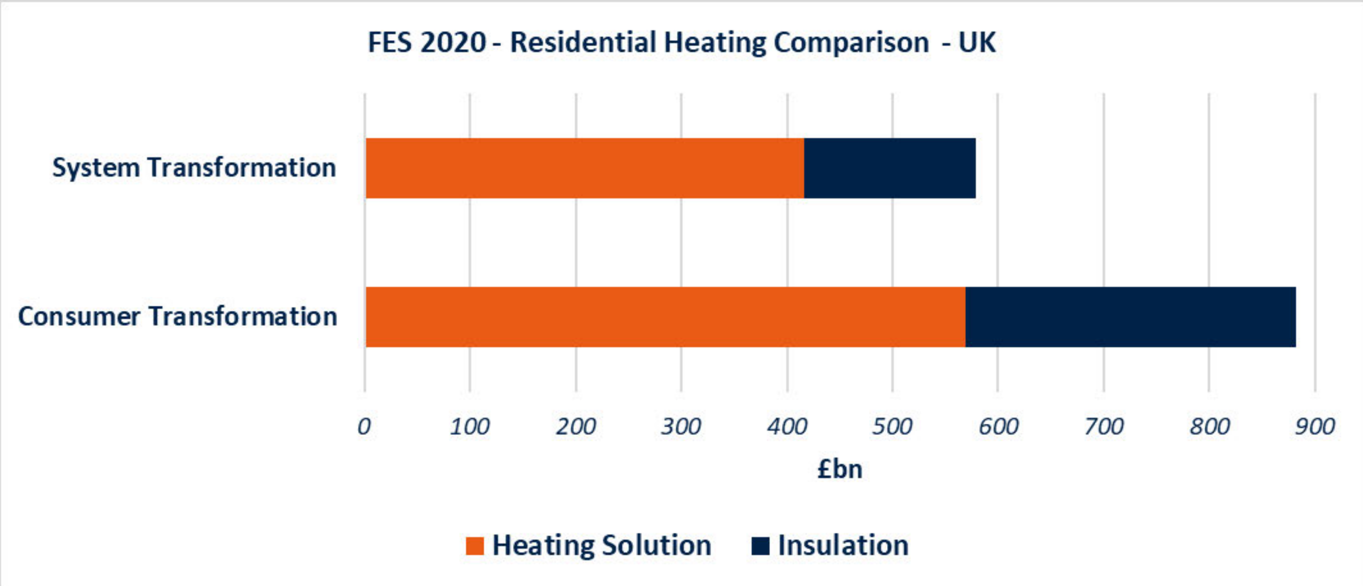

Figure 20-FES 2020 residential heating comparison [15]

Similarly, the cost benefit analysis carried out in the H100 NIC bid considered multiple studies and determined the cost for consumer for a hydrogen boiler to be £12,500 less than that for an air source heat pump, with considerably less disruption and pressure on the consumer to adapt.

As the success of LTS Futures would facilitate the optionality for customers, this value proposition applies to the work proposed in this needs case.

Our research and engagement consistently show that pursuing decarbonised energy solutions and minimising environmental impact are the two highest investment priorities for our customers. Following earlier qualitative research which showed that customers strongly supported investment to minimise environmental impact and the decarbonisation of heat, the willingness from customers to pay for environmental initiatives was assessed. This research showed that customers strongly support investment to minimise environmental impact and the decarbonisation of heat, to the extent that these two questions were each awarded the highest value in our willingness to pay research[16].

This 'first of a kind' demonstration project will deliver a LTS repurposing blueprint methodology that can be replicated and used to mobilise hydrogen market growth. The project will deliver evidence that supports the

[15] https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents
[16] https://www.sgnfuture.co.uk/wp-content/uploads/2019/12/SGN-RIIO-GD2-Business-Plan.pdf

use of hydrogen as a viable decarbonised energy vector for heat and aims to demonstrate that the costs associated with repurposing compare favorably to the electricity network upgrade costs required for electrification of heat.

Cost Benefit Analysis and Net Present Value

Scenarios

As this project proposes to carry out work of critical importance to the success of the gas industry's collective and collaborative efforts to prove and demonstrate the practical, safe and affordable energy system transition from natural gas to hydrogen, the indirect cost savings, may by applied, of pursuing a transition to hydrogen as a means of heat decarbonisation, therefore avoiding the higher costs and disruption to gas customers of installing electrified heating technologies.

The direct cost benefit of carrying out this project is the potential saving from proving the existing assets can be repurposed, therefore avoiding the more expensive option of decommissioning the existing LTS and installing a new LTS to facilitate hydrogen.

Due to the lower volumetric energy density of hydrogen compared to natural gas, there will be a requirement for new LTS pipelines to be constructed for the future hydrogen LTS network to be able to deliver the equivalent energy flowrate and linepack as the natural gas LTS network does now. The energy throughput capacity of the LTS and its energy storage capacity through linepack are dependent directly on the gas properties of the transported gas (i.e. the gas pressure and velocity)

Additional cost savings can be achieved by carrying out additional works to increase the capacity of the repurposed LTS and to prove the safe upgrading of PRS's to permit higher flowrates. These works will reduce the required length of new LTS pipelines to account for the reduced capacity for energy flow and linepack.

Table 13 below summaries the scenarios used in the cost benefit analysis of this project.

Table 13 - Scenario Summary - All GB LTS Assets

Scenario	Summary	Licensee Scale (SGN LTS Pipelines only)		GB Rollout Scale (All LTS Pipelines in GB)	
		Existing LTS Repurposed	*New LTS Constructed*	*Existing LTS Repurposed*	*New LTS Constructed*
Base Scenario	LTS across GB is fully decommissioned with a new LTS installed in its place.	0 km	3,030 km	0 km	11,000 km
Scenario 1	LTS across GB is repurposed to current gas pressures and velocities (30% capacity with hydrogen). New LTS pipelines constructed to restore capacity	3,030 km	2,103 km	11,000 km	7,635 km
Scenario 2	LTS across GB is repurposed and uprated to permit higher gas pressures and velocities, with additional work carried out to enable the upgrading of PRS installations to permit increased gas velocities. New LTS pipelines constructed to restore capacity	3,030 km	1,030 km	11,000 km	3,740 km

Base Scenario – Existing LTS is Decommissioned and a new LTS is Constructed

This scenario would materialise if the LTS Futures project was not carried out, or the project was carried out and the conclusion was that the LTS was not suitable for hydrogen and it was not practical/economical to repurpose the LTS to 100% hydrogen. This would entail the full decommissioning of the LTS, of which there are 11,000km of across GB, and the construction of a new LTS on the existing wayleaves.

It has been assumed in this analysis that any new LTS pipeline installed would be rated to carry 100% hydrogen at the equivalent energy flow rate of the existing LTS (capable of supporting fluid conditions of higher pressures and higher velocities (3.3 times the velocity of natural gas). New pipelines are also assumed to support the equivalent energy storage through linepacking of existing LTS pipelines containing natural gas.

Pipeline cost data from historical pipeline construction projects for pipeline diameter groups has been updated to 2021 values and used to estimate the cost of constructing a new LTS for hydrogen transportation.

The data was analysed to obtain average costs by diameter as shown in Table 14 below.

Table 14-Pipeline population and costs [redacted]

[redacted]

If the LTS cannot be repurposed, then the alternative is to construct a new LTS to transport hydrogen and the existing LTS will need to be decommissioned and removed in accordance with the easement / servitude for the pipeline.

Therefore, the cost of not using the existing LTS network for hydrogen is the sum of the cost of new LTS and the cost of decommissioning and removing the existing LTS.

[redacted]

[redacted]

[redacted]

Scenario 1

"The project is carried out and the existing LTS is repurposed to the equivalent pressure and velocity as the current natural gas LTS is operated at. New LTS is constructed to replace the capacity reduction due to the lower energy density of hydrogen."

This scenario would materialise if all of the 11,000 km of existing LTS were safely and practically repurposed to the current pressure and velocity conditions natural gas flows today. Hydrogen possesses a gross calorific value of 12.1 MJ/m^3, compared to natural gas's 39.55 MJ/m^3. Therefore, therefore at the same velocity and pressure, the energy flow rate (and mass flow rate) of hydrogen is 30.59% of that of natural gas.

Therefore, additional LTS pipelines are required in this scenario (note previous assumption on new pipeline's capability to carry hydrogen at the equivalent energy flow rate as natural gas (achieved through increased velocity and pressure)).

[redacted]

[redacted]

[redacted]

[redacted]

Based on what we know now, it is assumed it will cost between 15-30% of replacement costs to repurpose the LTS network. The actual cost will be determined under the live trial. This will be validated and refined with case studies and the cost of repurposing the existing LTS will be determined and fed into system transformation.

It should be noted that repurposing avoids the need to purchase new line pipe – steel production produces major CO2 emissions (1.83 tons of CO2 for every tonne of steel produced). Thus, an additional consideration is the 2.01 million tons of CO2 that be saved by repurposing and not having to produce 1.09 million tons of steel to replace the LTS[17].

While the LTS and NTS suitability is not the highest cost consideration in any system transformation[18], the cost is significant, as is deliverability.

Repurposing pipelines allows decarbonisation to occur at an accelerated rate and supports the development of a hydrogen economy, conversion and the deliverability of net zero targets for heat. Additionally, there are significant cost savings associated with repurposing as it avoids the need to incur planning costs, entering into land agreements and time.

Scenario 2

"Scenario 1 materialises, and all cost savings apply. Additional work is carried out to increase the capacity of the existing, repurposed, LTS. Further work is also carried out on PRS installations, allowing a further capacity increase, reducing the required length of new pipelines."

This scenario would materialise if the scope of the project was expanded:

- To explore the viability of repurposing the LTS and increasing the capacity, and;
- To allow further testing of PRS assets to determine if increased flowrates are possible using existing pipework and equipment.

The costs saving of this scenario is derived from increasing the capacity of the repurposed LTS for hydrogen energy flow and linepack capacity, and therefore reducing the required length of new LTS pipelines to achieve the equivalent and today's natural gas LTS network.

---

[17] https://www.theworldcounts.com/challenges/planet-earth/mining/environmental-impact-of-steel-production/story
[18] SGN North East Network and Industrial Clusters Project

To achieve the same energy flow rate through the system we need to understand if the LTS system of pipelines and pressure reduction installations can withstand the increased pressures and velocities required to deliver the equivalent energy flow rate as with natural gas.

The primary focus of the LTS Futures project is the repurposing of the existing pipeline network. The pipeline network is routed and buried on 3rd party land, and therefore presents the greatest challenge. The PRSs provide the essential connectivity and deliverability of the pipeline network, but these installations are located above ground on sites owned by the networks, and therefore there is greater scope to modify and rebuild if required.

In terms of the LTS network of pipelines and installations, the potential to increase capacity pressure is provided and limited by the pipelines, while the potential to increase flowrate is provided by the PRSs and how these relate to future hydrogen sources and supply locations.

Increasing the capacity through the uprating of pipeline pressures and the impact of increased flowrate on installations are being considered within the scope of the LTS Futures project.

The PRS testing currently scoped under FutureGrid will provide the learning relating to whether an existing NTS PRS pipework, equipment and components if of the PRS can withstand the same flow under hydrogen operation.

LTS Futures are proposing to extend this testing with an LTS PRS comprising of a range of existing regulators used across the GB network in order to assess whether increased flowrates are possible with the existing pipework and equipment, and to increase the flow rates to what we would require the network to flow in hydrogen service, to meet the current energy demand and understand whether the potential exists to increase the flow further which would further increase the capacity of the existing network. In combination with pressure uprating.

This will allow us to understand how much energy can be transported around the current network. This testing of increased flowrates is complex and requires a compressor and other equipment to increase the flows under conditions which do not impact on customer supply without having customers at the end. The estimated cost associated for flow testing and uprating a LTS PRS, regulators and equipment under such conditions is [redacted]

The proposed testing will determine the potential increase in the capacity which could be possible by increasing the flowrate through the existing LTS PRS, regulators and pipework, and will identify what additional experimental and theoretical studies are required.

This scenario assumes the project investigates increasing the capacity by uprating. A preliminary review of the GB LTS pipelines has shown there is a potential to increase the existing capacity from 0.3 of the required capacity to 0.6 if we were to uprate some of our pipelines. Additional work on PRS installations, as outlined above, could increase this further to 0.66.

This work, if successful, would reduce the required length of new pipelines at the GB rollout scale from 7635.1 km to 3,740 km, due to the increase in capacity from 0.3 (scenario 1) to 0.66.

[redacted]

[redacted]

[redacted]

[redacted]

Net present value analysis

The costs and savings outlined above have been processed through a net present value calculation.

Table 15-Scenario cost comparison

Scenario	Licensee Scale (SGN LTS Pipelines only) Cost to Customer	GB Rollout Scale (All LTS Pipelines in GB) Cost to Customer
Base Scenario	£5,404,141,350	£19,619,000,000
Scenario 1	£3,256,465,092	£11,822,153,512
Scenario 2	£2,427,376,267	£8,812,259,320

The proposed repurposing work in scenarios 1 and 2 on the existing LTS and the construction of new LTS pipelines under each scenario has been assumed to take place linearly from 2030 out to 2050 (shown in Figure 21). The rate of repurposing is likely to be different regionally in practise.

