Network
Innovation
Competition

Project Code/Version Number:
NGNGN04

Section 1 Project Summary

1.1	**Project Title**	H21 – NIC
1.2	**Project Explanation**	The project will provide quantified safety based evidence to confirm the gas distribution networks of Great Britain are suitable to transport 100% hydrogen. The evidence produced will be used to support the case for a GB hydrogen conversion which could represent the biggest single contribution to the Climate Change Act.
1.3	**Funding licensee:**	Northern Gas Networks
1.4	**Project description:**	*1.4.1. The Problem(s) it is exploring* The H21 Leeds City Gate NIA project concluded it would be technically possible and economically viable to fully decarbonise the GB Gas Distribution Networks by converting them from natural gas to 100% hydrogen. The safety based evidence for such a conversion needs to be provided before the viability of the option can be confirmed. A credible government policy decision on decarbonisation of heat will not be possible without this critical information *1.4.2. The Method(s) that it will use to solve the Problem(s)* The Project will undertake an experimental testing programme which will provide the quantified, safety evidence between natural gas and 100% hydrogen utilised within the existing GB as distribution networks. The project has three phases, **Phase 1A – Background testing** (at the Health and Safety Laboratories, Buxton). These tests will confirm potential changes in background leakage levels. **Phase 1B – Consequence testing** (by DNV GL, Spadeadam), these tests will confirm any changes to safety risk under background conditions, failure and operational repair. **Phase 2 – Field trials:** These trials will be undertaken on in-situ mains to corroborate the controlled results gathered in Phases 1A and 1B. These tests will not be undertaken downstream of the meter and will not affect customers gas supply *1.4.3. The Solution(s) it is looking to reach by applying the Method(s)* The H21 NIC Project will provide the safety case to confirm the GB gas distribution networks can be converted from natural gas to 100% hydrogen. This evidence will strategically complement the BEIS £25m funding programme which focuses 'downstream of the meter' (predominantly within buildings) and technical development of appliances. Together they will provide the safety based evidence required to progress a credible policy decision on heat. *1.4.4. The Benefit(s) of the project* An optimised solution to decarbonise heat is in the interests of all gas customers. A conversion to 100% hydrogen would be significantly cheaper, and more deliverable at scale than an all-electric option. The benefits for converting just $^1/_3$ of UK gas customers to 100% hydrogen have been estimated to provide a

	£48bn financial saving (versus alternatives) and 363mtonnes of carbon savings by 2050.		
1.5 Funding			
1.5.1 NIC Funding Request (£k)	13,310	1.5.2 Network Licensee Compulsory Contribution (£k)	1,517
1.5.3 Network Licensee Extra Contribution (£k)	0	1.5.4 External Funding – excluding from NICs (£k):	261
1.5.5. Total Project Costs (£k)	15,172		
1.6 List of Project Partners, External Funders and Project Supporters (and value of contribution)	Project Partners: Cadent, Scotland and Southern Gas Networks, Wales and West Utilities, DNV GL, Health and Safety Laboratories External Funders: DNV GL (£261K) Project Supporters: Element Energy, ERM, National Physical Laboratories, Kiwa Gastec and YOEnergy. (Also see letters of support Appendix J)		
1.7 Timescale			
1.7.1. Project Start Date	01 January 2018	1.7.2. Project End Date	24 December 2020
1.8 Project Manager Contact Details			
1.8.1. Contact Name & Job Title	Dan Sadler	1.8.2. Email & Telephone Number	dsadler@northerngas.co.uk 07584 391 466
1.8.3. Contact Address	Northern Gas Networks, 1100 Century Way, Thorpe Park Business Park, Colton, Leeds, LS15 8TU		
1.9 Cross Sector Projects (only complete this section if your project is a Cross Sector Project, i.e. involves both the Gas and Electricity NICs).			
1.9.1. Funding requested the from the [Gas/Electricity] NIC (£k, please state which other competition)	N/A		
1.9.2. Please confirm whether or not this [Gas/Electricity] NIC Project could proceed in the absence of funding being awarded for the other Project.	N/A		
1.10 Technology Readiness Level (TRL)			
1.10.1. TRL at Project Start Date	5	1.10.2. TRL at Project End Date	8

Section 2. Project Description

2.1 Aims and objectives

The current GB gas distribution network transports natural gas (predominantly methane CH_4) which is burnt in customers' properties across the country producing carbon dioxide, water and heat. Hydrogen (H_2) when burnt only produces water and heat so a conversion of the GB gas distribution networks to hydrogen would provide customers with all the benefits of the gas networks without the carbon footprint. The H21 Leeds City Gate (H21 LCG) NIA project has confirmed that a conversion of the GB gas distribution network to clean hydrogen is possible. This NIC project, will build on the H21 LGC project by addressing the technical issues, is a collaborative bid involving all the GB Gas Distribution Networks (GDNs).

Problem Statement: converting the GB gas networks to 100% hydrogen has the potential to provide the biggest single contribution to decarbonisation. The safety based evidence for a conversion to 100% hydrogen transported through the existing gas distribution networks and then utilised within buildings needs to be provided before the viability of the option can be confirmed. A credible government policy decision on decarbonisation of heat will not be possible without this critical information.

The UK, as with most other countries around the world, recognises the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of their level in 1990. In the UK, this is a legal obligation defined under the terms of the UK Climate Change Act 2008. Climate change is one of the most significant technical, economic, social and business challenges facing the world today and, to date, there has been little investigation or thought leadership into the opportunity to decarbonise the GB gas distribution networks.

Almost half of the energy consumed in the UK is to provide heat (760 TWh). That is more than that used to produce electricity or for transport. Around 57% of this heat (434 TWh) goes towards meeting the space and water heating requirements of our homes (Ofgem Future Insights series: The Decarbonisation of Heat (2016)). Great Britain has a world class gas grid and gas dominates its heat supply curve, heating 83% of its buildings and providing most of its industrial heat. Decarbonisation of heat via a gas grid conversion to 100% hydrogen capitalises on existing network assets and ensures customers do not require disruptive and expensive changes in their homes vs alternative solutions. Furthermore, providing a long-term solution to climate change which utilises both the gas networks and electricity networks provides customers of tomorrow with the same choice as customers of today, gas or electricity.

In 2016 the H21 LCG NIA project concluded that it would be both technically possible and economically viable to decarbonise the GB gas distribution networks by converting them from natural gas to 100% hydrogen. Furthermore, the study identified that this could be achieved using technology that is technically proven across the world currently.

Whilst the benefits of such a conversion, in the context of climate change, are undeniable there remain some essential evidence gaps which must be closed before a policy decision can be made, or even realistically considered, to allow such a conversion to take place. Section 10 of the H21 LCG report included a detailed roadmap of this outstanding evidence.

This roadmap was further developed in Northern Gas Networks (NGN) 'Executing the H21 Roadmap' document which was presented to Ofgem and the Department for Business, Energy & Industrial Strategy (BEIS) in December 2016.
This document clearly sets out the incremental steps required to de-risk a hydrogen for heat pathway. These are:

- Quantifiable safety based evidence in both the distribution networks and downstream of the meter (predominantly within buildings).
- Live trials, to promote customer and GDN asset manager acceptability (not part of this H21 NIC).
- Front End Engineering Design to confirm the economics and strategic rollout for policy.

Since publication of the H21 LCG report on 11 July 2016 there have been numerous publications both confirming the reports viability and calling for urgent action to provide the outstanding pieces of critical evidence. Most notable of these is the Committee on Climate Change's (CCC) October 2016 publication 'Next Steps for UK heat policy'.

Some extracts from this report are included below:

- "The Government will need to make a set of decisions in the next Parliament and beyond on the best strategy for decarbonising buildings on the gas grid. Specifically, it will have to decide on whether there is a role for (100%) hydrogen supplied through existing gas networks (extending the useful life of the gas grid infrastructure) alongside other technologies such as heat pumps."
- "The main options for the decarbonisation of buildings on the gas grid in the 2030s and 2040s are heat pumps and low-carbon hydrogen… At present the best balance between hydrogen and heat pumps, alongside heat networks, is unknown. More evidence is required."
- "Investment now in R&D and pilot projects is crucial in order to test the feasibility of hydrogen for heat and to reassure the public and businesses that fuel switching to (100%) hydrogen networks can be done safely, affordably, and with minimal disruption."
- "Both heat pumps and hydrogen bring significant challenges, but in order to reduce heating emissions close to zero in the long term, extensive use of at least one of these options will be required… It is not possible at this stage to identify either heat pumps or hydrogen as the dominant solution, nor should either be ruled out."

The CCC reports key immediate recommendation for policy (2017 to 2020) is that Government**, Ofgem and industry** need to recognise the (potential) case/need for a mandatory switchover of some form – particularly for hydrogen. This finding was further supported in Ofgem's Future Insights series which states in the conclusions "In general, we support the conclusion from the recent CCC report that the near-term steps should focus on active experimentation, not on a wait and see approach."

If the evidence for a GB gas distribution network conversion to 100% hydrogen can be provided the benefits in terms of climate change obligations are enormous. However, timescales to provide this evidence are now critical to enable optimised policy decisions within the next parliament.

The 'Executing the H21 Roadmap' document clearly identifies the requirement to provide quantifiable safety based evidence as the critical first step. This is the primary requirement, as without the safety based evidence in place it is not possible (or beneficial) to try to move towards a live trial. Confirming that hydrogen represents a comparable and manageable risk to that presented by natural gas, in both the gas network itself and downstream of the meter, (predominantly within buildings) is a critical forerunner to progression to a live trial, which will promote customer acceptability. This is supported in Ofgem's Future Insights series which states "Due to the inherent similarities between hydrogen and natural gas, heating with hydrogen would perhaps require less change for consumers versus a switch to heat pumps or district heating. **However rigorous appliance and safety testing** will be needed to allay any potential safety issues".

BEIS has announced a £25m funding programme which will focus on provision of evidence 'Downstream of the meter' (predominantly within buildings) and technical development of appliances. The H21 NIC project has been designed to complement this BEIS programme and together they will collectively provide all the safety based evidence required to progress towards a live trial and subsequent policy decision. It is appropriate that government leadership in the form of the BEIS programme should focus on 'downstream of the meter' due to the highly fragmented nature of this market which consists of many small companies with limited access to funding. The provision of the quantifiable safety based evidence within the gas network should be undertaken by the regulated GDN monopolies who have the expertise, access to the assets and importantly access to significant innovation funding via the Network Innovation Competition to undertake their complementary programme of work.

An additional conclusion in Ofgem's document is: "We are keen to engage with government and other stakeholders and ready to work on regulatory solutions for heat supply more broadly. However, given the interactions, we consider it is not sensible for us to take forward work in this area in isolation. We will therefore continue to liaise with BEIS and other stakeholders and seek to contribute to future work". The GB GDNs believe this H21 NIC proposal, coupled with the governments £25m programme 'Downstream of the meter', meets with this ambition and will address the problem statement.

The Method(s) being trialled to solve the Problem
The UK gas industry has evolved from its origins in the early 19th century to the extensive, secure and reliable network we have today. Over that period the gas industry has undergone one major gas conversion from towns gas to natural gas (1966 to 1977) and has also upgraded significant amounts of its metallic mains distribution network to polyethylene (PE) most recently as part of the Iron Mains Replacement Programme (IMRP). Over that period the risks and associated asset management requirements for the GB gas distribution networks have been extensively investigated and quantified. As part of the quantification of risk required for the IMRP an extensive analysis programme was undertaken throughout the 1990s by British Gas's Research and Technology division (now part of DNV GL) to develop a risk assessment methodology subsequently known as MRPS (Mains Risk Prioritisation Scheme) which allocated a measure of risk to each individual cast, ductile and spun iron and steel pipe segment. The methodology and outputs from this work can be found in following key papers:

- McAll, R.K; 'Development of a risk assessment scheme for cast iron distribution mains up to and including 12 inches diameter', R2642, March 2000.
- McAll, R K. 'MRPS Coefficient Update – 2007', R7635, February 2008.
- McAll, R K. 'MRPS Coefficient Update – 2007', 1T4JSDK-30, October 2016.