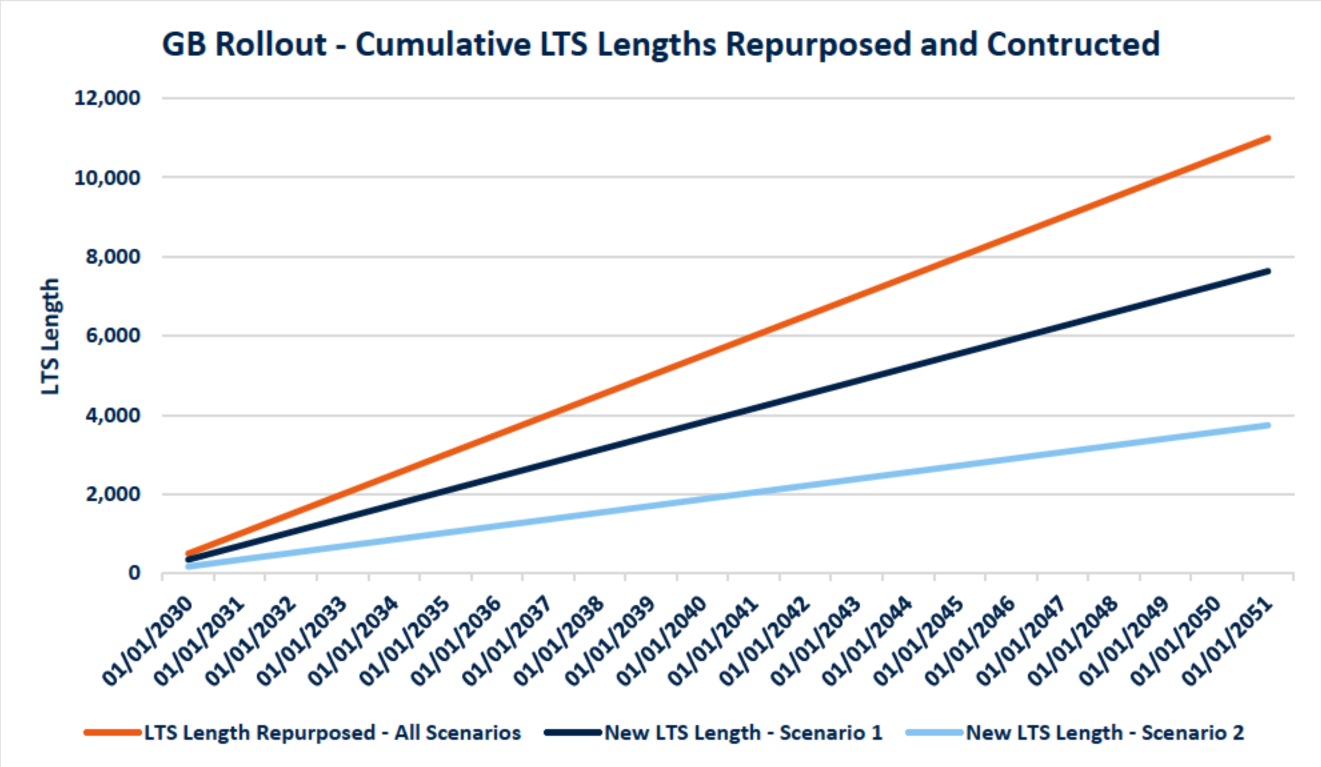

Figure 21-LTS repurposing and construction rate

As has been set out in the Treasury Green Book[19] (para 5.11), all costs and benefits in the appraisal of social value should be estimated in 'real' base year prices (i.e. the first year of the proposal). This means the effects of general inflation should be removed.

All values in the economic dimension are expressed in real prices relating to the first year of the proposal. This means that the average inflation rate is removed. Discounting is based on the concept of time preference, which is that generally people prefer value now rather than later. This has nothing to do with inflation, because it is

19 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938046/The_Green_Book_2020.pdf

true even at constant prices. Discounting converts costs and benefits into present values by allowing for society's preference for now compared with the future. It is used to allow comparison of future values in terms of their value in the present which is always assumed to be the base year of the proposal. For example if Projects A and B have identical costs and benefits but Project B delivers a year earlier, time preference gives Project B, a higher present value because it is discounted by a year less than project A.

In government appraisal costs and benefits are discounted using the social time preference rate as explained in Chapter 5 and paragraphs 5.32 to 5.39 as well as Annex 5 (of the Treasury Green Book). The reason for social discounting is to allow proposals of different lengths and with different profiles of net costs and benefits over time to be compared on a common basis. For reasons explained in Chapter 5 it does not need to be concerned with the cost of capital which is dealt with elsewhere by other means.

The STPR has two components: 11 'time preference' – the rate at which consumption and public spending are discounted over time, assuming no change in per capita consumption. This captures the preference for value now rather than later. ¨ 'wealth effect' – this reflects expected growth in per capita consumption over time, where future consumption will be higher relative to current consumption and is expected to have a lower utility.

The STPR used in the Green Book is set at 3.5% in real terms, with exception for risk to life values which use a lower rate of 1.5%.

For the Net Present Value Calculation of this CBA, the applied discount factor is 3.5%, which accounts for inflation also (which has subsequently been set at 0%).

For the Licensee scale (SGN LTS only), the total NPV savings of each scenario compared to the base scenario are presented in Table 16.

Table 16-NPV-Licensee scale

Total Saving (Net Present Value) compared to base scenario	Scenario 1	Scenario 2
2030	£74,144,322	£102,761,560
2040	£690,773,386	£957,388,900
2050	£1,163,915,657	£1,613,148,324

The total NPV Saving of each scenario at the GB Scale (all GB LTS pipelines) are similarly presented in Table 17.

Table 17-NPV-GB rollout scale

Total Saving (Net Present Value) compared to base scenario	Scenario 1	Scenario 2
2030	£269,154,147	£373,034,682
2040	£2,507,602,958	£3,475,416,901
2050	£4,225,174,857	£5,855,888,811

Appendix B - Benefits table

Method	**Method Name**							
Method 1	Scenario 1 - Saving of repurposing the LTS, thereby avoiding decommissioning and reconstruction of the existing LTS. LTS across GB is repurposed to current gas pressures and velocities (30% capacity with hydrogen due to gas properties). New LTS pipelines constructed to restore capacity of Energy Flow and Linepack.							
Net Zero Pre-Construction Work and Small Net Zero Reopener Submission – Cumulative Financial Benefits (NPV terms: £m)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**Benefit**			**Notes**	**Cross-references**
				2030	**2040**	**2050**		
Post-trial solution ***(individual deployment)***	N/A	N/A	N/A	N/A	N/A	N/A	Not applicable to individual pipelines as method supports and enables system transformation of GB gas networks from natural gas to hydrogen all its customers	N/A
Licensee scale ***(If applicable, indicate the number of relevant sites on the licensees' network)***	Method 1	3,256	5,404	£74,144,322	£690,773,386	£1,163,915,657	Application of savings (scenario 1) to SGN LTS assets (total 3,030 km)	NPV Appendix A

GB rollout scale ***(If applicable, indicate the number of relevant sites on the GB gas distribution network)***	Method 1	11,822	19,619	£269,154,147	£2,507,602,958	£4,225,174,857	Application of savings (scenario 1) to all GB LTS assets (total 11,000km)	NPV Appendix A

Method	**Method Name**
Method 2	Scenario 2 - LTS across GB is repurposed and uprated to permit higher gas pressures and velocities (66% capacity with hydrogen), with additional work carried out to enable the upgrading of PRS installations to permit increased as velocities. New LTS pipelines constructed to restore capacity. Less new LTS assets required compared to method 1

Net Zero Pre-Construction Work and Small Net Zero Reopener Submission – Cumulative Financial Benefits (NPV terms: £m)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**Benefit**			**Notes**	**Cross-references**
				2030	**2040**	**2050**		
Post-trial solution ***(individual deployment)***	N/A	N/A	N/A	N/A	N/A	N/A	Not applicable to individual pipelines as method supports and enables system transformation of GB gas networks from natural gas to hydrogen all its customers	N/A

Licensee scale ***(If applicable, indicate the number of relevant sites on the licensees' network)***	Method 1	2,427	5,404	£102,761,560	£957,388,900	£1,613,148,324	Application of savings (scenario 2) to SGN LTS assets (total 3,030 km)	NPV Appendix A
GB rollout scale ***(If applicable, indicate the number of relevant sites on the GB gas distribution network)***	Method 1	8,812	19,619	£373,034,682	£3,475,416,901	£5,855,888,811	Application of savings (scenario 2) to all GB LTS assets (total 11,000km)	NPV Appendix A

Appendix C - LTS pipeline integrity management

LTS Pipeline Integrity Management

As pipelines are routed through third party land, and are directly accessible to the public, the risks posed to the public are managed to ensure they are As Low As Reasonably Practicable (ALARP). The figure below outlines the gas industry's approach to reduction in risk through good practice, qualitative and quantitative risk analysis, and engineering judgement. Legislative requirements for managing pipelines to ensure risks are ALARP are defined in the Pipeline Safety Regulations 1996 (PSR).

A key requirement of all pipeline standards is the regulation of risk through the management of pipeline integrity. This ensures the quality and condition of the pipeline is such that it is fit for purpose to meet the operational requirements with an adequate safety margin.

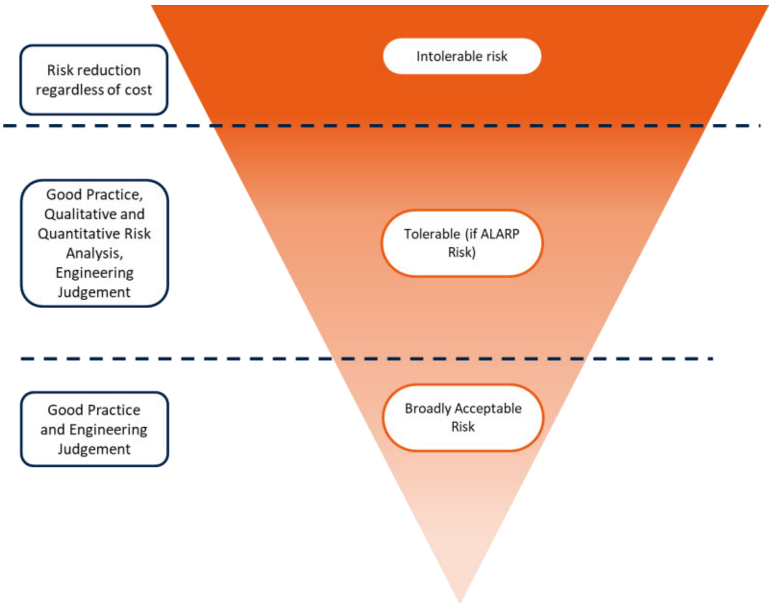

Figure 22-ALARP management

Compliance with safety legislation is generally discharged through compliance with standards. Integrity management requirements are specified in pipeline standards. The schedule and frequency of integrity management activities is optimised using operational records and data and applying operational experience.
The traditional asset life cycle follows the bathtub failure probability curve as illustrated in Figure 23 below. This curve shows an initial high probability of failure which reflects testing and commissioning failures, followed by a low, stable failure rate which gradually increases due to age and duty deterioration, and finally a significant increase as the asset reaches end of life.

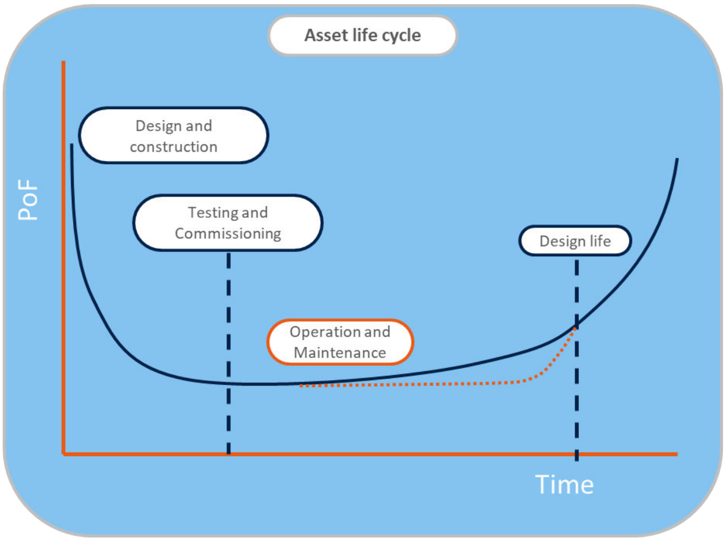

Figure 23-Bathtub failure probability curve

The operations and maintenance policy applied to gas pipelines (and all major accident hazard pipelines) is to maintain the asset integrity and confirm it through inspection. Through inspection the asset is revalidated and therefore the life of the asset is extended and the end-of-life stage is effectively removed as shown in Figure 24. Pipelines are not replaced as long as there is a business need for them. The damage mechanisms which lead to the end life of gas pipelines are due to external corrosion (time based) and fatigue (duty based). Integrity management identifies and controls the damage, and where necessary, revalidation, rehabilitation and upgrading actions are carried out.

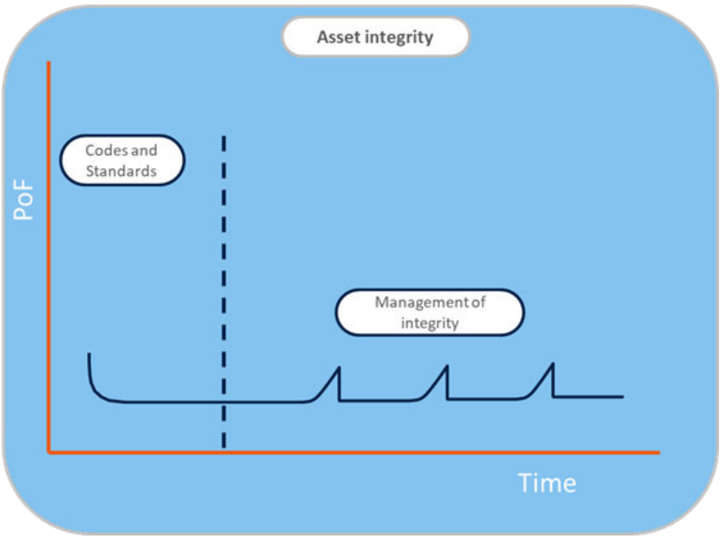

Figure 24-Asset life extended through inspection

Figure 25 highlights the pipeline life cycle for new and repurposed pipelines for the UK. The purple inner pathway provides the new pipeline life cycle including design, construction and testing, commissioning and accepting the pipeline and operation and maintenance. The orange outer pathway provides the method for repurposing of existing pipelines through initial risk assessment, revalidation, understanding hot working for pipelines carrying hydrogen and other gaps, proving the integrity of pipelines, purging and repressurising and finally repurposing the pipeline with the LTS Futures programme focusing on the earmarked [redacted] to [redacted] pipeline to be repurposed for hydrogen service. The trial will provide critical learnings on the operational and maintenance procedures required for new hydrogen pipelines.

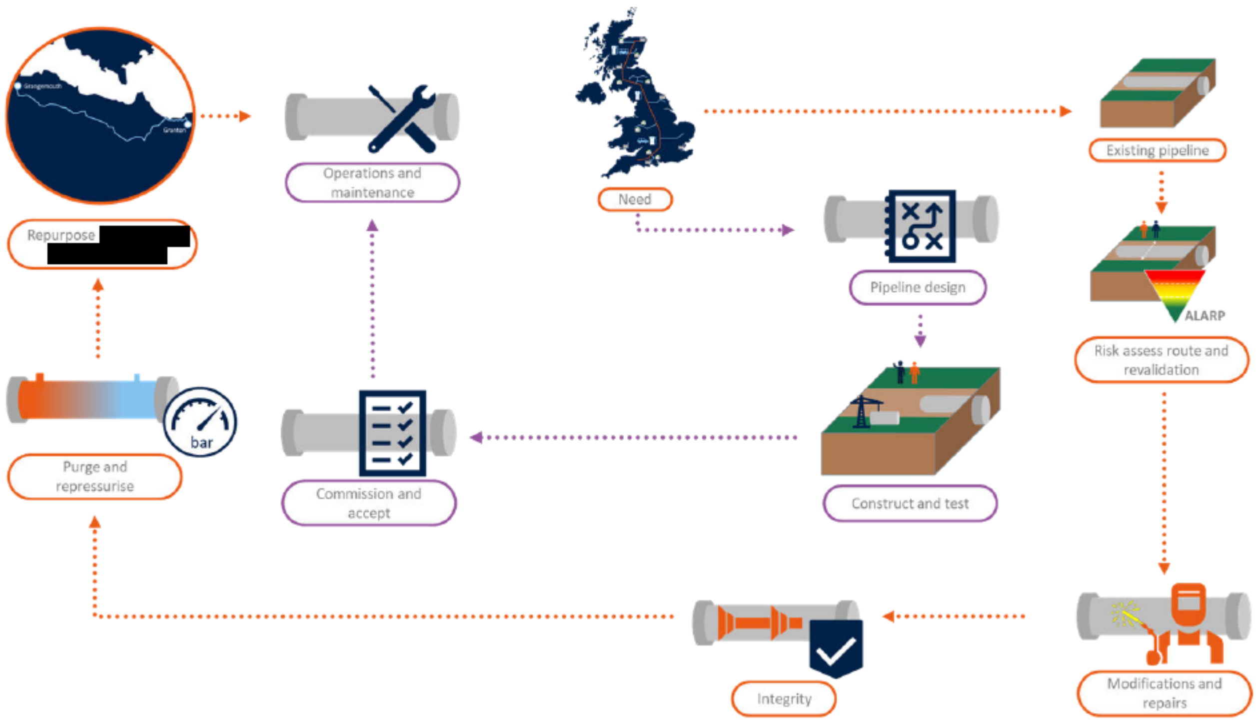

Figure 25-Pipeline life cycle for new and repurposed pipelines

LTS pipeline life transporting hydrogen

The life of LTS pipelines transporting hydrogen is dependent on the fatigue damage caused by cyclic stress due to cyclic pressure. Current research has shown that the fatigue life in hydrogen service will be lower than that in natural gas service, however the impact on the life of pipelines in hydrogen service is low because the pressure cycling experienced by LTS pipelines is low.

The pipeline original design life is normal set at 40 years as per IGEM/TD/1 standards for high pressure steel pipelines. The 40 years is based on a fatigue life based on a daily stress cycle of $125N/mm^2$ for natural gas. The transmission pipeline in the UK do not see this level of high-pressure cycling and the original design life can be extended as long as overall condition of the pipeline and pipeline route is maintained.

Whilst the vast majority of pipelines will have reached their original design life by 2045, none will have seen the daily pressure cycling which would limit their life. Provided the condition of the pipelines have been maintained, there will be no pipelines reaching the end of their design life by 2045.

Note the pressure cycling and pipeline condition is reviewed every 4 years as part of the TD/1 normal operating pressure affirmation audit.

Current research has shown that the fatigue life in hydrogen service will be lower than that in natural gas service. The supplement to IGEM/TD/1 Edition 6 has conservatively reduced the allowable number of cycles by factor of ten (10). This is conservative and will be refined after the material testing (Element 2). The impact life of the pipeline is minimal because the pressure cycling experienced by these pipelines is minimal. The records for Scotland, the South and the South East indicate that the pressure cycling is, with a small number of exceptions, less than the equivalent of twenty-five (25) cycles per year of a stress range of $125\ N/mm^2$. The estimated remaining fatigue life in hydrogen service is, for the majority of the pipelines operated by SGN, a useful life in hydrogen service of more than 50 years, as long as they continue to be maintained and managed in accordance with IGEM/TD/1 standards.

At this stage the extent of pressure cycling for hydrogen service is not known however it is thought that whilst there will be an increase in flow through the pipelines to meet energy requirements, the pipeline pressure will not be fluctuating significantly daily. The simplified approach to fatigue in IGEM/TD/1 Edition 6 and the supplement can be used to estimate the remaining fatigue life in hydrogen service given the historical pressure cycling in natural gas service, shown in the Figure 26 below.

The LTS Futures project will carry out further research to determine if the factor 10 reduction in fatigue life for hydrogen can be reduced and investigate if a more detailed study into the pressure cycling which may be required to transport hydrogen can be included in the uprating option.

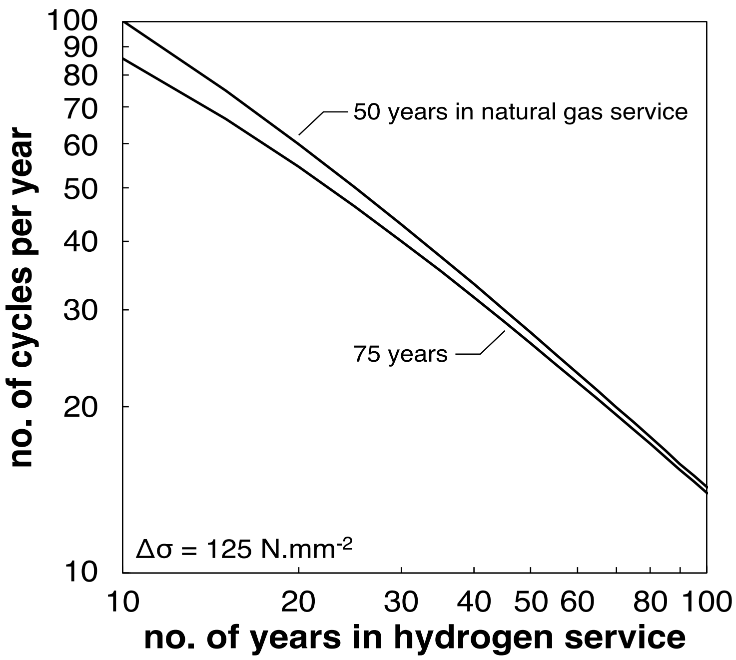

Figure 26-Fatigue life of pipelines through cyclic stress for hydrogen service

Appendix D - Uprating/capacity

Pipeline capacity is primarily dependent upon pressure as the volume is constant. The pressure induces circumferential stress in the pipeline wall, and the maximum allowable stress is defined as a proportion of the yield stress of the pipeline material, defined as the design factor. The maximum design factor is defined in pipeline standards, as 0.3 in Suburban (S) areas, and 0.72 in Rural (R) areas shown below in Figure 27. In cases where a pipeline is operating at a design factor below that defined by the standard, the pipeline may be uprated. The procedure for uprating a gas pipeline is defined in the pipeline standard IGEM/TD/1. The procedure requires a reassessment of the pipeline to confirm:

- The design factor at the proposed increased pressure meets the requirements of IGEM/TD/1;
- The condition and integrity with respect to damage tolerance is acceptable;
- The increased risk resulting from the increased pressure is acceptable and is in accordance with the UK risk framework specified by HSE.

Uprating of pipeline pressure defines the maximum operating pressure (MOP) of the pipeline. The normal operating pressure (NOP) of the pipeline is below the MOP, and the difference between the MOP and the NOP defined the pressure range available for line pack. Consequently, pipeline uprating provides the opportunity to increase the capacity of a pipeline by increasing the pressure (MOP) and increasing the pressure range available for line pack.

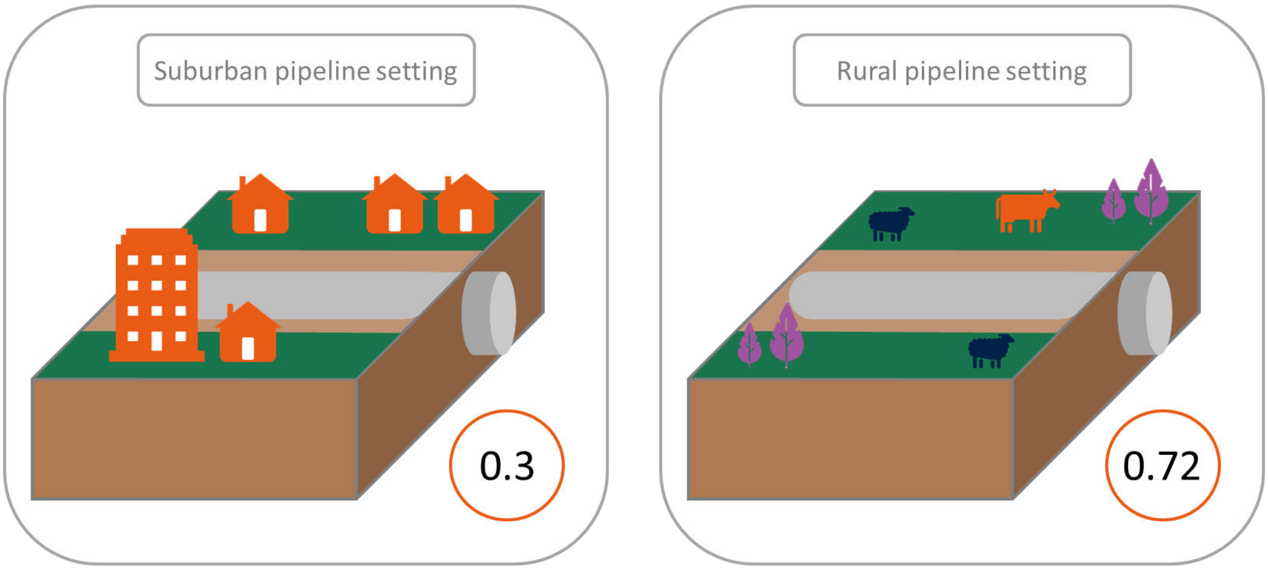

Figure 27-Suburban and rural pipeline settings and associated design factor

The current pipeline design factor informs the scope for pipeline uprating to potentially provide additional capacity. LTS Analysis of the GDN LTS data indicates that 92% of the LTS by length operates at a design factor of 0.5 and below, 67.4% of the LTS pipeline population operates at a design factor of 0.3 and below, and approximately 30% of the total population operates at design factors less than 0.2.

The pipeline standard ASME B31.12 and the hydrogen supplement to IGEM/TD/1 edition 6 allow operation of pipelines constructed using material grades of X52 (L360) and below at design factors up to 0.5. Assuming that LTS pipelines can theoretically operate at design factors up to 0.3 in Suburban areas and 0.5 in Rural areas this indicates that there may be capacity in the LTS pipeline system which could be made available through uprating.

Although design factor is a critical factor in assessing the uprating potential for a pipeline, there are a number of other factors that must be considered in this assessment such as pipeline diameters, material grade, wall thickness etc. Our natural gas system is unique in the way it behaves, evolving to the different supply and demand patterns and needs of downstream systems. This means that pipelines within the system will be designed and constructed to ranging specifications. With transition to 100% hydrogen potentially changing the geographical supply of gas from NTS feeds to industrial cluster and downstream tie ins, LTS uprating potential must take this into account. An assessment of the requirement for pipeline uprating to cover the reduced energy content of hydrogen compared with natural gas is required.

Energy delivery

The delivery of heat and energy in a gas network is measured by multiplying the gas flowrate by the calorific value (CV). The CV depends upon the gas composition and it is energy released when a known volume of gas is fully combusted under specified conditions. When measured at UK metric standard conditions of 15 ^{0}C and 1013.25 kPa, the CV of natural gas is approximately 39 MJ/m^3. For hydrogen, under the same specified conditions, the CV of gas is approximately a third at 12 MJ/m^3. Measurement of CV is fundamental to gas network operation as it enables the gas transporter to understand the amount of energy transported in the network and how much to bill customers. With transition to 100% hydrogen, energy delivery capacity within the LTS will fall by a factor of 0.3 if current natural gas operating conditions remain the same.

To ensure the same delivery of energy to customers with transition to 100% hydrogen, we must alter the conditions within the pipeline. There are two main factors that can be changed – we can increase the volumetric flow of gas within the pipeline (increase the gas velocity) and/or increase the pipeline pressure (known as uprating).

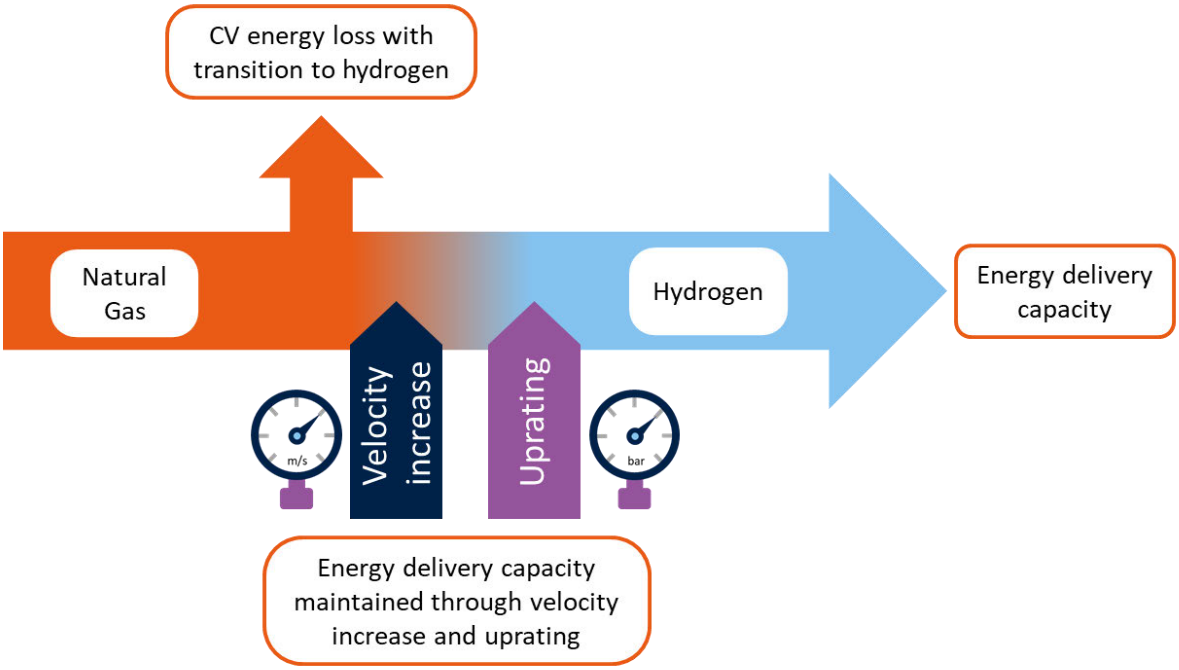

Figure 28-Uprating and velocity increase to account for hydrogen CV

Raising the Maximum Operating Pressure (MOP) of pipelines increases the potential throughput as gas within the pipeline can be moved more efficiently, therefore improving the energy delivery capacity to customers. Increasing the MOP of pipelines needs to be done safely and it will be dependent on a number of factors such as the construction of the pipeline, testing level, the pipeline materials specified minimum yield strength (SMYS) and pipeline route to identify any building proximity distance safety implications.

Linepack capacity

Linepack refers to the volume of gas stored within the higher-pressure tiers of transmission. Linepack must stay above the minimum required to ensure sufficient gas pressures but below the maximum operating pressure of the pipeline. The ability to compress and expand gas within this range is referred to as linepack flexibility and this is what allows the upper pressure tiers of the gas networks to act as a form of diurnal storage. Gas Network operators use linepack flexibility to respond to discrepancies in supply and demand as illustrated in Figure 29[20]. There are design limits on how much a pipeline can be cycled between the maximum and minimum pressures to maintain material integrity and avoid fatigue damage.