The National Leakage test programmes for Transco (the former gas transportation monopoly) and National Grid were undertaken through the 1990s and early 2000s investigating the leakage rates of the gas distribution networks. The objective of the test programmes was to update the leakage rates that are used to assess overall distribution system leakage. In the event a total of 862 tests were carried out in the period. The methodology for this work can be found in two key papers, which are not in the public domain but have been provided to the H21 NIC project team free of charge.

- Evaluation of Leakage Measurement Methods for the British Gas 1992 National Leakage Tests, March 1995.
- Methodology for Estimating Leakage Rates Used in the 1992 British Gas Leakage Tests.

Whilst these papers provide the evidence for leakage associated with natural gas and the methodology for acquiring that evidence they do not cover the implications for a 100% hydrogen network. The concept of a 100% hydrogen network is not new and has been studied in various papers and books since 1975, most notably:

- Dr Rodger E Billings, The Hydrogen World View.
- WHEC 16/13-16 June 2006 – Lyon France, Durability and transport properties of polyethylene pipes for distributing mixtures of hydrogen and natural gas. This showed that the PE pipe is acceptable for hydrogen conveyance.
- H. Iskov, M. Backman, H.P. Nielsen, Field Test of Hydrogen in the Natural Gas Grid. This investigated the effect of hydrogen on PE pipe up to 20 years old, no ill effects were found.
- Hyhouse. This measured hydrogen concentrations within a property after a simulated external leak. Generally, the concentrations of hydrogen within the property were much lower than expected due to the very low density and high diffusivity of hydrogen compared with natural gas.
- Singapore Standards CP51:2004. Standard for the distribution of town gas up to 65%v/v hydrogen. This standard defines Low Pressure (LP) distribution systems.

This evidence, coupled with a range of anecdotal evidence from across the gas industry community, suggests that a 100% hydrogen gas grid conversion is a credible option for large scale decarbonisation. However, considerably more evidence is required to confirm the networks compatibility and quantify the risks associated with a gas grid conversion than can be evidenced in the literature to date. The testing methodology set out in the 'technical description of the Project' below aims to provide this evidence which, when coupled with the BEIS 'downstream of the meter' programme, will provide the compelling evidence required to move towards live trials and ultimately a policy decision.

The development or demonstration being undertaken
The Project will undertake an experimental testing programme which will provide the necessary data to quantify the comparative risk between a 100% hydrogen network and the natural gas network. It builds on the existing H21 LCG NIA and has been strategically designed to complement the BEIS £25m 'Downstream of the meter programme'. Additionally, the Project will work closely with the successful 2016 HyDeploy NIC project sharing customer liaison and social science best practice.

By 2032 over 90% of the GB gas distribution network will be predominantly polyethylene (PE). However, there will still be some retained iron and steel mains. Furthermore, there will be a range of different PE pipe ages, transition fittings (between PE, iron, steel, different diameters etc.), services, service connections, buried valves, repairs, service governors and district governors. This H21 NIC project will provide the quantitative safety based evidence across a strategically selected range of these assets through a comprehensive three phase testing programme as outlined below.

Phase 1A – Background testing: A strategic set of tests are being designed to cover the range of assets and pipe configurations representative across the UK. A cross Section of these assets will be removed from the networks and transported to the Health & Safety Laboratory (HSL) site at Buxton. Controlled testing with natural gas and 100% hydrogen will then be undertaken. These tests will provide the quantitative evidence for changes to background leakage levels in a 100% hydrogen network.

Phase 1B – Consequence testing: Quantification of risk associated with background leakage as determined in phase 1a, failure leakage (for example mains fracture, 3rd party damage) and operational response, i.e. repairing leaks. this means establishing what the consequence of leaking hydrogen will be for varying scenarios with different potential sources of ignition and comparing these consequences to those for natural gas. These tests will be undertaken at the DNV GL site at Spadeadam.

Phase 2 – Field trials: On in-situ mains, the purpose of which is to corroborate the results gathered in Phases 1A and 1B. It is important to note these tests will not be undertaken downstream of the meter and will not affect customers gas supply. Extensive liaison with local authorities as well as a comprehensive customer engagement plan will be developed with residents surrounding the field trials area.

The Solution(s) which will be enabled by solving the Problem
Establishment of the compelling safety based evidence for a 100% hydrogen conversion in the GB gas distribution network. Specifically, that the pipes and equipment in 2032, i.e. following completion of the IMRP, will be as safe operating on either 100% hydrogen or natural gas. This then unlocks a solution to low carbon heat which cannot be adopted otherwise. This has the potential to decarbonise the gas grid through a conversion to 100% hydrogen and would represent the biggest single contribution to meeting the challenge of the UK Climate Change Act. This solution to decarbonisation would allow ongoing use of our national gas network ensuring the asset does not become stranded. It would enable unlimited system coupling between electricity and gas through power to gas technology and would have minimal impact on end use customers.

The carbon benefits of such a conversion have the potential to save a cumulative 190 million tonnes of CO_{2eq} per annum for the GB (based on 1.5mtonnes saved per 6 TWh – see H21 LCG – and total UK heat consumption of 760 TWh), and offering more than £145bn cumulative financial savings on a cumulative discounted basis. This route addresses the energy trilemma; substantial carbon savings, a significantly lower cost solution to the consumer, and a greater level of diversity and therefore security of supply.

2.2 Technical description of Project

Conversion of an existing gas network to 100% hydrogen has never been undertaken anywhere in the world. Such a conversion will require modification and/ or replacement of end use equipment, for example boilers, fires, cookers and industrial burners. This has been achieved before in the towns gas to natural gas conversion between 1966 and 1977. The impact of 100% hydrogen on end use appliances will be comprehensively investigated by the governments £25m 'Downstream of the meter programme' and will therefore complement the H21 NIC project.

The H21 LCG study has confirmed that, with minor reinforcement, the gas distribution network has adequate capacity for conversion (the transmission network would not be affected) to transport the same amount of energy and provide the same levels of energy security utilising 100% hydrogen. It has also identified that all the technology to convert the GB gas distribution network to 100% hydrogen can be evidenced across the world today (e.g. steam methane reformers, salt caverns, hydrogen appliances). However, the primary obstacle to progressing with such a decarbonisation pathway is the lack of quantitative safety evidence both in the home and in the distribution network.

The GB gas distribution network is currently being upgraded with PE as part of the IMRP. This programme began in 2002 and will be complete in 2032. The programme was predicated on reduction of risk to life and property from an aging gas network. This upgrade is a critical facilitator for a 100% hydrogen conversion because the welded PE network is suitable for transportation of hydrogen.

However, at the end of the programme 10% (on average) of the remaining mains population will be metallic. Furthermore, the network has an extensive range of below ground materials, jointing techniques, buried equipment (for examples valves), services, fittings, connections, existing repairs, district governors (pressure control equipment) etc. Currently there is no evidence of the impact of 100% hydrogen on these assets, or indeed the potential impact of ongoing operational management, of a 100% hydrogen network, i.e. repairing leaks.

The H21 NIC project will deliver an optimally designed experimentation and testing programme, supported by the HSL and DNV GL, which will allow collection of quantifiable evidence that the GB distribution network of 2032 will be comparably as safe operating on 100% hydrogen as it is on natural gas.

The work will cover:

- The background leakage position of the network, i.e. does it leak more on 100% hydrogen and if so by how much and where?
- The consequences of hydrogen leakage both background and through network failures such as 3rd party damage, i.e. where does it go and can it be ignited?
- The operational considerations for ongoing network maintenance, i.e. can leaks on the network be repaired safely?

This innovative project will fill critical safety evidence gaps surrounding the conversion of the GB gas distribution network to 100% hydrogen. This will facilitate progression to live trials to promote customer acceptability (see 'Executing the H21 Roadmap' document) and ultimately aid progress towards a government policy decision on heat within the next parliament.

2.3 Description of design of trials

This Section provides an overview of the trial being undertaken. A full technical description of the Project can be found in Appendix C.

The objective of the Project is to provide compelling safety based evidence for a 100% hydrogen conversion in the GB gas distribution network. Specifically, that the pipes and equipment in 2032, i.e. following completion of the IMRP, will be as safe operating on either 100% hydrogen or natural gas. This will be achieved through a three-tier testing regime as detailed in Sections 2.3.2, 2.3.3 and 2.3.4 below.

The gas industry is well placed to galvanise the expertise needed to undertake the work required to solve the problem. The project team and its Partners will draw on historical evidence methods for leakage detection and destructive testing (see Section 2.3.2) and has coupled that with international learning. This gives a high level of confidence that the testing regime and outputs will achieve the objective. The most significant challenge is to determine an appropriate range of assets to test in Phase 1A which will provide quantifiable evidence which can be extrapolated across the asset base to update the Quantitative Risk Assessment (QRA).

The leakage tests undertaken in the 1990s and 2000s had a budget in excess of £40m (at present value). This was based on quantifying risk and updating the existing network leakage model to ascertain the commercial impact of natural gas leaking from the network. These tests were also somewhat easier to carry out as they could be undertaken in-situ on an asset already 'filled' with and transporting the fuel (natural gas) which was being tested. The tests within this H21 NIC project are being designed at minimal cost whilst providing compelling and extrapolatable data. The biggest challenge is restricting the tests to a £15m budget whilst meeting the objective and solving the problem.

2.3.1 Pre-works: H21 LCG and 'H21 – Keighley & Spadeadam Designs' NIA

In addition to the H21 LCG NIA project the 'H21 – Keighley & Spadeadam Designs' NIA is being progressed alongside the preparation of this bid. The purpose of this project is to ensure project readiness should the H21 NIC bid be successful, to provide more certainty of costs and to inform the master testing plan. If the NIC bid is unsuccessful this NIA is still a significant contributor to the H21 LCG roadmap allowing network operators to understand the experimental testing and design build requirements which will be needed to fully understand the impact of 100% hydrogen conversion on their assets.

The primary focus of the 'H21 – Keighley & Spadeadam Designs' NIA is to understand what is required at the test sites and to ensure that these designs have an appropriate level of independent assurance to provide confidence that the final site designs will allow effective execution of the tests. The designs will be independently design assured using the principles of the gas industry's G17 process. Additionally, the designs will be evolved alongside the master testing plan, the purpose of which is to define how tests are carried out, what is being measured and what are the outputs required. This will ensure tests are always aligned to meet the strategic objective of the H21 NIC project. HSL staff will be working with the gas industry to develop appropriate test plans which will provide data and demonstration of leakage to feed into network modelling and the DNV GL QRA.

This NIA has already had a significant benefit. The original ISP identified the NGN site at Keighley for Phase 1A, background testing. Following an onsite meeting with the designer and project Partners it was quickly determined that an established test site would be required for the works. This assessment was made predominantly on a safety basis but also based on logistics such as site security, impact on surrounding residents, and ongoing operation use of the facility post project completion. There are only two test sites for this type of work in the UK and the team agreed that the HSL site at Buxton would be the best location for Phase 1A. This will ensure the work can be delivered within the timescales and that an appropriate level of governance can be established whereby the Spadeadam and Buxton sites provide input and assurance into each other's work.