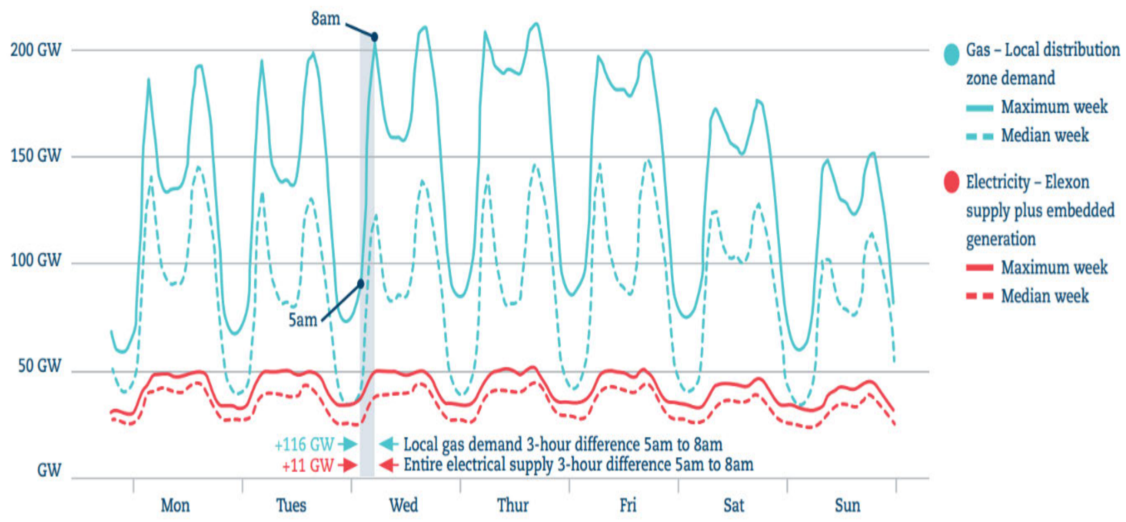

Figure 29-Diurnal variability in gas demand (Beast from the east 2018)

For 100% hydrogen, as a result of the difference in energy density by volume between hydrogen and natural gas, approximately 3.4 times the volume is required to provide the same line pack energy equivalent as natural gas. This is shown in Figure 30.

[20] https://www.birmingham.ac.uk/news/latest/2018/08/gas-consumption-beast-from-the-east-gas-system.aspx

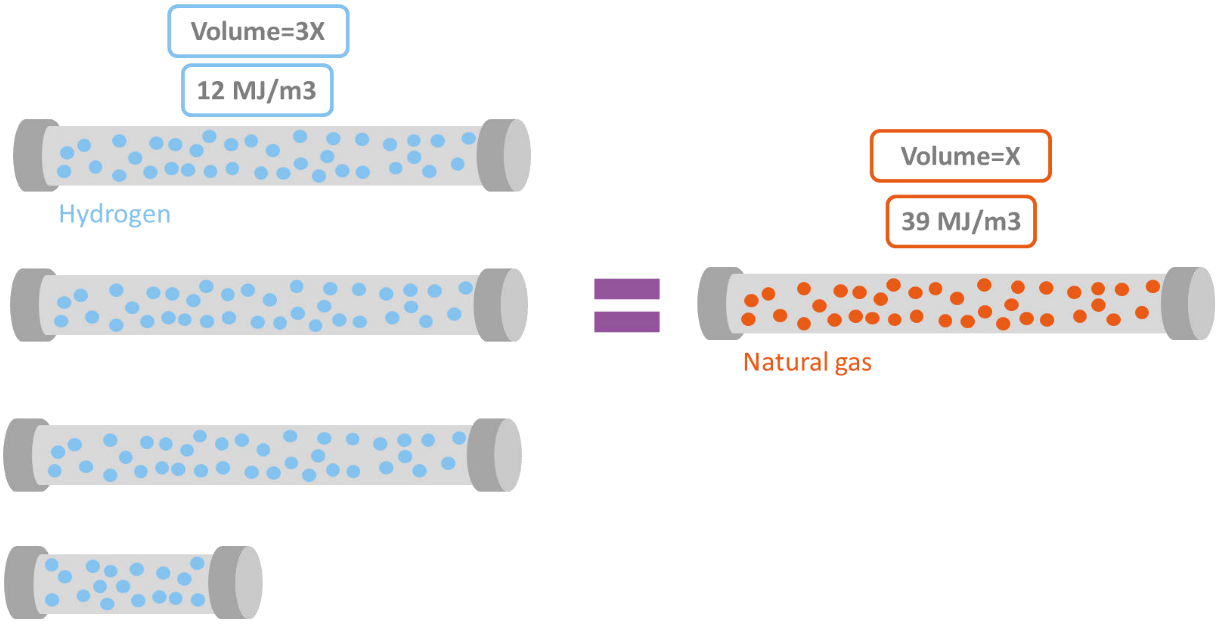

Figure 30-Linepack volume required to store the same energy value

Uprating of LTS pipelines raises the MOP of the pipeline and therefore the ability to further compress gas improving linepack flexibility. This will be key to minimising losses in linepack with the transition to 100% hydrogen from natural gas.

The delivery capacity of a pipeline used to provide diurnal storage, such as LTS, is a combination of transmission capacity and storage capacity (useable linepack). If the pipeline is being fully utilised to meet downstream demand, then the available linepack is zero and there is no storage capability. If the downstream demand is less than the transmission capability of the pipeline, then the “spare capacity” can be utilised to store gas in the form of linepack.

Most LTS natural gas networks in the UK operate on a fixed hourly flow from the National Transmission System with the downstream LDZ diurnal demand variation being absorbed by the linepack storage. As a result of a decision to keep NTS flows as stable as possible, the planning of the LTS has required the pipeline network to be able to deliver both the downstream demand requirements and the diurnal storage requirement. Where the LTS does not have sufficient capacity to meet the demand and diurnal storage needs of the LDZ, then some profiling of the flow from the NTS can be sought i.e. taking a higher rate during the day when demand is higher and less at night when demand is reduced.

The capacity of an LTS pipeline is dependent upon:

- pipeline diameter and length
- operating pressure
- flow rate and flow regime
- pressure drop due to flow
- fluid velocity

Pipeline design generally involves the assessment of transportation capacity to meet stable, steady state conditions. Additional factors which affect transient operating conditions include, operating philosophy (volumetric or pressure controlled at gas entry to network), the line pack requirement and location of storage. The actual capacity of a pipeline system is dependent upon several interacting factors, including pressure management requirements (minimum and maximum inlet and outlet pressures), line pack requirements and availability, location of any storage facilities and any additional input points. The design of the pipeline system must consider these interacting factors, and these are also important when considering the transition of an existing LTS network from transporting natural gas to transporting hydrogen.

The existing LTS pipeline system is designed to transport natural gas supplied at volumetrically controlled Offtakes from the NTS with the flows based on flow set points derived from daily nominations from LDZ System Control. The LTS transports the natural gas to pressure reduction stations feeding the lower pressure tier networks.

The operating philosophy of a system in hydrogen service will be different and will depend upon hydrogen supply locations and operating parameters, and hydrogen storage locations and capabilities, which are currently undefined. If the LTS is repurposed for hydrogen (particularly if the LTS feeds the whole LDZ) then how this would be achieved must be included in any conversion study. The same issues will have to be addressed i.e.

6. the location and delivery capability of the hydrogen supplies (pressure, flow variability, speed of response to change in demand etc.)
7. The downstream demand profile and the carrying capacity of the pipeline with hydrogen
8. The remaining useable linepack storage given the requirement in item 2

Assessment of the capacity of the LTS under the current operating conditions allows the supply of energy for heat provided by natural gas to be determined. The capacity of the existing LTS to supply energy for heat provided by hydrogen requires consideration, noting that some parameters are fixed (e.g. diameter, length) and some parameters will need to be limited (e.g. design factor). The appropriate design standards need to be confirmed (pipeline MOP options, proximity distances etc.) but the consequent network capacity assessment will not be significantly different to the current process for capacity assessment.

Appendix E - Why [redacted] to [redacted]

Trial pipeline [redacted] to [redacted]

The following identifies key characteristics that illustrate why the [redacted] to [redacted] pipeline is the optimal choice for live trial demonstration of hydrogen within an existing LTS pipeline, in addition to detailing technical operations to be completed under the live trial.

- The 30 km [redacted] to [redacted] pipeline is currently non-operational and filled with nitrogen. The pipeline is a typical LTS pipeline and its parameters, characteristics and route provide an excellent statistical representation of, and proxy for, the GB LTS pipeline population. As the pipeline is currently non-operational, adoption for the trial does not present a security of supply issue or diversionary requirement to facilitate the test.
- The material grade is the most significant determinant of the pipeline's suitability for hydrogen however the diameter, age, wall thickness, external coating, ancillary fittings and other factors have been considered as the part of the statistical analysis and all will factor in the overarching Quantified Risk Assessment (QRA) and blueprint for future pipeline repurposing.
- In order to ensure maximise learning from the project it is important that key and representative features of the LTS are captured in the live trial. Understanding how these features interact with each other and hydrogen will be validated in a controlled demonstration.
- The [redacted] to [redacted] pipeline provides the upper bound case material for the LTS. 93% of the population of LTS pipeline assets are comprised of these material grades. The pipeline's construction includes key components which are typical 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.

> By using a vintage X52 pipeline for the trial, we have confidence that we can apply the results to pipelines of grade B, including X42 and X46

- Prior to the start of the live trial, evidence and mitigation measures developed from the offsite trials will be used as inputs to the quantitative risk assessment and the case for safety for the [redacted] to [redacted] pipeline. The live trial will only proceed once we can demonstrate it can be carried out safely.
- An important aspect of the trial will be to show that LTS pipeline materials are compatible with hydrogen and that integrity is not compromised by conversion. An optimum trial will use a pipeline that has parameters that make it more sensitive to hydrogen degradation while also being representative of the LTS system as a whole.
- The [redacted] to [redacted] pipeline also presents an excellent opportunity due to its route and location. It passes through rural and suburban areas and includes key environmental features that influence the safe operation and management of LTS pipelines within GB (Figure 31). These features include major and minor road, rail and river crossings, crossings of other high-pressure pipelines, power network proximity and buried utilities.
- Road crossings, for example, impact the failure risk due to proximity to traffic and consequences of failure in terms of disruption and access. Traffic loading can increase stress and fatigue, which could be exacerbated by hydrogen embrittlement. The route also passes occupied premises, where building proximity distances (BDP) evidenced under the pre- work can be tested and validated as part of the planning process. The route includes locations where 3rd parties may carry out legitimate activities close the pipeline which may cause damage.

- There are population infringements (which exist on the majority of the LTS) which will require assessment using a new QRA methodology. Major roads, the airport, the river Forth, and key motorways all will test the repurposing process. Each of these features will feed into a statistically representative risk assessment and blueprint for LTS repurposing for any pipeline in GB.

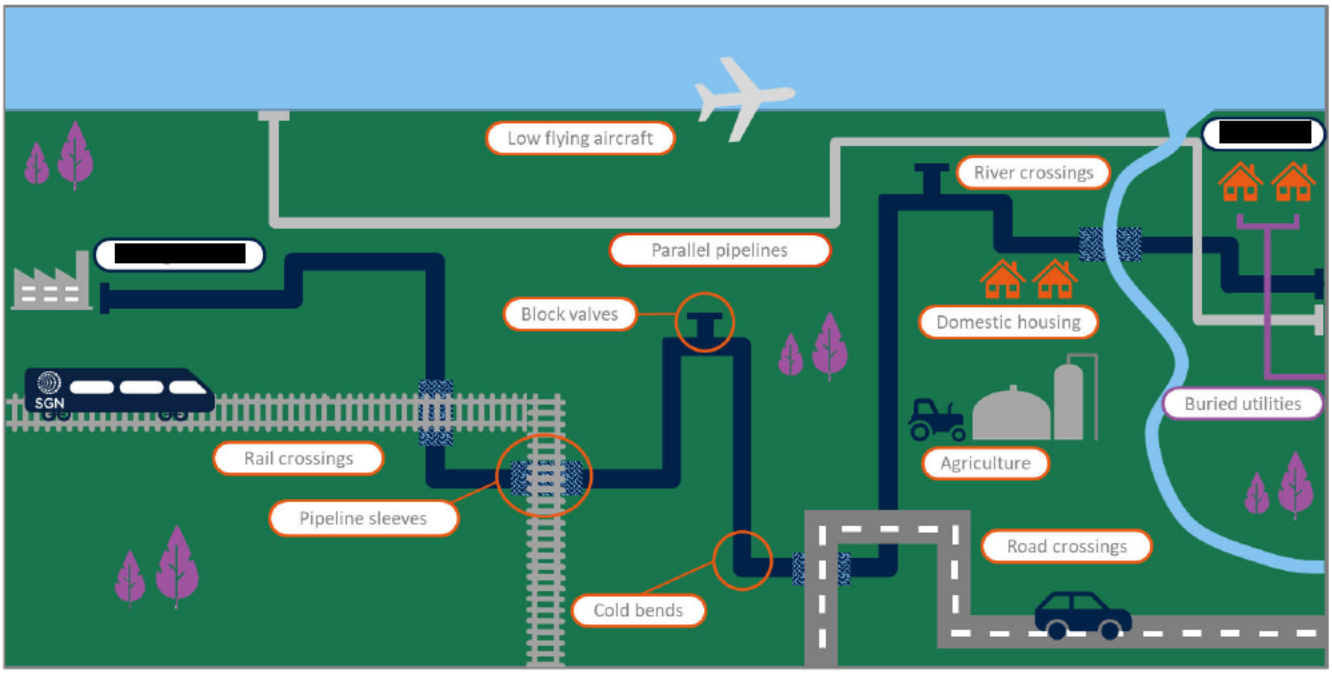

Figure 31 [redacted] to [redacted] key features

A key deliverable of the project is to develop and test incident response and ensure this applicable to as wide a range of major accident hazard pipelines (MAHPs) and features of LTS pipelines as possible. This will be the first repurposed hydrogen transmission pipeline to have an emergency response incident designed and simulated with participation from key stakeholders. The learning and procedures developed will be incorporated into the blueprint.

Live working is essential to progress the technology readiness of hydrogen in pipelines, informing the development, testing and application of key operational and emergency procedures, and the requirement to train staff in the application of procedures. The management procedures, work instructions and training will be directly applicable to any repurposed LTS pipeline and form part of the blueprint.