2.3.2 Phase 1A – Background testing (HSL at Buxton)

In 2032 at the end of the IMRP the gas networks will still be subject to leakage through its pipe and equipment. Understanding how this 'background' leakage level may alter when converting the gas network to 100% hydrogen is critical for three reasons:

- If changes cause a safety concern, quantified as part of the Phase 1B tests.
- If changes cause a commercial concern, i.e. there is no additional risk but there is a commercial impact from increased lost gas.
- An operational impact, e.g. a rapid increase in publicly reported gas escapes which could be a safety and/or logistics problem which would also undermine public confidence.

Selecting the assets to test at Buxton has required high levels of expertise and a range of different selection methodologies. The project team has selected the assets to test based on a range of criteria (see Appendix C). This has included:

- **Current pipe risk assessment criteria.** Consideration of the metallic mains population in 2032 and the associated risk score based on the existing risk scoring methodology used for the IMRP. This methodology, certified by the HSE, allows an understanding of which of the remaining metallic mains populations represent the highest risk.
- **Historical leakage data.** For different assets, particularly joints.
- **Operational experience.** NGN has drawn on engineering staff with over 230 years of operational experience to identify assets to test. This has then been cross checked with similar input from Cadent.
- **Potential to extrapolate the results.** Selecting an appropriate range of test that will provide data which can be extrapolated across all assets whilst keeping tests to an absolute minimum.

To ensure wide consensus on tests across all project Partners a three-phase approach has been adopted. Firstly, the GDNs identified the range of assets they would recommend for test based on the criteria above. Secondly, DNV GL reviewed the recommendations using their historical background data to confirm agreement. Finally, the HSL reviewed the recommendations and confirmed acceptability to meet the Project objectives.

Careful consideration has been given to the optimum location to undertake these tests. The actual costs for the site modifications are unlikely to alter irrespective of site location as the works will largely be the same on whichever site is selected. The Buxton sites was selected as it offers many strategic advantages as identified in Section 2.3.1.

The tests at Buxton will be undertaken on assets removed from the network. Where possible the assets will be obtained as part of ongoing IMRP works ensuring minimal additional customer impact. Other assets, specifically large diameter mains which are not part of the IMRP standard works, will be identified across the GB gas distribution networks which provides two advantages. Firstly, it allows the work to be shared across all networks making logistics and deliverability easier. Secondly, it allows customer impact to be kept to a minimum whilst engaging with a range of local authorities to raise awareness of the Project.

Once assets have been removed they will be transported to the Buxton sites for testing as per the design developed as part of the 'H21 – Keighley and Spadeadam Designs' NIA project. Tests, supervised and certified by the HSL, will then be undertaken in line with the master testing plan. These will include a baseline test on natural gas followed by a test on 100% hydrogen to quantify any difference.

The results of these tests will be used to confirm assumptions against the master test plan for Phase 1B to ensure the range of consequence tests covers the background leakage position.

2.3.3 Phase 1B – Consequence testing (DNV GL at Spadeadam)

There are only two locations in the UK that are used for this type of work due to its high risk and specialist expertise nature, these are Spadeadam and the HSL at Buxton. The H21 NIC project Partners (including the HSL) have agreed to do consequence testing at Spadeadam to make efficient use of resources whilst allowing the HSL to bring important oversight as an independent expert organisation intrinsically linked to the health and safety regulator.

DNV GL at Spadeadam has over forty years' experience carrying out hazardous testing at large scale. It is the site where much similar research was carried out for the natural gas industry (it was a former British Gas Research facility). Because of this heritage, Spadeadam already has existing infrastructure, equipment and facilities for performing experiments of the type planned, which will help to reduce costs. A further benefit is that Spadeadam has the professional experience gained over many years of gas industry research and testing that gives confidence that the hydrogen tests will be performed successfully to gain the most benefit, including direct comparisons with previous natural gas tests.

During this phase of the Project, it is essential that the safety of staff and members of the public is ensured, while potentially high hazard tests are carried out. The Spadeadam research facility occupies over 50 hectares of land within remote Ministry of Defence property on the border of Cumbria and Northumberland. This unique facility enables large exclusion zones to be established such that major hazard tests can be carried out safely.

The master testing plan at Spadeadam is being developed based on decades of gas industry experience in destructive/consequence testing. This has drawn extensively on the unique expertise and extensive background which DNV GL can supply and which has been provided free of charge for preparation of this NIC bid.

The tests at Spadeadam will look to cover three critical areas to be subsequently used in the quantitative risk analysis. All tests will be carried out using leaks simulated as per the site design (see Appendix C). This is a cost-effective way of understanding the consequence of leaks and failure without physically removing the assets from the network. The areas which will be quantified are:

Ground and air concentration testing: These tests will confirm how hydrogen dissipates in the air and the ground from network assets (both above and below ground) compared to natural gas. Tests associated with background leakage will be cross referenced with the results obtained in Phase 1A to ensure an adequate range of tests is being undertaken.

These tests will be undertaken by installing mains in trenches. These will then be tested to verify associated concentrations of hydrogen in the ground (including ductwork) and air for different types of backfill and cover (concrete, open ground, tarmac etc.) and at different distribution pressure tiers.

Background consequence testing: Having understood how the hydrogen is likely to migrate the consequence of such migrations needs to be determined, i.e. how leaking hydrogen could ignite and/or explode when exposed to a range of background ignition sources, for example engines, cigarettes, tools creating sparks under operational repair activities etc.

The ignition and explosion characteristics of hydrogen are well understood. These tests will be pre-defined in the master test plan based on expert assessment and assumptions. It is likely that this plan will need to be evolved by the team if the results from the ground and air concentrations testing indicate different tests may be appropriate. The results of these tests will then be contrasted against the known results for natural gas to update the quantitative risk assessment.

Operational testing: A gas distribution network must be safely and economically manageable. A 100% hydrogen network will still have background leaks reported by the public and 3rd party damages which will need to be repaired. In addition, new connections of either services or mains will need to be safely made. Understanding if the network can be managed/repaired using existing working practices is critical to quantifying the risk and progressing to any subsequent field trial.

These tests will simulate current operational practices for network repair and the associated potential forms of ignition from carrying out such work. For example, this may include simulating ignition sources such as roadside/excavation equipment, cable strikes, static build up, for varying types of excavations at varying depths and pressures of escape. Results from these tests will be used in the QRA but also to identify any modifications to operations working practices that may need to be considered. If such modifications are required they are outside the scope of this project.

2.3.4 Phase 2 – Field trials

As with all testing and QRA definitive conclusions can only be obtained with field trials. Field trials are essential to provide the final evidence requirement. Ultimately live trials for 100% hydrogen conversion will be required which involve physical conversion of customer's appliances and the network. However, this will only be possible once the BEIS programme is completed to provide the safety based evidence, and as importantly the physical appliances, for downstream of the meter use of hydrogen.

To provide definitive test results for the distribution network a test is required which doesn't interfere with the supply of gas to customers, i.e. a test on in-situ above and below ground assets which are not providing natural gas to customers.

To undertake these tests the Project team is working closely with the West Yorkshire Combined Authority to identify demolished/derelict sites where mains networks still exist. Using these types of sites will ensure no gas supply disruption to customers and a safe, but 'real-life' environment for carrying out field trials. These sites will be provided to the H21 NIC project under legal agreement with the council and a range of sites are currently being identified through extensive liaison.

The final site selected for test will be the one that provides the best value for money in terms of cost, range of assets available, surrounding land use and level of customer impact. The tests will include the following stages:

- Securing of the site.
- Validation of the condition of the mains and services.
- Corrective measures to the mains to facilitate connections, for example capping services etc.
- Addition of assets to test where appropriate, for example district governors.
- Design the modifications to the site and associated installation of physical works to facilitate measurement equipment, natural gas and hydrogen injection and other associated temporary works design. This will be developed in accordance with the master testing plan.
- Testing on natural gas to confirm background position.
- Testing on hydrogen to provide comparative data for the QRA.

Prior to progression to Phase 2 the H21 NIC must pass a critical stage gate. The Project Steering Committee (see Section 6 Governance and Appendix D) will only permit the Project to proceed if the results of Phases 1A and 1B provide credible evidence that there are no clear 'show stoppers' regarding 100% hydrogen gas grid conversion, i.e. that the QRA indicates the risk is manageable and furthermore that field trials will be safe. The HSL will have a critical role to play in the design and development of these tests as well as impartially informing the Steering Committee on the decision to progress.

2.3.5 Modelling work and QRA

The GB gas industry history means that undertaking QRA and computer based modelling for natural gas applications is well understood and developed. The results of the trials will be used to undertake a comparative quantitative risk analysis between hydrogen and natural gas.

Additionally, they will be used to update the computer based modelling systems, which are already in place for natural gas, to be appropriate for 100% hydrogen applications. This will provide a credible way to extrapolate the test results across all distribution network assets. This will then be used to update the QRA for the tests to give an overall QRA of the GB gas distribution networks operating on 100% hydrogen.

Undertaking the modelling work, building on existing developed systems and leveraging decades of expertise ensures that the costs for this H21 NIC are kept to a minimum whilst providing the compelling comparative safety based evidence to support a policy decision.

2.4 Changes since Initial Screening Process (ISP)

There have been no significant changes to the Project since the ISP other than the change of the Phase 1A test site from the original suggested location at Keighley to the HSL Buxton sites as explained in Section 2.3.1 above.

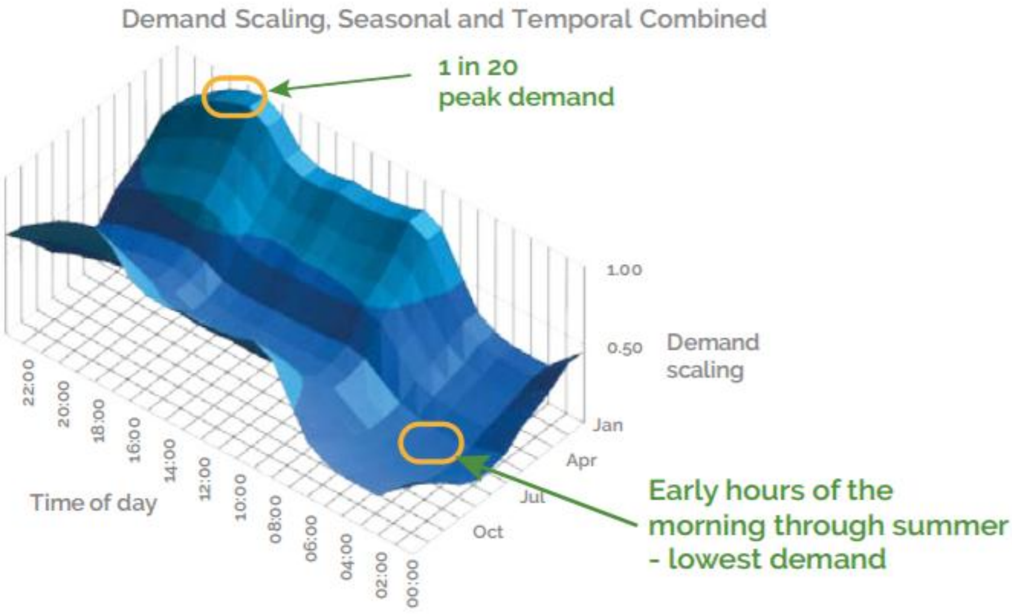
Section 3. Project Business Case

This project will provide the critical evidence to support a policy decision for an incremental conversion of the GB gas distribution network to 100% hydrogen. This evidence was identified as the first step in the 'Executing the H21 Roadmap' document. This H21 NIC, coupled with the Department for Business, Energy & Industrial Strategy 'Downstream of the Meter' programme, will play a pivotal role supporting an essential policy decision on heat decarbonisation by the early 2020s.