Appendix F - Hydrogen supply options

Several options were considered for the supply of hydrogen required for the live trial. The options were focused on each end of the pipeline [redacted] because of the need to safely undertake operations throughout the trial, such as pigging the pipeline and purging to hydrogen as part of commissioning. The options considered were:

- Tanker Supply at [redacted] – **Not viable**
- Tanker Supply at [redacted] – **discounted due to cost and complexity**
- Supply via a pipeline from [redacted] – **Preferred option.**

Tanker Supply at [redacted] PRS

Not viable – Insufficient space at [redacted]

The [redacted] to [redacted] pipeline terminates within [redacted], which is situated within an urban environment with Edinburgh College, domestic properties, roads and a mobile phone mast all in close proximity to the site. There are no suitable hydrogen production facilities close enough to the site to consider using so the only option for hydrogen supply at [redacted] PRS is via road tankers.

An assessment of the [redacted] footprint highlighted that the site is very restricted (50x70m) and doesn't have sufficient space to accommodate a hydrogen tanker delivery option without expanding the site. The [redacted]

[redacted]

Tanker Supply at [redacted]

Viable – discounted due to cost and complexity

The [redacted] to [redacted] pipeline terminates with a pig trap [redacted] therefore a site would need to be developed to supply hydrogen for the live trial operation. Following discussions with [redacted] the location shown in blue in Figure 33 has been identified as potentially suitable for a tanker offloading site. We initially enquired about using the areas shown in orange in Figure 33 (one surrounding the pig trap location and another to the north of the pig trap) [redacted] have plans for that land so the much smaller blue area is the only land close to the pig trap [redacted]. The size of the potential site is at the smaller end of what is possible for a tanker unloading facility and the shape not optimal for tanker movements.

This option would include:

- A temporary tanker unloading bay with a depressurisation unit to reduce the hydrogen pressure.
- A hydrogen entry unit: Metering, chromatograph, and flow computer, required for linepack validation and odorization.
- An E&I kiosk containing the flow computer for the metering and all other instrumentation and electrical equipment required.
- An incoming power supply kiosk.
- Ducting for E&I cabling.
- Temporary flare to dispose of hydrogen after the trial.
- Steel high pressure pipework to connect the depressurisation unit to the metering and odorization skid and the whole site to the [redacted] to [redacted] pipeline.
- [redacted]
- Safety barriers to prevent the tankers from impacting any of the equipment on site.
- Site office and welfare facilities. The site will be manned 24/7 during commissioning the pipeline to hydrogen.

[redacted]

Extensive market engagement with potential suppliers of hydrogen has determined BOC are the supplier most likely to be capable of meeting the requirements of the project. At a pipeline pressure of 19barg, the [redacted] to [redacted] pipeline will have a total capacity of 9.2tonnes. BOC quote the maximum usable capacity for a single tanker of hydrogen to be 220kg. Filling the pipeline using a supply via tankers will require 40 deliveries continuously supplying to ensure a safe commissioning to hydrogen. The tankers would be supplied by BOC from St Helens which is a 5-hour journey to the proposed site at [redacted] A realistic approach to filling the pipeline for this option would involve 4 hydrogen tanker deliveries per day to the site, with a total fill time of approximately 10days. The extensive number of deliveries required for this option could have a significant impact on the local community, especially as tankers would be required throughout a 24-hour period.

We operate several sites with tanker suppliers, 4 Liquified Natural Gas (LNG) sites in Scotland and a biomethane virtual pipeline near Portsmouth. There are significantly greater risks associated with a facility to download compressed hydrogen compared to a more conventional pipeline connection. These include:

- Human factors associated with frequent connection/disconnection of tankers. There will be a minimum of 80 deliveries during the project.
- Human factors associated with manoeuvring 2 tankers close to each other at change over. There will be minimum 80 tanker deliveries during the project and the site is small and not an optimal shape.
- Integrity, venting and purging of high-pressure (HP) hoses. Every tanker delivery will require a small amount of hydrogen to be vented as part of disconnecting the HP hoses.
- Monitoring for prolonged periods of time during tanker downloading.

The operation to commission the [redacted] to [redacted] pipeline to hydrogen via a tankered supply would require a continuous supply of hydrogen during the purging phase to ensure that the hydrogen and nitrogen don't mix. If a tanker is delayed on the journey from St Helens and a continuous supply cannot be maintained, gases within the pipeline will mix and the commissioning operation will have to be aborted. In this case the pipeline would have to be purged back to nitrogen from the [redacted] end and another commissioning operation arranged. This would cause several problems, firstly, the cost and time for the nitrogen purge and having to do the commissioning operation again but more importantly the safety risk of flaring a mixture of hydrogen and nitrogen. This would not flare cleanly due to the presence of a significant percentage of nitrogen.

This option was discounted due to the increased operation risks compared to a pipeline, the impact on the local community of tanker deliveries 24 hour a day for 10 days on multiple occasions and the risk of having to flare a mixture of hydrogen and nitrogen under a flight path if a tanker is late during the commissioning operation.

Key assumptions made

The following assumptions have been made in developing this option:

- BOC can supply hydrogen tankers at the required intervals 24/7 for the duration of the commissioning operation.
- A minimum of 3 fills will be required for the live trial. If more than 3 fills are required, this cost increases at a significantly greater rate than a pipeline supply.

Option Cost Estimate

The same process for developing the costs was used for all options and is discussed for the whole project in section 6.1 under Reducing Cost Uncertainty.

Table 18-Cost breakdown-Tanker Supply

[redacted]

These costs exclude SGN resource cost.

Supply via Pipeline from [redacted] [redacted]

Viable – Preferred option

There are two options of hydrogen supply from [redacted] [redacted]

[redacted]

Figure 34-Pipeline route options

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

We have selected the lowest cost route (option 4) as the preferred option, however there are several complexities on the route which could change the route during the design process.

A pipeline tie-in to an existing hydrogen supply ensures that the [redacted] to [redacted] pipeline can be purged from nitrogen to hydrogen and filled multiple times to support line pack validation assessments and presents considerably lower operation risks compared to a tanker supply.

This option would include:

- A ≤3” steel pipeline from the supply point in [redacted].
- A hydrogen entry unit: Metering, chromatograph, and flow computer, required for linepack validation and odorization.
- An E&I kiosk containing the flow computer for the metering and all other instrumentation and electrical equipment required.
- An incoming power supply kiosk.
- Ducting for E&I cabling.
- Temporary flare to dispose of hydrogen after the trial.
- Steel high pressure pipework to connect the incoming 3” supply pipeline to the metering and odorization skid and the whole site to the [redacted] to [redacted] pipeline.
- [redacted]
- Site office and welfare facilities.

[redacted]

- [redacted]

[redacted]

The LTS Futures programme will be undertaking a feasibility study into the pipeline route between November 2021 and February 2022

Key assumptions made

The following assumptions have been made in developing this option:

- A pipeline route option 4 shown in Figure 34 is possible. This will be determined by a Feasibility Study to be undertaken between November 2021 and February 2022.

Option Cost Estimate

The same process for developing the costs was used for all options and is discussed for the whole project in section 6.1 under Reducing Cost Uncertainty.

Table 19-Cost breakdown pipeline supply options

[redacted]

These costs exclude SGN resource cost.

Appendix G - Technical project description

Offsite testing

A programme of specific hydrogen hot working tests, hydrogen release tests and equipment operability and functionality tests will be carried out [redacted] The addition of the LTS component and ancillary fittings completes the site from system entry to end user. All the offsite testing will be validated through the live trial in a controlled environment.

- **Hot work testing**

Currently the industry has no recognised means of live working, known as hot work, on hydrogen pipelines. The LTS and NTS require this to complete live repairs, as well as constructing diversions and new connections.

Hot work tests will determine the procedural requirements for drilling, tapping and welding required for modifications and repairs on live hydrogen pipelines and assess the performance of the associated equipment under hydrogen service.

The test will involve welding a split sleeve and split tee onto LTS pipes [redacted], and drilling through the tee. The test will confirm that drilling (i.e. a hot tap) into a live hydrogen pipeline can be carried out safely, with consideration of embrittlement and hydrogen cracking. The performance of the associated drilling and sealing equipment will also be assessed. In addition, a grouted tee will be installed and tested. All 3 repair options will be mechanical. These will be subjected to fatigue testing to ensure there are fit for a live hydrogen pipeline. A procedure for hot tapping and welding on hydrogen pipelines will be produced for validation under controlled conditions under the live trial, this will include training of operational personnel and confirmation of expert contractor procedures.

The hot tap and welding procedure, the required training for operational personnel and the requirements for confirmation and demonstration of expert contractor competence will be included in the repurposing blueprint for application on NTS and the LTS pipelines. This will ensure the operational capability to carry out live repairs and modifications on both pipeline populations.

- **Delayed ignition causing potential overpressure from hydrogen vent stacks testing**

Significant overpressures may occur due to delayed ignition of a large hydrogen release. Venting of pipelines, pipework and equipment is an essential operational requirement for maintenance, repair and replacement activities. Tests to simulate delayed ignition of releases will be carried out at vents incorporated in the LTS pipework [redacted], where overpressure and noise at various distances from the vent will be measured.

The results of the tests will inform the QRA and the blueprint, but also identify any required changes to the industry standard for venting, IGEM/SR/23, for application to hydrogen systems. The revised requirements to operational venting procedures will be applied to the [redacted] to [redacted] live trial and compared with the equivalent procedures applied to natural gas pipelines, to assess changes to the safe management of and safe distances applied to standard operational venting. This will include training requirements for of operational personnel. The revised requirements and training requirements for operational venting procedures will be incorporated into the blueprint for application in the future operation of NTS and LTS pipelines in hydrogen service.

- **Stabbings and auxiliary fitting vibration testing**

There are a number of stabbings and auxiliary fittings (for example drain points, attachments for pressure gauges etc) on LTS pipelines. Damage to such fittings can be caused by vibration in the pipeline, leading to cracking and potential leakage.

Testing [redacted] will consist of visual and vibration testing to identify any potential issues. The live trial will provide a 'real-life' comparison enabling inspection procedures to be developed (if different to inspecting for natural gas).

This learning will be used in the repurposing blueprint to identify the key issues for consideration with stabbings and auxiliary fittings on other pipelines when transporting hydrogen.

- **PRS operability and functionality testing**

Equipment operability and functionality testing proposed under the project includes PRS testing [redacted]

The PRS testing currently planned under FutureGrid will assess if a representative PRS can withstand the same flow under hydrogen operation. The LTS Futures project is proposing to expand the planned testing by installing [redacted] a PRS removed from network operation due to diversionary works [redacted] This PRS has been in service for >30 years and will allow testing of increased flow rates and pressure to understand its uprating potential and compatibility with increased pressure, flow rate, and velocity.

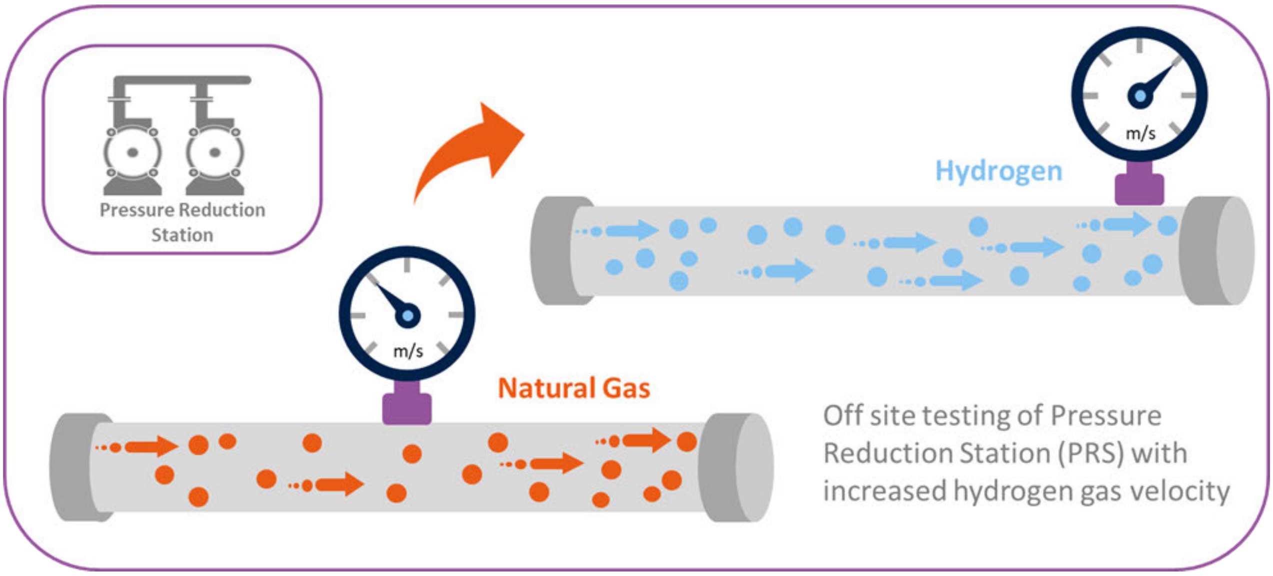

Figure 35-Hydrogen gas velocity testing for PRS

A series of operability and functionality tests will be carried out on an LTS PRS [redacted]. Subjecting the equipment to different hydrogen flow rates at varying pressures will provide evidence of how it will perform, particularly with regards to noise and vibration and also provide an understanding of the impact of hydrogen on the equipment.

The PRS testing will identify if there are differences in operating the equipment in a 'real-life' situation whilst enabling operating procedures to be developed and validated. Management procedures, work instructions and training will be developed to support operation and maintenance the equipment, informing the blueprint.

- **Burst and fatigue tests of defects**

Research indicates that hydrogen will degrade material fracture toughness and ductility such that tolerance to defects is reduced and fatigue crack growth is increased. This will reduce the failure pressure of pipeline defects in hydrogen service and increase the probability of failure of pipelines subject to damage in operation.

Burst tests in the same material as some of the small-scale tests will be carried out to determine the reduction in failure pressure. The tests will involve machining defects into a pipe section and pressuring the pipe section to failure. Fatigue tests will be carried out by subjecting a pipe section containing seam and girth welds to cyclic pressure until failure due to through wall fatigue cracking occurs.

The results of the tests confirm whether the failure pressure of defects and the number of pressure cycles to fatigue failure reduce for pipelines in hydrogen service. The revised probability of failure results will inform the QRA.

The test results will be used to provide procedures for safe damage assessment and monitoring of pressure cycling. The revised procedures for damage assessment and fatigue monitoring will be applied to the [redacted] to [redacted] in a controlled environment under the live trial. The procedures will be compared with the equivalent procedures applied to natural gas pipelines to assess changes which will affect the future operating life and the rate of repair of this pipeline in hydrogen service. This will determine whether existing defects will require repair and the allowable number of pressure cycles which may be tolerated between monitoring and inspection. The revised procedures and training requirements will be incorporated into the blueprint for application in the future operation of NTS and LTS pipelines in hydrogen service.

- **Hydrogen measurement unit**

We have included the measurement system for linepack validation as a single skid mounted unit that can be validated [redacted] and then moved to [redacted] for the live trial.