The mature and extensive GB gas distribution network cost effectively delivers energy to customers who utilise highly efficient appliances, designed over decades to work in conjunction with UK homes, to convert that energy to heat. The H21 NIC will establish the quantified safety based evidence that the GB gas distribution network if operating on 100% hydrogen represents a comparable and manageable risk compared to the existing natural gas system. A subsequent incremental conversion of the GB gas grid to 100% hydrogen would represent the single biggest contribution to decarbonisation benefiting heat, transport and electricity generation with a methodology transferable across the globe. The quantified benefits are laid out below.

3.1 Great Britain energy system benefits

Great Britain has a world class gas distribution network primarily delivering heat to customers effectively, efficiently and reliably. This existing asset has been designed over 200 years to manage the complex and wide-ranging profile of heat demand. A key recognised challenge for decarbonising heat through an alternative energy vector (other than gas transported through the gas networks) is the enormous annual volume of energy required (circa 40% of net UK energy) and the incredibly variable nature of heat demand. This is demonstrated on the chart below (taken from the H21 Leeds City Gate (LCG) report) showing the extent of both the inter-seasonal demand profile and intraday variations.

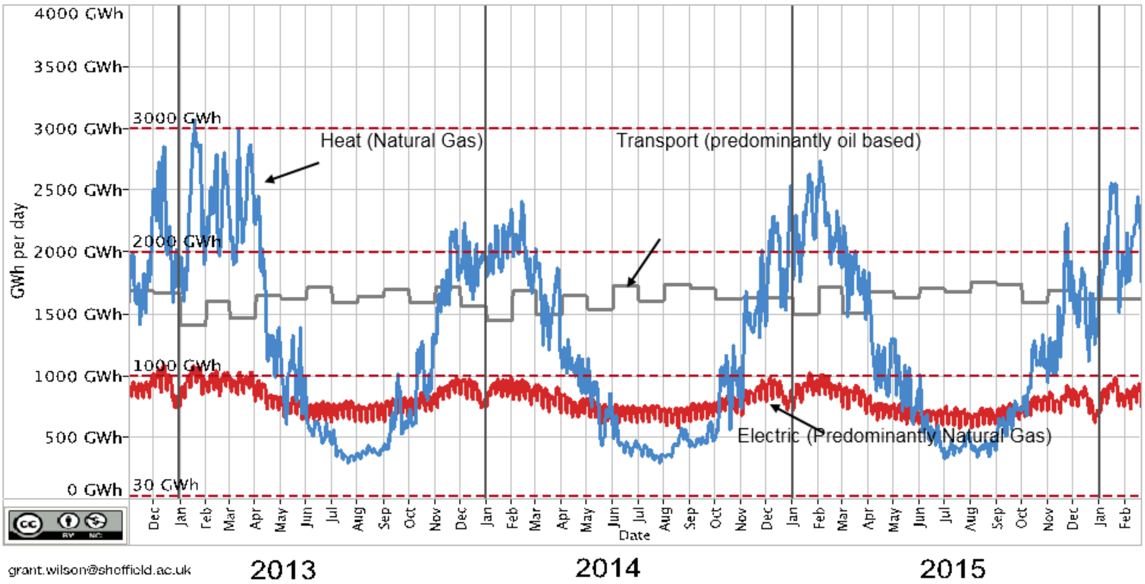


Both inter-seasonal and intra-day demand are highly variable with a 500% increase between summer lows and winter peaks. The gas network, due to its designed capacity and the inherent properties of gas to store energy indefinitely, manages these variations in a system that is 99.9% reliable.

As explained in detail in Section 4 and Appendix B alternative methods for the large-scale decarbonisation of heat, for example electrification, have significant technical challenges. These challenges manifest across the energy supply chain including:

- How to generate the volume of low carbon electricity required for heat.
- How that is then transported and stored to manage UK heat demand through the existing GB electricity distribution network whilst managing the daily and seasonal swing in demand.
- How to change the 83% of domestic gas users home appliances given the historic performance of alternative low carbon technology take up.
- How to decarbonise industrial and commercial heat which often doesn't have an electrical alternative but accounts for around 40% of annual usage.

The graph below, produced by Dr Grant Wilson at Sheffield University, demonstrates the scale of the decarbonisation challenge when considered in a net UK energy context:



Currently the UK requires in the region of 1,500-2,000 TWh of energy to support heat, transport and electric generation. Around 83.6 TWh (Digest of UK Energy Statistics 2016) of this energy comes from renewable sources which is 5% of net energy demand. If the UK is to generate all its energy for transportation, heat and electric demand from renewables alone it will need to increase output by circa 20 times current levels. This 20-fold figure is significantly higher when considering peak heat and energy losses down electric cables (see Section 4). Additionally, we need to put into context large infrastructure options such as Hinckley Point C which will generate approximately 25 TWh (circa 1.5% of net UK demand) of annual electricity at a capital cost of £25bn and a build time of over 10 years.

In contrast, the existing gas grid is well proven in providing peak demand, securely through a network that has already been designed to meet a maximum 6-minute peak demand every 20 years. If the gas network can be repurposed to transport low/zero carbon gas it will provide an enormous benefit to the UK meeting all the aspects of the energy trilemma, i.e. security of supply with a network that is 99% reliable (and largely unaffected by weather), low carbon, and value for money for customers when compared to alternatives.

3.2 Decarbonising the gas grid – the options

There are various forms of low carbon gas and all have the potential, to varying degrees, to play a part in the progression to a low carbon energy system. An incremental GB gas distribution network conversion to 100% hydrogen also needs to consider the availability of alternative forms of bio-methane. These primarily include:

- Bio-methane produced through anaerobic digestion.
- Bio-SNG produced via 100% black bag waste or biomass gasification.

Both these low carbon gas options are evident today and there is little doubt that they will, and should, continue to contribute to net UK energy supporting the short to medium term carbon reduction targets. However, whilst potentially important contributors, both are limited by feedstock availability when considering the bigger picture of the target within the UK Climate Change Act. This is to decarbonise UK net energy by at least 80% by 2050 across all energy sectors including heat, electricity and transportation.

In addition to bio-methane and bio-SNG, the potential to reduce the carbon content of the grid gas by partial blending of hydrogen, which is currently being investigated by the HyDeploy project. This option is limited in its potential since the maximum envisaged hydrogen addition is 20% by volume and this in turn will only reduce the carbon footprint of gas usage by 6.6%, (as hydrogen contains $^{1}/_{3}$ the calorific energy of natural gas by volume the blend would still require 93.4% natural gas to supply the required energy). This approach may however prove to be important by allowing unlimited deployment of renewables onto the electric grid offering a means of avoiding electrical grid constraints on the deployment of variable renewable electrical generation removing constrained energy issues through efficient system coupling (i.e. conversion of excess electricity to hydrogen gas).

Notwithstanding these credible and worthwhile alternatives there is still a requirement for a large scale, low carbon, gaseous alternative to natural gas, i.e. 100% hydrogen, to meet the longer-term objectives. Quoted directly from the Committee on Climate Changes 'Next Steps for Heat' report, "Both heat pumps and hydrogen bring significant challenges, but in order to reduce heating emissions close to zero in the long term, extensive use of at least one of these options will be required".

The advantage of the 100% hydrogen conversion option for the GB gas grid is that it is a large-scale one, unlimited by feedstock, which can be implemented incrementally over time across the UK gas grid, i.e. one city then the next. Furthermore, the operation of the gas grid can allow the conversion to be rolled out to provide the biggest benefit based on cost and carbon reduction. The gas network in 2050 could consist of major cities converted to 100% hydrogen providing the single biggest carbon saving with smaller towns, villages or even low population density areas (for example, Cornwall) being retained on sustainable low carbon methane supplies. An additional benefit of a 100% hydrogen conversion is that any bio-SNG plants can readily be upgraded to supply hydrogen when the grid in that area is converted, yielding an additional 16% of energy due to simplification of the gasification process.

Unlocking the potential for an incremental conversion of the GB gas network to 100% hydrogen could represent the biggest single contributor to the Climate Change Act. It would decarbonise heat utilising all the benefits of gas and the gas networks. Nearly all the benefits of such a conversion will be realised by gas customers by avoidance of installation of heat pump/alternative solutions, avoided costs associated with extensive reinforcement of electricity networks and additional extensive 'low carbon' electrical generation and storage. These cumulative avoided costs form the basis of Section 4. This H21 NIC project will provide the critical safety based evidence to unlock this potential.

3.3 Network licensee benefits

3.3.1 Aligned with Strategic direction

All GB Gas Distribution Networks (GDNs) are seeking to make best use of the gas network in a future low carbon economy. The potential 100% hydrogen presents for long term decarbonisation utilising an established supply chain has been recognised by all GDNs. Over the last few years GDNs have individually and collectively been considering hydrogen options for long term decarbonisation. Some of the key hydrogen specific projects to date are summarised in the following table:

Project name	Funding GDNs
H21 Leeds City Gate (NIA)	NGN (Lead), WWU
HyStart (NIA)	Cadent (Lead), NGN
HyDeploy (NIC)	Cadent (Lead), NGN
Hydrogen Clusters	Cadent
H21 – Strategic modelling, Major Urban Centres (NIA)	NGN (Lead), Cadent
H21 – Alternative hydrogen production and storage technologies (NIA)	NGN (Lead), Cadent
H21 – Domestic and commercial metering (NIA)	NGN (Lead), Cadent
H21 – Keighley and Spadeadam Design	NGN (Lead), Cadent
100% Hydrogen (NIA)	SGN

All GB GDNS are collaborating and providing part of the mandatory contribution to this H21 NIC bid.

3.3.2 Individual network benefits

The short-term benefit to GB GDNs would be quantification of any changes to leakage position and risk of converting GB gas distribution network assets to 100% hydrogen. This NIC project would also establish the testing protocols to determine such parameters. Longer term benefits would only arise on conversion which would not begin until the late 2020s at the earliest.

3.3.3 New opportunities

Incremental conversion of the GB gas distribution networks to 100% hydrogen provides numerous new opportunities and additional benefits. These include:

- Removal of carbon monoxide risk from customer homes – it is impossible to produce carbon monoxide from a hydrogen fuelled gas appliance.
- The potential for decentralised electrical generation from a low/zero carbon gas network. This could be in the form of micro combined heat and power (CHP) in the home. This would produce electricity locally from a low carbon fuel stock (hydrogen grid) and, as a direct result, would reduce significant amounts on centralised electrical generation requirements as losses in the system are removed (see Section 4 and Appendix B).
- Centralised electrical generation through the construction of new hydrogen powered power stations supplied off the hydrogen transmission system. This could remove the requirement for decentralised carbon capture and storage from natural gas fed power stations as the carbon capture would be undertaken at central locations (for example Teesside) as part of the hydrogen production process.
- Transportation – accelerated decarbonisation of transportation through hydrogen fuelling stations, supplied by a secure hydrogen gas grid, complementing electric vehicles and providing the fuel for heavy load, high polluting vehicles such as garbage trucks which don't currently have electrical alternatives.
- Improved air quality and removal of particulate matter and NOx as high pollution vehicles and domestic vehicles are replaced by hydrogen (and electric) powered vehicles.
- A long term sustainable solution whereby the UK can achieve its climate change obligations getting to a 'clean energy' position within the timescales available. This would then facilitate a transition to an entirely green energy position as global renewable generation increases and, with it, a global green hydrogen market.
- Generation of GB jobs across the supply chain and exporting expertise across the world.
- Elimination of methane (itself a potent greenhouse gas) emissions associated with distribution network operations.

3.3.4 Underpinning the life of the network
The use of 100% hydrogen capitalises on the existing asset base and will allow the ongoing use of the gas distribution system which is already paid for by customers and has an asset life of circa 100 years. This exploits the sunk costs associated with an existing asset and avoids its costly decommissioning.

3.4 Customer benefits
83% of households have their heat delivered over the gas grid – typically for use in modern, efficient gas boilers. Heating infrastructure is primarily based around circulating hot water systems. A low carbon solution for heat which utilises existing infrastructure offers substantial financial and non-financial benefits.

3.4.1 Financial benefits
Gas customers receive their heat at present using gas boilers and fires supplied via the natural gas grid. If the gas grid can be used to transport a zero-carbon gas (hydrogen) then customers can continue to use energy in a similar manner as they do today without costly changes to their homes. If this is not going to be possible then an equivalent quantity of low carbon heat must be delivered via another means.

The financial benefits to gas customers have been calculated in detail using the information provided in the H21 LCG report and further interpreted using the KPMG 2050 Energy Scenarios report. This has used the incremental conversion scenario presented in Section 11 of the H21 LCG report which assumed the conversion of circa 30% of UK gas customers by 2050.

The KPMG '2050 Energy Scenarios' report suggested significant differences in cost **and deliverability** between an all-electric and alternative gas options for decarbonisation. The all-electric option for decarbonisation was estimated to have a cost differential per consumer of over 2.75 (midpoint – see Appendix B) times the gas alternative. Additionally, practical obstacles for the all-electric option were considered high as opposed to low/medium for the all-gas option.

The savings shown in the table below are calculated based on this 2.75 factor between an all-electric option and a 100% hydrogen conversion option. These are expressed cumulatively on a Net Present Value basis (discount of 3.5% for first 30 years and 3.0% thereafter), consistent with Appendix A.

	2020	2030	2040	2050
Cumulative NPV (£m)	0	5,505	32,457	48,250

It is important to note that these figures are based on a 30% conversion scenario as presented in Section 11 of the H21 LCG report. This equates to a GB average annual saving between 2030 and 2050 of around £2.4bn per annum. The actual rate of conversion is dictated by the speed at which hydrogen production/supply can be established and this could be three times as fast as the figures represented above provided the appropriate supply chain is established. This would give three times the benefit increasing savings by 2050 i.e. **£145bn.**

No costs associated with additional direct benefits which would arise from an incremental gas grid conversion to 100% hydrogen have been included. These would include reduction in transportation charges for customers as hydrogen fuelling stations were built to support decarbonisation of transport. The potential exists to reduce electric costs for customers through the decarbonisation of electricity via decentralised and centralised generation. Additionally, the costs associated with the decommissioning of the gas grid have not been accounted for. These were estimated by National Grid to be circa £8,000m, a cost which is avoided by continuing to use the grid to deliver low carbon heat.

3.4.2 Non-financial benefits

There are significant tangible non-financial benefits to an incremental conversion of the UK gas distribution network to 100% hydrogen. Firstly, and perhaps most significant, is the perceived benefit to customers whereby customers of tomorrow have the same choice as customers of today, gas or electric. It is recognised that to the meet the climate change obligations the UK cannot continue to burn unabated natural gas for decentralised heat which means some change for customers is inevitable.

A conversion to 100% hydrogen enables households to continue using energy as they do today with minimal impact in the home when compared to any alternative options. Both the Wales & West Utilities' (WWU) Bridgend study and KPMG's Energy Scenarios report conclude that customers want solutions which are (a) non-disruptive, (b) give the functionality they want and have come to expect from their existing heating system and (c) don't require substantial capital outlay. This tends to mean that existing customers want a gas solution which requires little or no change on their part. As with all deep decarbonisation of heat strategies some change is required. However, conversion to 100% hydrogen only requires an upgrade of the existing appliance as was done in the original towns gas to natural gas conversion between 1966 and 1977. This is significantly less intrusive than any alternative technology which represents an equivalent level of decarbonisation.

Additional benefits arise when considering a social impact perspective with improved air quality resulting from hydrogen vehicles and the much more rapid decarbonisation of transport. Finally, enhanced energy delivery and utilisation technology options provided by a hydrogen and electric world (see Section 3.3.3 above) affords customers with increased opportunities and choice in the home as well as the government with more options for energy efficient and low carbon solutions. As with all targets more options provide more possibilities to meet the challenge.

3.5 Environmental benefits

The rationale for any natural gas to 100% hydrogen conversion programme must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with the Kyoto Protocol. The carbon savings associated with an incremental conversion of the GB gas distribution grid to 100% hydrogen are well defined and quantified utilising established technology. The table below summarises the results on a cumulative basis as required for Appendix A.

	To 2030	To 2040	To 2050
Mtcarbon saved	1.5	83	363

As with the financial benefits it is important to note that these figures are based on a 30% conversion scenario as presented in Section 11 of the H21 LCG report. The actual rate of conversion is dictated by the speed in which hydrogen production can be established and this could be three times as fast as the figures represented above provided the appropriate supply chain is developed. This would give three times the benefit increasing savings by 2050 to **1,089mtcarbon.**

Section 4. Benefits, timeliness, and Partners

4.1 Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing Customers (Criteria a)

4.1.1 (i) – how the Project contributes to the governments clean growth plan (due to publish in 2017) and its obligations defined under the climate change act

Within the last year there has been a public recognition by government that it needs to readdress heat policy. This was first publicly discussed in Baroness Neville Rolfe's (the then Department for Business, Energy & Industrial Strategy (BEIS) Minister of State for Energy and Intellectual property) address at the Policy Exchange 'The Heat Summit: How we can decarbonise heating' on 14 December 2016. At this summit, the Baroness's keynote speech acknowledged that **"As a first step we need to thoroughly re-assess the evidence, and support practical projects to test different approaches"** and "Our ambition is to be able to agree in the next few years, together, on the right long-term direction for heat policy'. Furthermore, it was acknowledged in the speech "As we know there are a wide variety of technologies which can deliver low carbon heat – ranging from the electric heat pumps and district heating networks I have already mentioned, to perhaps a more radical possibility; replacing natural gas with hydrogen in the gas grid".

Both Ofgem and the Committee on Climate Change (CCC) have recognised the potential for a 100% hydrogen gas grid conversion. The CCCs 'Next Steps for Heat' report has a key immediate recommendation for policy (2017 to 2020) which is "**Government, Ofgem and industry** need to recognise the (potential) case/need for a mandatory switchover of some form – particularly for hydrogen". This finding was further supported in Ofgem's Future Insights series which states in the conclusions "In general, we support the conclusion from the recent CCC report that the near-term steps should focus on active experimentation, not on a wait and see approach".

An additional conclusion in Ofgem's document is "We are keen to engage with government and other stakeholders and ready to work on regulatory solutions for heat supply more broadly. However, given the interactions, we consider it is not sensible for us to take forward work in this area in isolation. We will therefore continue to liaise with BEIS and other stakeholders and seek to contribute to future work". The Gas Distribution Networks (GDNs) of Great Britain believe this H21 NIC proposal coupled with the BEIS £25m hydrogen programme 'Downstream of the meter' meets with this ambition.

The credibility of a 100% hydrogen gas grid conversion

The H21 – Leeds City Gate (H21 LCG) Network Innovation Allowance Project assessed the feasibility of converting a major city's gas distribution network from natural gas to 100% hydrogen using technology which can be demonstrated across the world today. The project was designed to be a 'blue print' study to prove that the gas distribution networks could be converted to 100% hydrogen. Specifically, it confirmed the gas network has sufficient capacity to convert to 100% hydrogen with minimal reinforcement.

- That a secure supply of low carbon hydrogen could be provided to meet the annual and peak demands of the city. This would be achieved via Steam Methane Reformers (SMR) coupled with carbon capture and storage.
- That intra-day (within day) and inter-seasonal storage could be managed alongside hydrogen production facilities (SMRs) using salt caverns developed in the salt deposits available across the UK and specifically in the north-east region.
- That the City could be converted incrementally with minimal disruption to customers. This would be undertaken in a similar fashion to the towns gas to natural gas conversion which occurred across the UK between 1966 and 1977.
- The overall costs for such a conversion and a recommendation for how that could be financed with minimal impact in customers' bills.

- How an incremental conversion (i.e. one city then the next) to 100% hydrogen within the UK gas grid is technically possible and economically viable.

The H21 LCG project identified in Section 10 'The H21 Roadmap', the next steps required to develop the outstanding evidence to allow a policy decision. This roadmap was further developed in the `H21 – Executing the roadmap' document presented to Ofgem and BEIS in December 2016. This identified provision of the quantified safety based evidence for UK gas grid conversion to 100% hydrogen as the critical first step. The H21 NIC project will provide this evidence and is the first NIC project that will be collaboratively funded, supported and, subject to successful award, executed across all GDNs.

Since publication of the H21 LCG report in July 2016 it has been extensively reviewed and has received significant national and international attention and critical acclaim. BEIS announced on the 21st April 2017 a £25m programme to provide critical evidence to de-risk a 100% hydrogen conversion option for decarbonisation 'downstream of the meter'. There have also been significant movements around the world recognising the potential for low carbon gas and, more specifically, hydrogen. Most notable of these are the establishment of the Davos Hydrogen Council and the Oil and Gas Climate Initiative.

Other important documents have been published since the H21 LCG report release, and all have three similar principle themes. Firstly, that 100% hydrogen conversion should be considered a serious option for decarbonisation. Secondly, that a deliverable policy decision on decarbonising heat must be made in the early 2020s if the UK is to meet its Climate Change Act obligations. Finally, that there is an urgent need to provide the evidence to confirm the viability of a 100% hydrogen conversion option. Examples of these reports include:

- Hydrogen Roadmap – Innovate UK.
- Role of Hydrogen in the UK Energy System – Energy Research Partnership.
- Managing Heat System Decarbonisation – Imperial College.
- How to Decarbonise Domestic Heating – Policy Exchange.
- Scenarios for Deployment – E4Tech/UCL/Kiwa.
- 2050 Energy Scenarios – KPMG.
- Next Steps for Heat – Committee on Climate Change.
- Lowest cost decarbonisation for the UK: the critical role of CCS – The Parliamentary Advisory Group on Carbon Capture and Storage.

Further information on the H21 Leeds City Gate project including the film, executive summary, full report and an interview on Australian Sky News can be found at the links below or by typing 'H21' into the NGN website search bar.

- Film: http://www.northerngasnetworks.co.uk/2016/07/watch-our-h21-leeds-city-gate-film/
- Executive summary: http://www.northerngasnetworks.co.uk/wp-content/uploads/2016/07/H21-Executive-Summary-Interactive-PDF-July-2016-V2.pdf
- Full report: http://www.northerngasnetworks.co.uk/wp-content/uploads/2016/07/H21-Report-Interactive-PDF-July-2016.pdf
- Australian Sky News Interview http://www.northerngasnetworks.co.uk/archives/11735

The difference between the BEIS £25m programme and the H21 NIC
In 2016 Dan Sadler, the H21 NIC bid lead, was seconded to BEIS in the role of Technical Advisor Future of the Gas Networks. A fundamental part of that role involved working with the relevant policy teams (specifically heat and science) to help define a BEIS programme which would focus on de-risking hydrogen for heat 'downstream of the meter'. This is the £25m programme which has been announced at the link below:

https://www.gov.uk/government/publications/funding-for-innovative-approaches-to-using-hydrogen-gas-for-heating

The BEIS programme is intended to run over three years and will consist of nine packages: (1) Programme management (2) Definition of a hydrogen quality standard (3) Establishing an appliance and equipment testing capability (4) Development of domestic hydrogen appliances (5) Understanding commercial appliances (6) Understanding industrial appliances (7) Assessment of suitability of existing buildings (8) Trialling hydrogen appliances in unoccupied buildings (9) Preparations for testing appliances in domestic setting.