The entry unit will include inter alia:

- flow meter,
- chromatograph,
- flow computer,
- odorisation unit
- instrumentation and control system

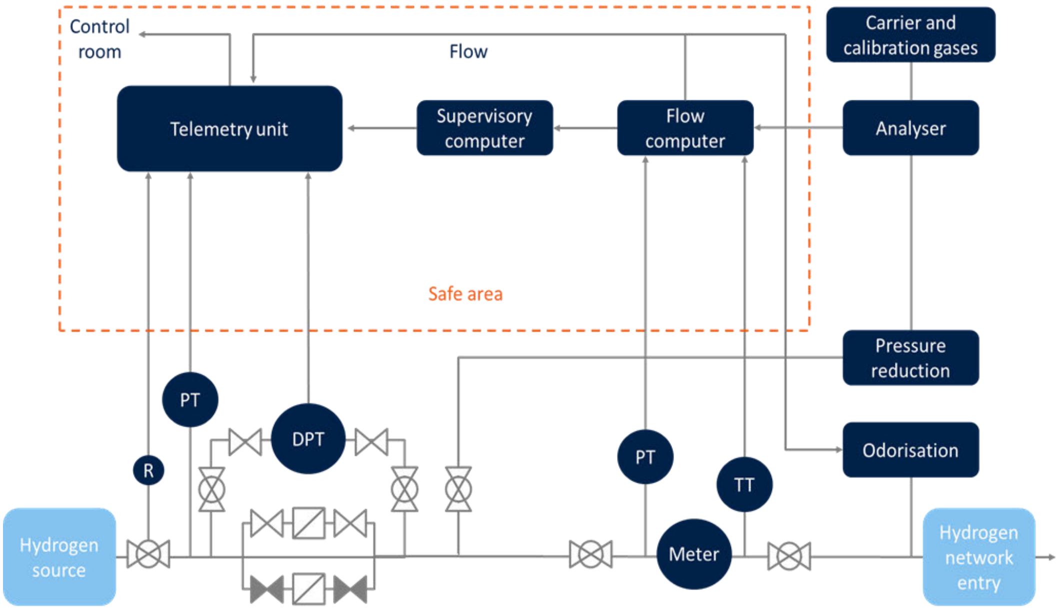

Figure 36-Hydrogen measurement unit

All of the testing to be completed [redacted] will feed into the operational and maintenance procedures for the live trial, the QRA and ultimately the blueprint.

The skid-mounted unit will intend:

- To provide high-quality measurements suitable line pack and capacity calculations and analysis
- To demonstrate compliance with regulations including hydrogen quality, safety (odorisation) and protection of downstream assets.
- By first installing the skid [redacted] under well-bounded and controlled conditions, we can first check and validate that the skid and measurement systems work accurately with hydrogen. Following assurance that the system, measurements, designs and documentation are safe, accurate and working properly [redacted] the skid could then be moved to the [redacted] to [redacted] pipeline for the live trial. This will enable us to control the variables in line with standard scientific methods.
- To be the first-of-a-kind hydrogen measurement system for measuring the flow and quality of gas entering the LTS at a custody transfer point and to be able to transmit flow and quality data to a control room

Live trial

The live trial will validate a number of the previous findings and conduct various simulations, training and exercises. The four main exercises carried out on the demonstration pipeline will include:

Emergency Response Simulation

Hydrogen pipelines are Major Accident Hazard Pipelines (MAHP), the emergency services are the first responders in the event of an accident, and the Local Authority (LA) must prepare an emergency plan which satisfies legislation. As this will be the first hydrogen pipeline repurposed, it will provide the foundation and blueprint for how to do deal with an emergency incident. The response of the emergency services is specific to the pipeline location and route and what they have to deal with in the location. The LA must be satisfied that the location of a major accident hazard is acceptable. The HSE must be satisfied that public safety is being addressed. The live trial will ensure all these factors are incorporated into the blueprint. The high-level stakeholder plan detailed below provides the LA, emergency services and community groups will be involved.

Linepack assessment

Linepack is the amount of stored energy (gas) contained within the higher-pressure tiers of Britain's gas transmission and distribution network. The routine daily use of linepack flexibility (driven primarily by changes in demand for space and water heating) points to the critical role of this stored energy in providing flexibility to Britain's existing energy systems. For 50% of the days during the October to March heating season, the within-day flexibility was greater than 377 GWh[21].

The linepack and energy content of natural gas pipelines changes with the gas composition during the day. As pure hydrogen is not a mixture of gases, linepack assessment once validated should be more accurate. The measurement systems for linepack calculations are currently made at a minimum of two points. At the entry point to the LTS there is a full metering and gas quality measurement system which also serves as a custody transfer point between the NTS and the GDN. At the exit point of the LTS there will be a pressure measurement.

Changing from natural gas to hydrogen will significantly reduce the energy that can be stored as linepack. The live trial of a statistically representative and sufficient length will seek to validate the measurement systems and data collection required to calculate linepack in hydrogen LTS pipelines.

Uprating and Capacity

Pipeline capacity studies are required to investigate the potential capacity in LTS pipelines when transporting hydrogen. The work to be carried out in the LTS Futures Project will consider the potential for uprating the pipeline pressure and flowrate, so that the potential increase in pipeline capacity can be assessed, and how this

[21] https://d2e1qxpsswcpgz.cloudfront.net/uploads/2020/03/ukerc_bn_linepack_flexibility.pdf

will impact on pipeline storage capacity provided by linepack. Studies will centre on analysis of the [redacted] to [redacted] pipeline trial, and uprating and network analysis case studies of selected LTS pipelines.

Hot working

From the gap analysis work completed in previous phases, one of the largest gaps for repurposing to hydrogen service is there is currently no recognised method of live welding on a live hydrogen pipeline. This is required for both LTS and NTS to allow for new connections. The testing completed [redacted] will validated under the trial and staff trained on the new welding procedure.

Appendix H - Project plan

[redacted]

[redacted]

Appendix I - Stakeholder engagement

The 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 energy transition. The LTS Futures programme form a key part of the national hydrogen programme and is recognised under the Gas Goes Green programme. We already have key members updating and participating in the following groups:

Table 20-LTS Futures key engagement groups

Key engagement groups	
ENA Gas Strategy Group	ENA Gas Goes Green Steering Group
ENA Whole System Strategy Board	ENA Open Networks / Gas Goes Green – Whole Energy Systems
BEIS/Industry Hydrogen Programme Management Board	ENA Data and Digitalisation Steering Group
ENA Network Safety and Impacts (part of BEIS/Industry Hydrogen Programme) (LTS Futures is a key project)	ENA System Transformation (part of BEIS/Industry Hydrogen Programme)
ENA Gas Environment Group	ENA Integrated Hydrogen Trials (part of BEIS/Industry Hydrogen Programme)
FutureGrid Steering Group	IGEM Gas Quality Working Group
HyDeploy Advisory Board	IGEM Hydrogen Working Group
Marcogaz – Work Group Gas Quality/Renewable Gases	NECCUS
Northern Ireland Energy Policy	Spatial GB Clean Heat Pathway Model - Advisory Group
Stornoway LCITP Steering Group	Scottish Energy Advisory Board
Scottish Government Heat Decarbonisation External Advisory Group	Scottish Government 2024 New Build Zero Emissions (from heat) Working Group
Scottish Government Energy Networks Leadership Group	CEN/CENELEC – Sector Forum Hydrogen
H21 Advisory Board	IGEM LTS Futures

We will continue to participate proactively and commit to sharing the project learning effectively to inform the wider strategy for decarbonisation.

As the project will aim to repurpose a LTS pipeline to hydrogen, a carefully developed and managed stakeholder and communication plan for the project will be vital for the project. Engagement will be on a local, regional and national scale. At a high level, the activities and resources that this plan will seek to deliver includes:

- Industry workshops
- Educational resources and workshops
- LTS Futures launch event
- Project video

- Promotional materials
- Website platform
- Social media
- Dissemination of project information and learning at external events
- Attendance and participation at cross-industry/sector conferences

We will continue to engage with stakeholders on the project as it develops. This engagement will be delivered on a local, regional, national and a political level. Key stakeholders for the project have already been identified and shown below. Further stakeholders may be identified as the project progresses and mapped according to their level of importance and influence. A comprehensive stakeholder and community engagement plan will be developed and implemented throughout the key stages of the project and we will engage with local stakeholder on this to ensure the plan is inclusive and effective.

[redacted]

Figure 37-Current engagement for the LTS Futures programme

[redacted]

Table 21-LTS Futures programme stakeholder engagement

[redacted]

[redacted]

[redacted]

[redacted]

HSE programme engagement

HSE is a key stakeholder for the programme. Below details engagement with the HSE on the LTS Futures programme. HSE [redacted] have been engaged since the inception of the project in January 2019.

Table 22-HSE programme engagement

Date of Engagement	Type of Engagement	HSE	[redacted]
Jan 2019 – May 2020	Phase 1		
February 2020	LTS Knowledge Transfer Day	HSE	
May 2020 – present	IGEM LTS Futures Group	HSE	
March 2021 – present	Material Testing Strategy Group		

November 2020 – September 2021	ICHS 2021 paper and Conference		[redacted]
March 2021	HSE Safe Net Zero Conference	HSE	[redacted]
November 2020 – June 2021	BEIS/HSE gap analysis	HSE	[redacted]
August 2021	GSG/GTOSG HSE/Industry Interface	HSE	[redacted]
September 2021	Specific LTS Futures Group	HSE	[redacted]
13th August 2021	Net Zero Carbon Transition Sub Group	HSE	[redacted]

Appendix J - Top risks and mitigation controls

Element	Project component	ID	Risk description	Control mitigation
Element 1: Live trial design (Hydrogen supply)	Contract for H2 supply	1.1	[redacted] unable to supply hydrogen for the live trial of the [redacted] to [redacted] pipeline changing the preferred of route of hydrogen supply.	We have ongoing engagement [redacted] regarding hydrogen supply for the trial and feasibility study will provide further confidence. The detailed design will determine the route and there is a stagegate (no 1) at the end of the detailed design. [redacted] Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
				Tanker option to be used as a back up if hydrogen supply cannot be secured [redacted] Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		1.2	[redacted] unable to supply the required hydrogen pressure for uprating and capacity assessment not allowing us to uprate the [redacted] to [redacted] pipeline and therefore not being to complete a full live trial for the GB LTS blueprint for repurposing and uprating	[redacted] The feasibility study and detailed design will confirm the feasibility, stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		1.3	Hydrogen cost increases	[redacted] Cost risk contingency has been built into the project to regarding market volatility (6.3).
				If 1.1 materialises then pursue fixed cost proposal from BOC for tanker supply.

	Routing of Hydrogen pipeline	2.1	We are unable to identify a suitable pipeline below ground route [redacted] so change in preferred supply option needed	We have ongoing engagement [redacted] and have discussed potential routes and their challenges. Route option 4 is considered most suitable by all parties. Feasibility study and detailed surveys will commence in November and conclude in February confirming a suitable pipeline route. The feasibility study and detailed design will confirm the feasibility, stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
				If 2.1 materialises we have identified temporary supports and required protective measures for the above ground pipeline.
	Infrastructure for live trial	2.2	Cost of material (e.g., steel, construction materials) increases incurring more costs	Engagement [redacted] to provide estimate cost of pipeline. This has been reviewed by an independent quantity surveyor and Real Price Effect (RPE) analysis applied to current prices. Cost risk contingency built into project (6.3).
		2.3	Delay in pipe manufacture causing delay in timelines	A feasibility study is being undertaken in parallel to the reopener submission to identify the pipe required for manufacture to ensure an order can be placed at the end of detailed design (costs for feasibility do not form part of this project and conclude in February 2022). The feasibility study and detailed design will confirm the feasibility, stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		2.4	Planning consent not provided [redacted] for our preferred route causing routing change	Further to 2.1 we have discussed our preferred route [redacted] No issues have been raised at this stage. Planning process is part of the critical path on the project plan and the need for planning permission for the live trial will be identified as part of the Feasibility Study (not part of this submission) and Detailed Design. [redacted] Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		2.5	Legislative notifications for the pipeline are not submitted in the time due to delays in design approval not allowing for 12 months before the start time causing delay to the start.	The most onerous is the Gas Act which must be submitted 12 months before construction starts on a new pipeline. This will be submitted once design works have been approved by key stakeholders and highlighted as soon as possible if this is going to be 12 months before current start date. The design feasibility study has been brought forward to allow for potential delays seeking to conclude Feb 2022. We will hold regular team meetings to monitor progress against the programme.

		2.6	Design of temporary flare provide by third party is delayed causing delay to live trial	[redacted] The feasibility study starting in November will provide greater confidence in the design required. Detailed design of whole hydrogen entry unit will be completed at the beginning of the project. The feasibility study and detailed design will confirm the feasibility, stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		2.7	Design of bespoke hydrogen measurement unit is delayed causing delay to live trial	We have worked [redacted] to specify the performance requirements of measurements for the linepack validation and metering. Optioneering has begun to provide greater confidence in the design required. The detailed design for the unit will begin at the start of the project and a product acceptance report will be completed. The optioneering will be incorporated into the detailed design. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
Element 1: Live trial design [redacted] to [redacted] pipeline)	Condition of the pipeline	3.1	Detailed condition and some records of pipeline are currently unknown causing the feasibility of repurposing and uprating of the pipeline to be unknown	We have reviewed the latest Cathodic protection (CP) readings and no issues have been identified, the pipeline currently holds nitrogen pressure concluding there are no major loss of containment defects currently present. Above ground surveys (CIPS/DCVG/detailed line walk and river crossing) are due to start end of the year (pre-project commencement) with results being provided before project start date. The surveys and inspections on the pipeline are expected to supplement any missing records. An in-line inspection and hydrotest are due to start at the beginning of the project. The project cost includes a projected level of remediation works based on similar pipelines. This includes investigative digs following the in-line inspection and repair shell installation. These costs have been reviewed by an independent quantity surveyor. Following the in-line inspection, we will be cutting out a section of the [redacted] to [redacted] pipeline for lab testing to confirm the compatibility with hydrogen. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		3.2	Surveys and inspections for the pipeline repurposing and uprating feasibility could provide inconclusive results causing a reduced confidence in full condition of the pipeline.	The suite of surveys and inspections currently scheduled provide a holistic integrity review of the pipeline to verify the condition. Any locations of missing data should be complemented by another survey/inspection or dig verifications. The hydrotest will confirm whether the pipeline has any major defects but will not provide defect locations and severity. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.