This BEIS programme focuses on work 'downstream of the meter' (i.e. predominantly within the building). The H21 NIC project is being designed to complement this BEIS programme and focuses on providing the safety based evidence for 100% hydrogen conversion 'upstream of the meter', i.e. on the GB GDNs network assets. These complementary but fundamentally different programmes will, subject to successful H21 NIC bid, collectively provide all the safety based evidence required to progress towards a live trial and subsequent policy decision. There will be no duplication of work.

How the rollout of the proposed Method across GB will deliver the Solution more quickly than the current most efficient method in use in GB

To date the main considerations for low carbon heating has been electrification of heat, predominantly considering air source heat pumps. Despite government incentives incredibly low take up rates of this technology indicates a low level of acceptability by UK customers. Acknowledgement by BEIS that heat policy needs a rethink is evidence of the success of current methods. However, the problem could be much more fundamental than customer acceptability.

When considering decarbonisation of energy, the issue is often simplified into segments of the energy landscape, for example 'heat' or 'transport' or 'electricity'. This segmentation can detract from the technical complexities of the bigger picture and often leads to solutions for one area which can be to the detriment of other areas.

Furthermore, current assumptions of what is/isn't low carbon are often based on pre-conceived assumptions. For example, an air source heat pump being low carbon is based entirely on the assumption that the electricity used to supply such an appliance is generated in a low/zero carbon manner.

The UK uses between 1,500 TWh and 2,000 TWh of energy every year across heat, electric and transport (Digest of UK Energy Statistics 2016). When considering the whole energy system an all-electric option is unlikely to be a viable option for an 80% reduction in emissions by 2050. By distilling this challenge down to its energy supply chain segments, it is easier to understand the challenge and why a 100% hydrogen gas grid conversion could represent such a compelling opportunity.

Energy production: Currently the UK generates 83.6 TWh (Digest of UK Energy Statistics 2016) of energy from renewable sources which is around 5% of net energy demand. If the UK is to generate all its energy for transportation, heat and current electric demand from renewables alone it will need to increase output by circa 20 times current levels and likely more when considering peak heat requirements and electrical energy transmission losses. Additionally, we need to put into context large infrastructure options such as Hinkley Point C which will generate 25 TWh (circa 1.5% of net UK demand) of annual electricity at a capital cost of £25bn.

Energy (grid) transportation: Three significant constraints need to be considered in an all-electric world:

- **Electric grid capacity** – if the electricity networks are going to be required to supply all the demand for transport, heat and current electricity usage this will require a significant reinforcement to the electricity grid. This will need an increase in capacity of at least 5 times current levels but more like 10/15 times capacity to ensure it can meet UK peak heat requirements.
- **Storage** – for one city (Leeds) the H21 LCG report has identified that over 700,000 MWh of inter-seasonal and 4,000 MWh of intraday storage is required for greatest production efficiency. This is not possible with the battery technology currently available.

- **Energy efficiency of the overall electrical system** – currently considered to be 40% across the European Union. This means more energy will be required to account for losses in the system. Gas does not lose energy through transportation along pipes and can store energy indefinitely.

Consumption: How energy is finally used is often the dominant topic of discussion when considering decarbonisation. Without considering the production and network transportation constraints for decarbonisation pathways we risk making policy decisions which are not deliverable. In effect, we are 'ordering the meal without knowing what is in the kitchen'. Furthermore, many end use applications, for example garbage trucks and industrial heat, do not have alternative electrical technologies.

The H21 LCG project is a system approach (production, transportation and consumption) to decarbonisation achievable with technology and systems already evidenced across the world today. Whilst the H21 LCG project was predicated on decarbonising heat, which is acknowledged as incredibly difficult to achieve in the UK, it is important to remember that a 100% hydrogen conversion will not only decarbonise domestic heating. It will also decarbonise industrial and commercial heat which often doesn't have an electrical alternative. Such a conversion can progressively support decarbonisation of transport with hydrogen fuelling stations built off the gas grid, decentralised and centralised electrical generation with micro Combined Heat and Power (CHP) in the home and hydrogen fuelled power stations. Unlocking the potential for a 100% hydrogen gas grid conversion will rapidly accelerate the UKs ability to meet the challenge of the UK Climate Change Act and would represent the biggest single contribution to decarbonisation.

4.1.2 (ii) If applicable to the Project, the network capacity released by each separate Method

This is not directly applicable to this project.

4.1.3 (iii) The proposed environmental benefits the Project can deliver to customers

The key rationale for the conversion of the GB gas distribution networks to 100% hydrogen is to deliver large scale carbon reduction in line with the targets of the UK Climate Change Act. This would be achieved with minimal disruption to customers versus alterative solutions, permitting the continued use of our national gas network and allow the UK to continue to take advantage of the inherent properties that gas delivers in the context of intra-day and inter-seasonal storage.

The carbon benefits to customers have been calculated in detail using the information provided in the H21 LCG report (further detail can be found in Appendix B). This has used the incremental conversion scenario presented in Section 11 of the report which would cover circa 30% of UK gas customers by 2050. This is considered highly conservative and, with the correct incentives and policies, these figures could be realistically tripled. The table below summarises the cumulative savings forecasted.

	To 2030	To 2040	To 2050
mtcarbon saved	1.5	83	363

This equates to a 50mtcarbon saving per annum by 2050. This figure would be significantly higher as electricity further decarbonises and the hydrogen production system is optimised.

4.1.4 (iv). The expected financial benefit the Project could deliver to customers

The financial benefits to gas customers have been calculated in detail using the information provided in the H21 LCG report and further interpreted using the KPMG 2050 Energy Scenarios report. This has used the incremental conversion scenario presented in Section 11 of the report which would cover circa 30% of UK gas customers by 2050.

The KPMG '2050 Energy Scenarios' suggested significant differences in cost and deliverability between all-electric and alternative gas options for decarbonisation. The all-electric option for decarbonisation was estimated to have a cost differential per consumer of over 2.75 (midpoint – see Appendix B) times the gas alternative.

Additionally, practical obstacles for the all-electric option were considered high as opposed to low/medium for the all-gas option. The table below summarises the results, this is described in more detail in Appendix B.

	To 2030	To 2040	To 2050
100% hydrogen conversion	£3,585m	£22,616m	£50,67m
All electric (using 2.75 scaling factor)	£9,813m	£61,897m	£138,691m
Savings to gas customers versus all electric	£6,227m	£39,281m	£88,016m
Savings to gas customers versus all electric (NPV)	£5,505m	£32,457m	£48,250m

This equates to a GB average annual saving between 2030 and 2050 of around £2.4bn per annum

4.2 Provides value for money to gas Customers (Criteria b)

4.2.1 (i) How the Project has a potential Direct Impact on the Network Licensee's network or on the operations of the GB System Operator

This project has a direct impact on all GB GDNs and is being collaboratively funded and executed. If the critical evidence to allow a 100% hydrogen conversion is established and a subsequent policy decision to convert the UK incrementally is taken it will avoid stranding this asset and the extensive decommissioning costs. It will also ensure customers of tomorrow have the same choice as customers of today – gas or electric across the energy landscape (heat, electric, transportation).

4.2.2 (ii) Justification that the scale/cost of the Project is appropriate in relation to the learning that is expected to be captured

The cost of this project is low compared to the benefits and learning which it unlocks. As shown in Section 4.1.4, £13.5m of NIC funding (with a further £1.5m of funding from the GB GDNs) has the potential to generate £88bn by 2050 of savings for gas customers. This saving is based on only a 30% customer conversion (see Appendix B). If all the UK gas customers were converted to 100% hydrogen this saving could be circa £300bn by 2050.

The project scale has been carefully designed to maximise the learning and minimise the costs. The challenge for the H21 NIC project is to design a testing plan which can provide the compelling safety based evidence without requiring hundreds of millions. The costs have been minimised by value engineering the Project across the following principle areas, (see in Appendix C for more detail):

- **Assets selected for testing:** By undertaking a comprehensive asset selection process it has been possible to reduce the number of tests required. These are now the absolute minimum to allow results to be extrapolated with confidence by the industry.
- **Leveraging the gas industries historic expertise:** Highly experienced project Partners have been utilised to define and collectively agree the testing plan/requirements. This has drawn upon existing evidence avoiding duplication of historical tests associated with natural gas consequence testing. It has also provided access to established gas risk modelling systems to extrapolate results avoiding extensive development costs.
- **Developing the 'H21 Keighley & Spadeadam Designs' NIA:** This has saved significant costs through value engineering the site selection for the background testing away from Keighley to the Health and Safety Laboratory (HSL) facilities at Buxton.
- **Project Partners:** The Project Partners have the specific expertise to develop the H21 NIC. All Partners are agreed that the H21 NIC bid represents an optimised testing plan to solve the problem statement.

- **To ensure credibility of results:** The tests, and therefore test Partners, must produce results that can be trusted by government, industry and wider stakeholders.

When considering the scale of this NIC project it is also important to note that the leakage trials, undertaken to inform the commercial leakage and risk models, performed in the 1990s by British Gas's Research and Technology (now part of DNV GL) and other safety based testing had an estimated current day value in excess of £40m which is 2.6 times more than this strategically designed project.

4.2.3 (iii) The processes that have been employed to ensure that the Project is delivered at a competitive cost

The project has developed upon two comprehensive NIA projects; the H21 LCG project and the 'H21 Keighley & Spadeadam Designs' project. The former has identified the critical steps to provide the essential evidence to support a policy decision, and the latter has focused on value engineering the testing plan requirements and physical works to keep costs to a minimum.

The two Primary Partners, DNV GL and the HSL, have been selected based on their specific and unique ability to add value to the Project. These two Partners own the only two sites in the UK that can undertake such consequence testing and they have a unique historic background which has allowed, and will continue to allow, optimised testing.

They have unique credibility when disseminating test results due to their historical expertise and/or connections with the Health & Safety Executive. Rates for these two Partners are in line with pre-tendered network frameworks rates or the agreed rates from the HyDeploy project for DNV GL and the HSL respectively.

Other major costs, for example modification to testing sites, project management, excavation, removal and delivery of network assets and installation of measurement equipment (for Phase 2) will be awarded based on a combination of competitive tenders or via one of the GB GDNs existing framework agreements.

DNV GL acknowledge the potential for ongoing testing on these facilities and have committed to maintain and make available the facilities for a period of three years following project completion for any additional test which may be undertaken at their facilities for the GB GDNs. This means that the facilities can be used at a fraction of the cost compared with testing from scratch. Priority on facility availability will be reserved for the GB GDNs. The HSL have made a similar commitment offering a discount of 5% on their rates for three years after project completion for any additional testing, subject to final contractual agreement.

The GB GDNs have executed many projects through the IFI, NIA and NIC structures and have well established contractual and governance arrangements for delivery. The project has an experienced management team structured to deliver the Project cost-effectively.

A detailed budget has been developed for the Project, as shown in Appendix G, and is summarised in the following table (figures exclude contingency).

	Total Labour Across Project						Equipment	IT	Total
	No. of staff	Man-days	Rates range	Rates average	Labour costs	Contractor costs			
	FTEs	Days	£/day	£/day	£k	£k	£k	£k	£k
Phase 1A	11.4	2,426	280 – 1,580	693	1,273	2,620	1,613	50	5,557
Phase 1B	15.6	3,305	280 – 1,580	774	398	240	2,682	28	3,347
Phase 2	10.2	2,166	280 – 1,580	708	1,991	280	2,064	72	4,407
NIC Funding request	Totals (excluding contingency, including external funding)				3,662	3,140	6,360	150	13,311
External funding (DNV GL at Spadeadam)									261

4.2.4 (iv) What expected proportion of the potential benefits will accrue to the gas network as opposed to other parts of the energy supply chain, and what assumptions have been used to derive the proportion of expected benefits

The main benefit to the gas network from a 100% hydrogen conversion is it underpins its continued utilisation. By delivering low carbon energy over the existing network, the gas network retains its importance in the wider mix of low carbon heat and wider energy solutions. The £88bn of avoided costs are based on an all-electric scenario.

4.2.5 (v) How Project Partners have been identified and selected including details of the process that has been followed and the rationale for selecting Project Participants and ideas for the Projects

All GB GDNs have internal processes to identify new project ideas and participants in their innovation projects. This is explained in more detail in Section 4.4.

4.3 Is innovative (i.e. not business as usual) and has an unproven business case where the innovation risk warrants a limited Development or Demonstration Project to demonstrate its effectiveness (Criteria d)

4.3.1 (i). Justification for why the Project is innovative and evidence it has not been tried before;

Conversion of an existing gas grid to 100% hydrogen has never been undertaken anywhere in the world before. The critical, compelling safety based evidence which proves conversion of the GB gas distribution networks to 100% hydrogen represents a comparable risk to that currently managed with natural gas does not exist and has never been explored. This evidence is crucial to allow progression to a live trial and ultimately a policy decision in the early 2020s which will allow a 100% hydrogen conversion to take place.

The H21 NIC will be the first project to fully explore and provide the safety based evidence comparing natural gas and 100% hydrogen use within GB gas distribution network assets in an optimised programme of testing and quantification.

4.3.2 (ii). Justification for why the Project can only be undertaken with the support of the NIC, including reference to the specific risks (e.g. commercial, technical, operational or regulatory) associated with the Project.

The BEIS £25m funding announcement will focus on provision of evidence 'Downstream of the meter' (predominantly within buildings). The H21 NIC project has been designed to complement this BEIS programme. This will collectively provide all the safety based evidence required to progress towards a live trial and subsequent policy decision. It is appropriate that the BEIS programme should focus on 'downstream of the meter' due to the highly fragmented nature of this market which consists of many small companies with limited access to funding which requires centralised leadership. The provision of the quantifiable safety based evidence within the gas network should be undertaken by the regulated GDN monopolies who have the expertise, access to the assets and importantly access to significant innovation funding via the Network Innovation Competition to undertake their complementary programme of work which is not covered under the current GD1 allowances.

The Project Risk Register can be found in Appendix F. Key risks this programme seeks to address are technical and operational, i.e. understanding the comparative safety risk of transporting 100% hydrogen versus natural gas. These risks would not need to be addressed or understood if the GB GDNs were to continue to operate the network using natural gas. The rationale for the Project is to provide critical evidence to de-risk a hydrogen decarbonisation pathway which would be in the interests of gas customers financially, environmentally and practically (in terms of reduced impact in the home and highways versus alternative solutions). There is no direct financial benefit to the network to undertake such a programme, and no reason it should do so under business as usual operation.

The GDNs believe this H21 NIC proposal, coupled with the BEIS £25m programme 'Downstream of the meter' meets with Ofgem's conclusion in their Future Insights document; "We are keen to engage with government and other stakeholders and ready to work on regulatory solutions for heat supply more broadly. However, given the interactions, we consider it is not sensible for us to take forward work in this area in isolation. We will therefore continue to liaise with BEIS and other stakeholders and seek to contribute to future work".

4.4 Involvement of other Partners and external funding (Criteria e)

4.4.1 Processes undertaken to select the Project

From inception in October 2014 the H21 LCG project was developed and delivered at the launch event on 11 July 2016 at the IMechE headquarters in London. During the Project Dan Sadler, the H21 LCG Project Manager, was seconded to BEIS in the role of Technical Advisor – Future of the Gas Networks. A fundamental part of that role involved working with the relevant policy teams (specifically heat and science) to help define a BEIS programme which would focus on de-risking hydrogen for heat 'Downstream of the meter'; this is the £25m programme announced by BEIS in April 2017. Within the secondment contract was an agreed dispensation to allow Dan to continue to manage, deliver, evolve and socialise the H21 LCG concept.

This secondment was critical to the gas industry in helping to understand what **essential and critical evidence** is required by government to progress towards a policy decision for 100% hydrogen conversion of the GB gas distribution network. In December 2016, the 'Executing the H21 Roadmap' document was presented to Ofgem at a meeting with the NGN CEO and distributed throughout BEIS. On the 26th January 2017, a meeting was held in the BEIS office at 3 Whitehall Place where the document was presented to senior leaders from all the GB gas distribution networks. On the 31st January 2017, at a meeting of the gas distribution network Chief Executive Officers, all GB GDNs agreed it was critically important to progress with the H21 NIC bid as a collaborative cross industry bid in the interests of gas customers and climate change.

4.4.2 Collaboration and Partners

The importance of this project is recognised by all GB GDNs and is the first collaborative NIC across **Cadent, NGN, SGN** and **WWU** who are all providing an equal contribution to the mandatory 10% funding requirements. NGN is the funding licensee and project sponsor.

To deliver a project of this scale and complexity in the timescales available, safely and effectively whilst ensuring that its delivery is risk managed requires collaboration between the right Partners and high levels of expertise. Other than the GDNs the Primary Partners for this project have been selected based on their ability to undertake the work and the value for money they can provide to the Project.

The Partners will all be signatories to the Project Collaboration Agreement. Other suppliers, such as mains work contractors for site modification/build works, will be contracted using established contract/sub-contract structures. Most of the participants have contracted with GDNs for this type of work in the past and all Partners have reviewed the draft collaboration agreement, and understand its provisions.

As explained in more detail in Section 6 and Appendix H, the lead Partners are DNV GL and the Health & Safety Laboratory (HSL). DNV GL are a global technical advisor to the UK oil and gas industry, owners of the Spadeadam testing site and custodians of the original natural gas leakage testing and QRA gas modelling software. HSL are the UK's foremost health and safety experimental research establishment and owners of the Buxton testing site.

As explained in Section 2 there are only two locations in the UK that are used for this type of work due to its high risk and specialist expertise requirements. These are Spadeadam and Buxton. Both these sites are required for this project for deliverability, governance, credibility and access to both sites specialist technical expertise.

Other Partners for the Project include Element Energy, the National Physical Laboratory, Radius Pipe Systems, YO Energy, ERM and Kiwa Gas Tech. These Partners will provide specific and uniquely experienced individuals and/or services and will provide specialist support in varying degrees at strategic points throughout the Project. To date all the Partners have provided their support in the development of the H21 NIC bid free of charge (See Appendix H for project Partners and CVs).

External funding
DNV GL will contribute £285k to the Project to build two houses on their site (see Appendix C) and the additional site videography. In addition, it should be noted that this project will directly compliment the BEIS £25m 'Downstream of the meter' programme of work. Whilst mutually exclusive, both programmes are critical to de-risking a hydrogen for heat pathway and combined have a total value of £40m.

An indirect value has also been attributed to the provision of expertise from DNV GL utilising all their original results and methodologies developed over decades of natural gas testing. This has allowed a significant reduction in costs for the H21 NIC through a refined testing programme and already established computer modelling platform. All other Partners and individuals have been selected due to their unique ability to add an indirect financial benefit to the Project through their specialist experience and expertise.

4.5 Relevance and timing (Criteria f)
As identified by the Committee on Climate Change a deliverable policy decision on heat needs to be made by the early 2020s for the UK government to meets its obligations as defined in the UK Climate Change Act. A policy decision, which includes the conversion of the UK gas grid to 100% hydrogen, will not be possible within that time frame if this H21 NIC bid does not progress. This could be to the detriment of all UK gas customers if they are subsequently pushed in to alternative sub-optimal decarbonisation heating solutions. In a worst-case scenario, a heat policy that does not have access to all the evidence could encourage customers to adopt one technology which could subsequently be found to be unable to meet decarbonisation objectives when considering whole system approaches.

Additionally, if this NIC project subsequently identifies some strategic work required on GB gas distribution network assets this can be incorporated into RIIO-GD2 business plans to ensure enabling works for conversion are undertaken upfront ensuring no ongoing delay.

Section 5. Knowledge dissemination

This project will conform to the default IPR arrangement set out in the Gas NIC governance document.

The GB gas distribution networks (GDNs) and Partners are committed to sharing the knowledge generated by this project. Its purpose is to provide urgent and essential evidence to allow optimised UK government policy decisions on decarbonising heat in the early 2020's. More widely it will inform the supply chain of stakeholders, in both the natural gas and hydrogen industries, of the viability of a 100% hydrogen conversion option. Wider still, the Project will be used to inform international opinion and potentially international energy policy. Fundamentally, the Project will provide quantified evidence to the public on the difference in risk between a 100% hydrogen gas distribution network and the current natural gas network.

5.1 Learning generated and the applicability to other network licensees

There are four principle aspects of learning associated with the H21 NIC project:

- Background leakage position of existing GB gas distribution network assets and subsequent safety differences between 100% hydrogen and natural gas networks.
- Development of a quantitative risk assessment process and predictive computer model (see Section 2/Appendix C) extrapolating the results of the tests to allow accurate prediction of the effects of a 100% hydrogen network across UK assets.
- Confidence in model application and accuracy via validation through field trial application of hydrogen.
- Identification of areas of concern and potential mitigation measures requiring further development via other projects.

This knowledge and learning will be relevant to the whole GB gas industry. The fundamental properties of hydrogen, types of GB gas distribution network asset and the consequences of release will not change significantly in different areas of the country.

The Project team has significant experience in capturing knowledge and learning, communication via presentations, workshops, conferences and training courses. This will ensure that the Project is scientifically rigorous and robust enough for all stakeholders, including gas customers.

There are key categories of data that will be derived within the Project from a variety of sources. The major aim is to gain greater understanding and knowledge on the behaviour of hydrogen in the gas distribution network and where applicable to compare this with the behaviour of natural gas. This is primarily to gain further understanding on the specific safety risks for hydrogen. Key areas of generated learning which will be applicable to all GB GDNs include:

Background testing: Comprehensively quantifying the differential in background leakage position for 100% hydrogen versus natural gas within the range of existing assets within the GB gas distribution network. This will provide the data for the subsequent assessment of baseline risk, commercial impact and operational impact associated with an incremental conversion of the GB gas distribution network to 100% hydrogen.

Consequence testing: Quantification of the risks associated with a 100% hydrogen gas distribution network compared to the existing known risk of natural gas. This will provide the data to update the FROST computer modelling package to understand any potential change to risk across the GB gas distribution networks.

Field trials: Field trials will provide comparative safety-based evidence for a 100% hydrogen conversion in a real environment. This will check that the extrapolation of results across all GB gas distribution network assets is accurate, that tests undertaken in controlled environments can be used to accurately predict real world environments and that operational procedures (repairs, flow stops etc.) can be safely and effectively carried out in a real-world environment. This will ensure that all stakeholders can have confidence in the results obtained in Phases 1A and 1B.