		3.3	In-line inspection for the pipeline repurposing and uprating feasibility are not possible causing a reduced confidence in full condition of the pipeline.	A study into the possible methods for pigging the pipeline is currently underway which will assess the options available against the requirements to recommend the optimum solution. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
		3.4	A major hydrostatic test failure confirms the pipeline cannot be repurposed	Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
	Landowners of the pipeline	4.1	While the pipeline has been mothballed, encroachment of buildings and changes to building proximity distances may have caused the pipeline to not meet current hydrogen standards.	Building proximity survey to be completed during the detailed line walk (pre-project commencement) and the QRA on the [redacted] to [redacted] pipeline will confirm any modifications required to meet hydrogen standards. The project costs include an allowance for the protective slabbing to be installed and a diversion at a known infringement location [redacted] These costs have been assessed by an independent quantity surveyor. Stagegate 1 and 3 provides project control ensuring evidentiary requirements are met before project progression.
		4.2	The easements for the existing [redacted] to [redacted] pipeline are not suitable for hydrogen or are missing resulting in 'no right' to access the pipeline causing delays while the updated servitudes are agreed.	Land referencing for the pipeline has commenced by a land agent to identify any potential missing easements. SGN's Legal department are reviewing all the easements for the pipeline to assess their suitability for use with hydrogen pre-project commencement. [redacted] Stagegate 1 and 3 provides project control ensuring evidentiary requirements are met before project progression.
		4.3	Unable to gain consent from landowners causing delays for potential remedial works, impacting the timeline for the live trial	Preliminary analysis of landowners along the pipeline has been undertaken to identify gaps in landowner referencing. There will be engagement with landowners throughout the project and they are ranked as the programme's highest priority stakeholders due to the requirement to access land to undertake remediation activities. Our stakeholder engagement plan will be rolled out at the start of the project. Our programme land agent has been instructed to support with landowner relations during the project. Stagegate 1 and 3 provides project control ensuring evidentiary requirements are met before project progression.
Element 2: Lab Testing	Availability of material	5.1	Delays in securing [redacted] to [redacted] pipeline material sample for lab testing causing	Research will be conducted after the in-line inspection to locate optimal location for cut out and landowner engagement consent. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.

	specimens for testing		delays to the live trial due to landowner relations	
			Unable to secure all material specimens required for testing to ensure development of a blueprint causing delays to development of the GB LTS QRA/blueprint	Engagement with Major Projects/Asset/Maintenance and GDNs has provisionally secured valuable assets for testing. No issues currently identified in securing required pipe specimens. [redacted] If pipeline specimens planned for collection from gas networks are unsuitable, we would seek to recover from diversionary or remediation works, which may impact the timeline. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
	Lab availability	5.2	Under capacity of third-party labs will cause our extensive testing programme to be delayed causing a delay to the GB LTS QRA/blueprint	Testing requirements have been scoped and availability of lab testing facilities has been explored as part of the submission preparation. Procurement event will start in November to ensure labs are secured and testing can commence. The [redacted] to [redacted] pipe material will be prioritised. A further Covid 19 lockdown would impact significantly, covered in a separate risk. Stagegate 1 provides project control ensuring evidentiary requirements are met before project progression.
Element 3: Offsite Testing	Testing rigs	6.1	Unable to secure all pipe sections and PRS required for testing rigs not allowing to do the necessary testing to confirm the feasibility of the project	We have engaged with Major Projects/Asset/Maintenance and GDNs to ensure valuable assets for testing are committed and secured. Two PRS [redacted] have provisionally been secured for testing. Stagegate 1, 2 and 3 provides project control ensuring evidentiary requirements are met before project progression.
		6.2	Test rigs not suitable for testing due to incorrect construction/installation causing delays to the offsite testing and project timelines	We have worked [redacted] to develop an optimal test programme which is complimentary to other works ongoing [redacted]. Stagegate 1, 2 and 3 provides project control ensuring evidentiary requirements are met before project progression.
		6.3	Long lead time items (such as compressor) required for the off-site testing facility could cause delay to the offsite testing and project timelines	We have confidence that the long lead items pertaining to the offsite testing can proceed upon project commencement. There are no dependencies on the live trial for these items to proceed. Supplier engagement will continue while the reopener is being assessed to increase confidence in the lead times. Stagegate 1, 2 and 3 provides project control ensuring evidentiary requirements are met before project progression.
	Test outcomes	6.4	Hot work testing confirms it is not possible to live weld onto a live hydrogen pipeline causing delays to offsite testing and the live trial due to alternative	A review of repair techniques will be undertaken at the start of the trial and a grouted tee will be tested with hydrogen which will provide an alternative technique for connections and diversions. Stagegate 1, 3 and 5 provides project control ensuring evidentiary requirements are met before project progression.

			means of connection/repair methods to be confirmed	
Element 4: Live Trial	Construction of H2 supply pipe	7.1	Failure to meet safety requirements during construction causing delays to the live trial	Specific and appropriate training and competency to contractors, follow site specific work instructions and safe control of operations processes
	Hot work exercise	7.2	Unable to carry out the hot work exercise at the live trial as the offsite testing has shown it is not feasible causing an alternative method for connections and diversions.	Hot work testing to be carried out [redacted] includes an alternative grouted tee to be able to provide the GB LTS hydrogen pipelines a solution for diversions and connections.
	Linepack validation	7.3	Unable to measure the line pack accurately causing further refills of the pipeline and therefore delays in the live trial	The measurement unit is being calibrated and validated [redacted] before being transferred up to [redacted] This will increase confidence in the accuracy of the measurement unit. Stagegate 8 provides project control ensuring evidentiary requirements are met before project progression.
	Emergency response simulation	7.4	Low engagement and knowledge transfer of hydrogen pipeline to emergency services causing unprepared and low competencies of emergency staff if there were an emergency situation	Emergency response desktop exercise to be completed before commissioning to allow socialisation of new information prior to simulation where more information will be provided. Emergency services and local authorities have been identified as a key stakeholder and will be involved in our Stakeholder Engagement Plan. Stagegate 3 provides project control ensuring evidentiary requirements are met before project progression.
	Staff skills	7.5	SGN resource do not have the correct skills, knowledge and competencies for the live trial causing delays to live trial	We are developing the training and competency requirements for the live trial in line with training programme with SGN's training team. Training courses will be provided [redacted] (element 6) on live hydrogen assets for SGN personnel.
Element 5: QRA and Case for Safety	Case for Safety	8.1	HSE has objection causing delays to the live trial	We have engaged with the HSE throughout the development of the LTS Futures programme, they have been identified as a critical stakeholder and part of our stakeholder engagement plan. [redacted] Stagegate 1 and 3 provides project control ensuring evidentiary requirements are met before project progression.

Overall Project Risks	Resources	9.1	Insufficient resources assigned by the project management team leading to delays in the progression of the project.	Regular review of resource availability. SGN has appointed core team for expansion under the project. Implement and maintain a project programme to monitor deliverables against the timescales and ensure that any shortage of resources impacting delivery of the overall project are clearly identified. Review programme at monthly progress meetings.
	Project Start Up	9.2	Contractual/financial delays between SGN and its partners and contractors causing delay to the project.	Provision of dedicated expert support for the project team from partners/contractors/SGN
	Engagement of Stakeholders	9.3	Delay in engaging partners/landowners/HSE may cause delays in repurposing the pipeline, building new pipeline and testing to allow project and blueprint to develop.	Early engagement of potential partners/landowners/HSE and other key stakeholders will help in avoiding delays in developing the blueprint
	COVID-19	9.4	COVID-19 interruption, delays, resource disruption to: Live Trial Lab testing Offsite Testing	Engage with contractors and HSE to ensure work procedures are appropriate. Manage work in line with latest Government guidelines. Continue to monitor impact on project, participants, supply chain and industry. Staff working from home, adapting flexible working hours where necessary. Staff wellness and symptoms are being monitored and recorded
	Regulatory Treatment and regulatory option	9.5	A regulatory solution for the project is not found or the preferred option is not accepted by Ofgem causing delay to the funding decision and delay to project.	Engaged with Ofgem through the development of the reopener submission. No indication to date that they intend to reduce the scope or partially fund the project. Preferred regulatory option presented to Ofgem in submission. Follow up engagement post-submission with Ofgem
		9.6	Preferred regulatory option not accepted by regulator causing delay to the project	Similar to H100 Fife regulatory spectrum of models mapped, preferred option has precedent reviewed by specialist legal representation. Preferred option presented in the submission.

Appendix K - Letters of support

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix L - LTS and NTS collaboration

SGN has worked closely and iteratively with subject matter experts, consultants, policy decision makers, legislation, regulation and the Health and Safety Executive (HSE) to challenge and review the project scope and strategy. We have incorporated the appropriate testing to deliver evidentiary outcomes to support the safe and efficient repurposing of the existing LTS to hydrogen service. Current knowledge gaps have been identified and prioritised for investigation.

The LTS Futures team works closely with the NTS FutureGrid team to ensure learning is shared, there is no unnecessary duplication, and the technical programmes are complementary. The combined learning from the National Grid FutureGrid project and the LTS Futures project will provide the full picture in terms of the technical ability to use the existing national infrastructure to transport hydrogen. This will support a fundamental component of the evidence base that will define the cost of decarbonisation. We will continue to work closely with the FutureGrid projects team to ensure that overlaps are minimised and that any gaps in the evidence base that have become apparent during FutureGrid project are picked up by the LTS Futures project, wherever possible.

Differences between LTS and NTS

The NTS network is made up of carbon steel pipelines, Pressure Reducing Stations (PRSs) and compressor stations operating at pressures up to 95 barg. The majority of the LTS network is comprised of carbon steel pipelines and PRS's operating at pressures between 7 and 70 barg, the combination of both these networks allow the safe transmission of natural gas from onshore terminals to customers.

There are a number of inherent differences between LTS and NTS pipelines both in terms of age and material factors, but also in terms of operation. The differences are identified in Figure 39 below and must be considered as part of the collaborative and complementary approach to the research programme.

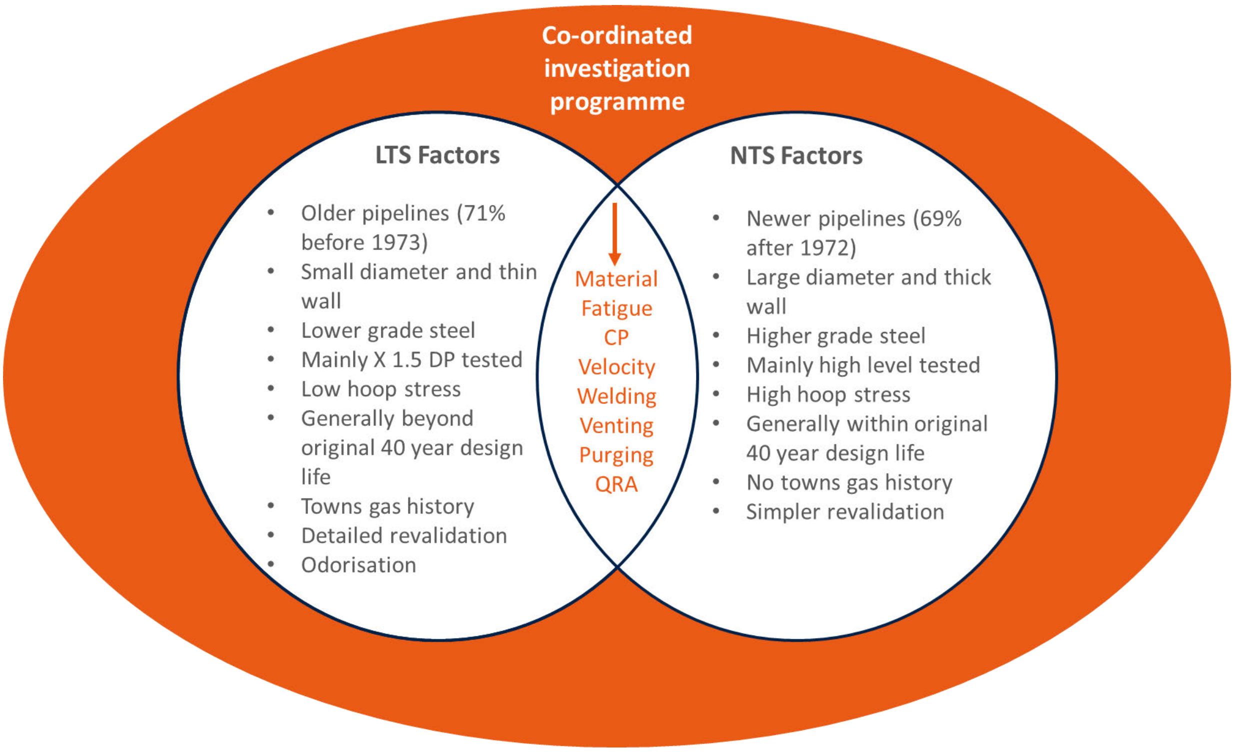

Figure 39-Co-ordinated transmission investigation programme

NTS / LTS Research Programmes

The NTS and LTS have been designed and constructed and are maintained and operated to the standard IGEM/TD/1 and have an identical process for proving pipeline integrity. Table 23 identifies the work being carried out as part of both research projects:

Table 23-Complementary research activity

	NTS - FutureGrid	LTS - LTS Futures
Demonstration and Trial	Large scale offline flow facility constructed from decommissioned NTS assets.	Live trial of a 30km 457 mm dia x X52 pipeline repurposed to 100% hydrogen which is representative of the LTS pipeline population.
Purpose	Pressure flow tests representative of NTS conditions will be carried out to compare 100% natural gas with 2%, 20% and 100% hydrogen.	Revalidated and repurposed pipeline will be purged and filled with hydrogen pressurised to 17 bar. Validation on all previous works as well as hot works on live hydrogen pipeline, line pack calculations, emergency response incident stimulation. Operational inspection and maintenance procedures revised for application to hydrogen pipelines will be applied during the trial.
Supporting Tests	Supporting standalone hydrogen test modules to assess integrity and functionality of decommissioned NTS assets. This will include 150,000 pressure cycles giving 125N/mm2 stress range in a flow loop.	Programme of specific hydrogen trials into hot working, hydrogen releases, probability of failure burst tests, and equipment operability and functionality tests on LTS equipment (including odorisation unit), developed to complement the programme of FutureGrid tests.
Extension of existing models and procedures	Rupture test of 6" dia test section to measure overpressure due to delayed ignition, and update of QRA software.	Application of current QRA methodology to assessment of real infringements along the pipeline route, for demonstration of safety to HSE
	Development of a hazard assessment of the NTS system under hydrogen service, comparison with the hazard assessment for natural gas service.	Development of repurposing procedure for application to LTS pipelines.
	Programme of material and fatigue tests on X65, X60 and X52 line pipe material.	Programme of material and fatigue tests on X52, X42 and Grade B vintage line pipe material.

Complementary Activities

There will be some similarities and what appears to be duplication in the research and testing carried out for FutureGrid. However, it is important to recognise that the LTS has different operating parameters including pressure, material and cycling, and additional tests are required to demonstrate safety of operation with hydrogen. Examples of this include:

Material Tests - LTS Futures is conducting laboratory and full-scale material testing to quantify and bound the effect of hydrogen on the wide range of materials (grade and vintage) in the LTS. It will conduct tests on grades up to Grade X52. FutureGrid is testing higher strength materials. The results of the FutureGrid tests will be applied to the 7% of the LTS that is of a higher grade than Grade X52.

Quantified Risk Assessment- Updates to the consequence models for hydrogen releases developed by FutureGrid will be combined with the failure frequency assessment developed by LTS Futures to update the existing QRA methodology for hydrogen.

Pipeline Failure Consequences- Results of FutureGrid tests will be used to validate previous research and feed into the QRA model for hydrogen pipelines.

Pipeline Failure Frequency- Previous LTS Futures research will be utilised to assess the potential increase in failure frequency due to material degradation for input to the Quantified Risk Assessment (QRA) of infringements on the [redacted] to [redacted] pipeline route. Pipeline Land Use Planning (LUP) Zones will also be taken into account.

Impact of Pressure Reduction on Equipment- Learnings from the PRS FutureGrid testing can be used to identify the testing requirements for LTS equipment.

Fatigue Assessment- Fatigue testing will be conducted by FutureGrid and LTS Futures to validate the guidance in the supplement to TD/1.

Avoided Duplication

Results of other projects may inform the LTS Futures project outcomes so to avoid duplication specific areas not being covered, including:

Leak Testing- FutureGrid will be completing leak tests which include measurements of leak rates from joints on typical assets. The testing is representative of the LTS network.

Assessment of Coating and Cathodic Protection- Both LTS and NTS pipelines are mitigated against external corrosion by external coatings and Cathodic Protection (CP). FutureGrid is investigating the effect hydrogen has on CP and coatings which is representative of the LTS network.

Other work proposed under LTS Futures includes further development of safety case, standards and procedures gap analysis, specific demonstration operating procedures, and proposed commercial models and regulatory/legislative options that will help inform the development of enduring commercial solutions to be adopted by the gas industry in relation to hydrogen supply. The project has been structured as a national project to maximise learning dissemination and avoid duplication.

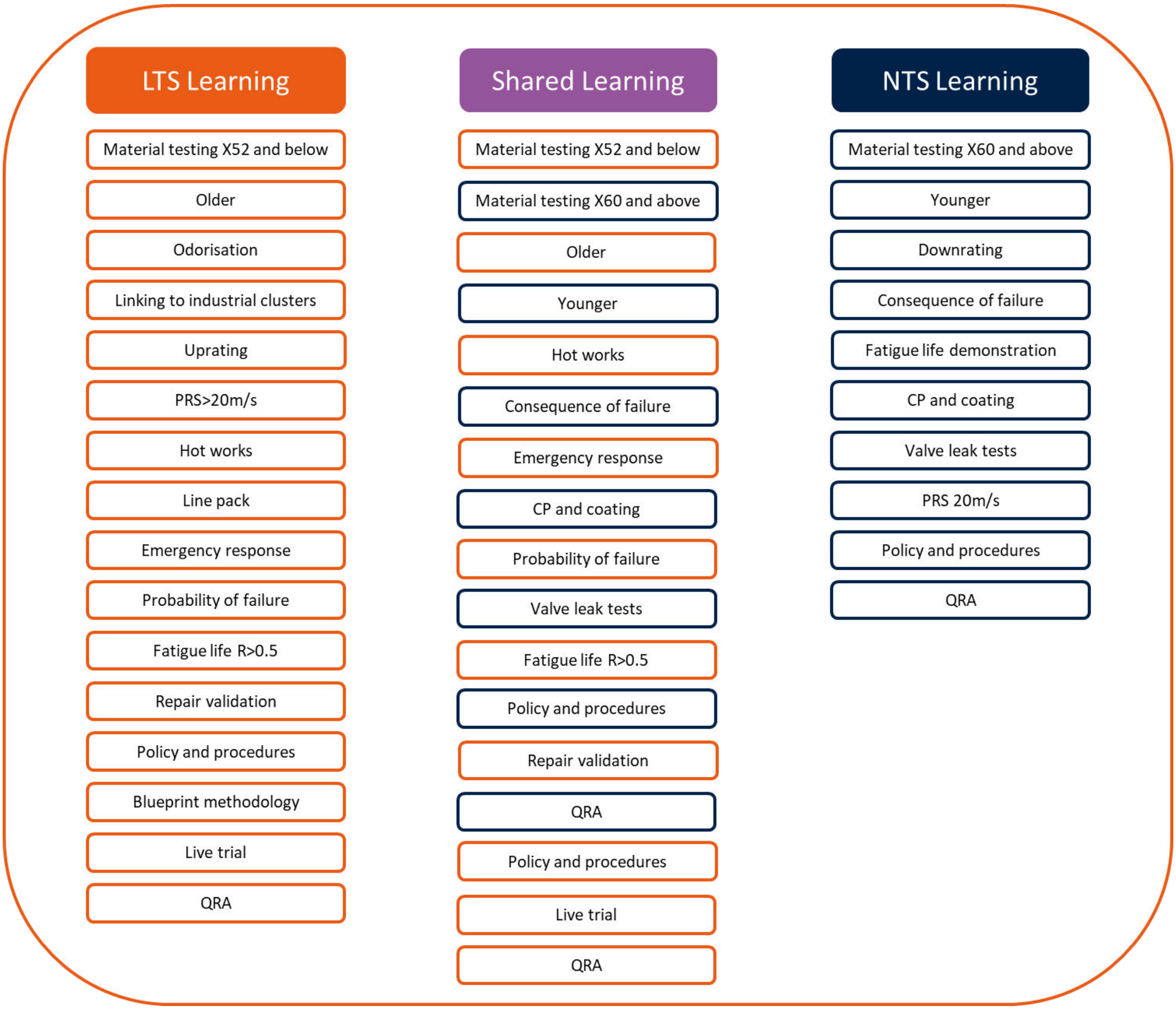

Figure 40-Shared learnings between LTS and NTS programmes

[redacted]

[redacted]

Appendix M - Outcomes table

Starting Point 2021				End Point 2025	
No 100% hydrogen LTS pipeline				**Repurposed 100%H2 LTS pipeline**	
Subcomponent	**TRL**			**TRL**	**Outcome**
1) Blueprint methodology	3-4	Under the LTS Futures HyTechnical project, TD 1, 3, 4 and 13 change of use supplements have been developed for hydrogen. Currently there are no procedures for the repurposing of existing LTS infrastructure for Hydrogen.	→	8	The project will aim to have developed a blueprint for repurposing and uprating existing LTS infrastructure to hydrogen through completion of the programme. The live trial of the [redacted] to [redacted] pipeline aims to develop new procedures for the repurposing and uprating of LTS infrastructure for hydrogen by conducting various simulations, training and exercises. Completion of a live trial for repurposing and uprating existing LTS pipelines to hydrogen should ensure design, construction, operation and maintenance of the pipeline are all covered within the blueprint, in addition to cost assessment.
2) Wayleave suitability	2	No current understanding regarding wayleave suitability, access and landowner engagement requirements for operation of a hydrogen LTS pipeline	→	8	Completion of the live trial design for the [redacted] to [redacted] live trial with hydrogen provides critical learning and a strategy for landowner engagement and pipeline wayleaves. Learnings can also be gained on permitted development rights for networks to undertake works on repurposing LTS assets for hydrogen. Learnings fed into the blueprint methodology for repurposing.

3) Material testing	3-4	ASME B31.12 Hydrogen Piping and Pipeline Standard allows new pipeline X52 and operating <50%SMYS, however there are currently no standards for the repurposing of existing LTS pipeline infrastructure for hydrogen.		7	Completion of a programme of testing on material that represent GB LTS networks to understand any impacts that hydrogen has on vintage metals. Testing will be completed on samples of X52 pipe grade. Material tests will determine the failure point with hydrogen. Completion of material testing will influence the acceptability of defects (acceptable, or repair, or replace) and provide the relationship between the two parameters and associated tolerance, which will be incorporated into the QRA and blueprint.
4) LTS skills and competencies	2-3	No current understanding of the skills and competencies required to operate and maintain assets in the hydrogen economy with procedures required to support it		8	Development of skills and competencies for operation and maintenance of existing LTS pipelines for hydrogen. Project specific procedures will be developed under the programme for example, if proven viable through off site tests, a procedure for hot tapping and welding for hydrogen pipelines will be produced and validated through the [redacted] to [redacted] live trial. Operational personnel will be trained [redacted] Operational procedures for hydrogen venting will also be covered in addition to management procedures, work instructions and training for operation of all LTS equipment. Learnings will be fed into the blueprint.
5) Industrial cluster development	4-5	Significant development in positioning industrial clusters as the driver for hydrogen production and decarbonisation, however limited understanding of how hydrogen production will connect with existing pipeline infrastructure and distribute to end users		8	Completion of live trial design for the hydrogen supply to the [redacted] to [redacted] pipeline including Pre-FEED, detailed design, procurement, installation of pipeline and operation and maintenance of the asset will provide critical understanding of the process for connecting decarbonising industrial clusters in GB to the network. Learnings can be utilised by other GDN's to

					integrate industrial clusters to the gas network.
6) HSE engagement	5-6	HSE have been involved in the SGN chaired IGEM group LTS Futures. HSE have since had involved in HyTechnical project. HSE require the safety case for repurposing LTS assets to hydrogen		8	Through the completion of LTS Futures Programme elements, the proposed outcome will be that HSE have no objection to repurposing of [redacted] to [redacted] pipeline to hydrogen and the new hydrogen supply pipeline.. The project team continue to engage closely with the HSE.
7) Pressure Reduction Installation	3	Gaps identified in SGN Futures of LTS Phase 1 project. No work has been done in repurposing PRS for hydrogen		8	A PRS will be tested with hydrogen at the increased velocities to provide evidence if uprating is feasible in offsite testing as part of Element 3 of the programme. Design, materials and specifications are validated, supporting the viability of LTS uprating for storage and energy delivery capacity purposes.
8) Quantitative Risk Assessment	3	Extensive research and testing of the consequences & characteristics of hydrogen has been done. Gaps identified in SGN Future of LTS Phase 1 project such as Building Proximity Distance (BPD) and minimum separation distance to parallel pipelines. DNV have identified gaps in overpressure of high-pressure pipelines and further work is required on delayed ignition.		8	20/21: Under LTS Futures HyTechnical project, QRA desktop study to determine hydrogen BPD and minimum separation distance with hydrogen/natural gas parallel pipelines. 20/21: Under LTS Futures HyTechnical project, SR25 for hydrogen is being developed. 21/22: Future Grid rupture test to provide evidence to consequence of overpressure due to delayed ignition 22/23: LTS Futures to provide probability of failure of defects in burst and fatigue tests. 22/23: [redacted] to [redacted] specific QRA23/25: Generic QRA for GB LTS assets

9) ALARP pipeline validation	3	PIPESAFE QRA software currently used for gas pipelines is currently being developed for hydrogen, however there are current knowledge gaps regarding the safety of existing LTS pipelines to convey hydrogen		8	Completion of the [redacted] to [redacted] live trial aims to illustrate the necessary measures required for hydrogen pipelines to prevent a major accident and limit any potential consequences. The evaluation will include a full Quantified Risk Assessment QRA and specific consideration of material requirements, pressure boundaries and the control regime, additional maintenance and risk management requirements to ensure risks are ALARP.
11) Storage	3	HSE Gap analysis has identified further assessment and validation of linepack losses with transition to hydrogen. Uprating assessment on LTS pipelines could potentially mitigate against losses.		8	Linepack storage and uprating assessment and process will be undertaken and validated through the [redacted] to [redacted] live trial. Linepack losses through transition to hydrogen are assessed through LTS uprating assessments with findings disseminated to other GDN's, BEIS, HSE etc.
12) Odorisation	4	Odorant currently used in natural gas lab tested and proven to be suitable for hydrogen gas in pipelines and end use.		8	Odorant NB validated by real-world data as suitable for a hydrogen LTS network. Providing a replicable configuration for hydrogen odorant injection
13) Policy timing	7	Engagement with BEIS to ensure the project is delivered in a suitable timeframe to allow the demonstration of hydrogen for heat to support Heat Policy Decisions.		8	Evidencing 100% hydrogen in the LTS as a key step of the Gas Quality Decarbonisation Pathway, as part of Gas Goes Green and the UK's national hydrogen programme. Illustrating the viability of the LTS to convey hydrogen provides critical evidence to support UK heat policy decisions in 2025 for future energy solution(s).
14) Social acceptance	4	Key stakeholder engagement through previous LTS Futures phases has assisted in government buy-in and strong stakeholder support		8	Engaging with a diverse group of stakeholders to deliver and inform the project, in turn providing valuable insight into social acceptance of hydrogen and willingness to support and act across a multitude of sectors.

15) Cross vector knowledge	3-4	No proven understanding of the interfaces between networks for production of hydrogen from reformation of natural gas. No demonstrated understanding of hydrogen distribution from supply into existing gas networks	➡	8	Fully evidenced impact utilising a refinery site with hydrogen supply to connect into the [redacted] to [redacted] LTS pipeline, illustrating the impact of connection for future planning
16) Business case for repurposing vs new LTS infrastructure	5	It is unknown the extent of what transmission assets can be repurposed and uprated to meet net zero future and how much that transition will cost. It is estimated to cost nearly £12billion to replace the LTS whereas repurposing would be a third of that cost.	➡	8	The programme aims to provide the blueprint for repurposing, uprating and cost assessment. This hopes to allow us to understand the extent of the LTS network can be repurposed and uprated for hydrogen transportation. Case studies aim to be run through the blueprint to refine the cost assessment.
17) Design changes	4	The TD hydrogen supplements provided under HyTechnical allow for new hydrogen pipelines to be built. We need understand how that works in practice especially working with an industrial cluster. The changes that are required to an LTS pipeline for hydrogen pipeline are unknown.	➡	8	The programme hopes to have designed, constructed and operated a new hydrogen pipeline at an industrial cluster. All work would be apprised under the PS5 PS6 process. The changes required for the live trial and the testing done under the programme will be apprised and fed into the blueprint
18) Statistically representative project nature	2	Currently it is unknown how we will repurpose the majority of our LTS assets for transmission	➡	8	The [redacted] to [redacted] pipeline is representative of 93% of the LTS pipeline, with remaining 7% covered by FutureGrid. Repurposing the [redacted] to [redacted] pipeline aims to provide a methodology of how to repurpose and uprate the majority of our LTS assets.
19) Hydrogen decarbonisation pathway confidence	6	Currently it is unknown if we can repurpose the LTS assets to hydrogen	➡	8	Repurposing and uprating the [redacted] to [redacted] pipeline and linking to the [redacted] industrial cluster will provide the political and investor confidence to invest in the hydrogen economy. The linepack validation will provide the understand of how much hydrogen storage is required.

20) Benefits to complementary projects	2	There are no projects investigating repurposing the LTS to 100% hydrogen		8	LTS Futures is the leading project for >7bar GDN assets. As stated, the project complements FutureGrid in many ways as well as other projects around the world

Appendix N - Cost plan

[redacted]

[redacted]