Quantitative Risk Assessment (QRA) and development of the computer modelling software: The results of the QRA will be published and access to the base data used for model development will be made publicly available.

Operational procedures: Operational evidence from Phase 2 – Field trials, will provide unique evidence relating to the technical and operational issues associated with 100% hydrogen. It will also allow an understanding of what changes, if any, may be required to operational procedures for a 100% hydrogen conversion and provide direction for future studies in this area.

Manufacturer information: Information will be provided to relevant manufacturers of the impact on performance of equipment, components and fittings as part of the Project. Working with the manufactures of different assets, the Project will identify any areas of concern and potential solutions.

All information will be captured by the work programme and recorded using a regular reporting structure to provide the basis for dissemination. The Project Partners are confident that the quality of the captured learning will be good and substantial enough to generate an understanding of the major hazard risks associated with the conversion of the distribution network to 100% hydrogen.

5.2 Learning dissemination

The project Partners recognise the importance of effective knowledge dissemination and learning, and are committed to it. The project team includes all the GB GDNs. A stakeholder/advisory board will be established to ensure effective and efficient knowledge dissemination, (see Section 6, Governance).

Effective knowledge dissemination is critical to the Project successfully achieving its aims and objectives. Effective development and subsequent execution of the strategy for knowledge dissemination and/or stakeholder engagement on a project of this complexity, and with such a significant potential future impact, is critical. Inaccurate and/or incomplete information disseminated to the wrong stakeholder could cause confusion and concern and could delay the H21 NIC Project itself. For example, agreement to progress with the field trials, or in the worst case, delay a subsequent policy decision on conversion.

A comprehensive strategy for knowledge dissemination will be developed and evolved throughout the Project. This plan will be owned by the H21 core team Project Manager and discussed/updated at the monthly project boards as, see Section 6, Governance. It will be the responsibility of the Steering Committee to sign off the initial plan and subsequent amendments. The H21 Programme Director will be responsible for signing off specific items of knowledge for dissemination in line with the agreed plan prior to any Partner discussing the information with external stakeholders. This is critical to ensure that the information is managed as part of the Project and during the Project stages. This strategy will consist of core component parts:

- Stakeholder plan.
- Knowledge and learning dissemination plan.
- Communication plan.

5.2.1 The stakeholder plan

There is a wide range of stakeholders for whom the data, knowledge and learning generated from this project could have significant impact. This ranges from the Department for Business, Energy & Industrial Strategy (BEIS) to support ongoing policy decisions to individual businesses where the results could influence their longer term strategic direction. It is therefore important that each of these individual stakeholders and groups be clearly identified and that a specific plan of engagement is developed. At initial project kick off the following stakeholder groups will be included within the plan.

- Gas distribution networks and trade associations.
- Ofgem.
- Health & Safety Executive (HSE).
- Appliance manufactures and trade associations.
- Local Authorities.
- Financial investors (e.g. GB GDN shareholders).
- Gas shippers and suppliers (including hydrogen producers).
- Relevant government departments (e.g. BEIS).
- Gas customers.
- National Grid Transmission.

Effective engagement with some of these groups has been a key part of the work already undertaken as part of the H21 Leeds City Gate (LCG) NIA project and referenced within this document, (see Appendix I and Section 6 for details). As such, real routes of communication have already been established and initial knowledge and learning shared. This project will look to build directly on these relationships and extend across the wider stakeholder group.

5.2.2 The knowledge dissemination plan

Building on the stakeholder plan, the knowledge dissemination plan will ensure appropriate dissemination of targeted knowledge to key stakeholders. The level and detail of information which will be released will be reviewed and could vary from a high-level update on progress, an update to manufacturers on testing results or a full detailed technical report.

5.2.3 The communications plan

The communications plan will effectively execute the stakeholder and knowledge dissemination plans. It will define the method of communication appropriate for each stakeholder and the interface which could vary significantly dependent upon the specific item in question. As with all modern projects an easily accessible website will be created and will form the hub of all disseminated knowledge and communications.

The wide range of stakeholders dictates that our communication strategy must include a diverse range of methods that should be adapted to the requirements of each audience. To ensure clear and consistent interpretation of the data is made all public communication will be approved prior to release by the H21 Programme Director in line with the knowledge dissemination strategy approved by the Steering Committee.

During the Project, communication will vary greatly dependent on the stakeholder group and information being disseminated. It is also important the profile of the H21 NIC project is maintained to ensure industry momentum generated throughout the H21 LCG project is maintained. Communications will include:

- Creation of an H21 Website.
- Attendance and presentations at key conferences, for example at the Low Carbon Networks & Innovation Conference.
- Attendance at appropriate meetings and round table events.
- Open day events at the testing sites.
- Network and local events; site visits and presentations given to interested stakeholders.
- Publications – specific areas for wider communications including gas and utility industry journals and periodicals.
- Social media (e.g. tweets, text, email, Facebook, LinkedIn): to increase dissemination to a wider audience.
- Written reports.
- Short films posted on the H21 website.
- Press releases.

At project completion, a comprehensive report and film will be publicly available to all stakeholders via the website as was the case with the H21 LCG report and film.

In addition to communications in line with the strategic plan, a relationship for channel for communication will be developed with the BEIS 'Downstream of the meter' programme team. The exact relationship and terms of reference will need to be developed once BEIS have appointed a management contractor and subject to award of this bid. Preliminary discussions have already taken with BEIS internal staff to ensure open and active communications.

5.3 Intellectual Property Rights (IPR)

The project will comply with default IPR provisions. The purpose of the Project is to generate safety data for the conversion of the distribution networks to 100% hydrogen. Since this data will be common to hydrogen in gas networks across the country there is no intention or opportunity to exploit arising IPR commercially in GB. Copyright will exist on the reports produced as part of this work, but they will be published in the public domain where required for effective knowledge dissemination.

Background IPR, such as that within equipment supplied for the purposes of executing the Project (e.g. measurement devices), will remain owned by the suppliers as commercial products. This will include the Project Partners' background IPR in their existing quantitative risk assessment software and models. The testing and analysis work carried out in the Project will generate knowledge of hydrogen properties and release consequences for comparison with those of natural gas. DNV GL and HSL have carried out extensive tests with natural gas in the past, the results of which will constitute background IPR where used in the Project. The results of any wholly novel tests with natural gas carried out as part of the Project will be foreground IP. No additional software capability will be developed as part of the Project. Any quantitative risk assessment procedures that are developed as part of the final recommendation will be software agnostic to allow ready implementation by any gas network operator.

Section 6. Project readiness

Required level of protection

The Network Licensee does not require protection against cost over-runs beyond the default provision of 5% above the funding request. This project does not give rise to Direct Benefits and so no protection provision is required.

6.1 Evidence of why the Project can start in a timely manner

The GB Gas Distribution Networks (GDNs) and all the Project Partners are confident of the ability of this project to deliver the objectives in a timely manner. This is due to the high level of technical preparation, quality of expertise and extensive stakeholder engagement undertaken to date which underpins this proposal. The key factors ensuring a timely start to the Project are summarised in the following section.

Network Innovation Allowance work to date:

The H21 Leeds City Gate Network Innovation Allowance (H21 LCG) project assessed the feasibility of converting a major city's gas network from natural gas to 100% hydrogen concluding it was both technically possible and economically viable. The H21 LCG project report identified in Section 10 'The H21 Roadmap' a range of projects/next steps required to obtain the outstanding evidence to facilitate a policy decision. This roadmap was further developed in the 'H21 – Executing the roadmap' document presented to the Department for Business, Energy & Industrial Strategy (BEIS) and Ofgem in December 2016 and the wider gas industry in January 2017. This identified provision of the quantified safety based evidence for the GB gas distribution network grid conversion to 100% hydrogen as the critical first step.

In addition to the H21 LCG project the 'H21 – Keighley & Spadeadam Designs' NIA project has been progressed alongside the preparation of this bid and throughout 2017. The primary purpose of this project is to ensure project readiness should this H21 NIC project bid be successful by providing confidence in costs, informing the master testing plan (what, how and why testing is being undertaken), and site designs for the respective test sites are already in place. Note, to date, this resulted in the move away from Keighley for Phase 1A – Background testing, as suggested in the ISP, to Buxton as explained in Section 2.

Stakeholder engagement:

Through the H21 LCG project there has been an exceptional level of stakeholder engagement over the last two years, a comprehensive list of which can be found in Appendix I, and highlights are detailed below.

- The natural gas supply chain, including gas producers, shippers and appliance manufacturers.
- The hydrogen supply chain, including hydrogen production companies, fuel cell manufactures, hydrogen associations, for example Scottish Hydrogen and Fuel Cell Associated and the UK Hydrogen and Fuel Cell Association.
- Academia, including lectures at Oxford, Leeds and Teesside universities.
- International, including Europe via Eurogas and the Director General of the European Commission, Hong Kong, Australia, the USA and Japan.
- The wider energy sector via over 20 conferences
- Advisory bodies and institutions, including the Committee on Climate Change, Energy Utilities Association, Energy Networks Association, Institute of Gas Engineers and Managers, Association of Meter Operators, The Energy Systems Catapult/Energy Technologies Institute, Policy Exchange, Carbon Connect, Energy Research Partnership, Carbon Capture and Storage Association and the European Zero Emissions Panels.

This extensive engagement has ensured that this H21 NIC submission is based on galvanised opinion across the supply chain leveraging expertise but focusing on the critical evidence gaps without duplicating effort. This has ensured that the bid is highly credible from the start with the upfront benchmarking and national and international stakeholder engagement broadly completed.

Another important area of engagement has been at national and local government level. National government engagement has influenced the BEIS £25m 'Downstream of the meter' programme and a recognition that decarbonising heat needs a fundamental review, (see Section 6). At local level, across the ten councils of West Yorkshire and five councils of the Tees Valley there is significant support and appetite to progress the H21 LCG concept, (see Appendix J, Letters of support). Additionally, the local authorities are actively supporting the field trials stage of the Project ensuring minimal delays and enhanced value for money for gas customers, (see Appendix C for more detail).

Whilst the H21 LCG was originally funded by Northern Gas Networks (NGN) and Wales & West Utilities (WWU) the value, quality and credibility of the Project has been recognised by all GB GDNs. This has resulted in this H21 NIC being the first NIC proposal ever put forward which is collaborative and co-funded across all GB GDNs.

Unique expertise
The H21 NIC Project team/Partners have been assembled from some of the most knowledgeable and experienced organisations and personnel in the UK with international 'reach back' across the world. This has ensured the Project will be delivered effectively with a strong focus on value for money ensuring minimal spend to solve the problem statement. All Project Partners have provided their time free of charge to support the H21 bid and have a consensus on the adopted approach. Contractual arrangements are agreed in principle avoiding any delays in project execution following subsequent award of the NIC.

This Project is the first of its kind anywhere in the world. The extensive background work and stakeholder engagement undertaken to date has ensured consensus across all Partners and the wider industry on the structure of the Project, its budget and its deliverability. The programme, whilst aggressive, is achievable and has been strategically designed to complement the BEIS £25m 'Downstream of the meter' programme ensuring timely delivery in line with policy requirements for carbon reductions associated with heat decarbonisation objectives. Key aspects of the Project are described in the Sections below, supported by evidence in the Appendices.

6.1.1 Project plan
A detailed project plan is shown in Appendix E. The three key project phases: Phase 1A Background Testing, Phase 1B Consequence Testing and Phase 2 – Field trials are identified as well as the associated Quantitative Risk Assessment (QRA)/modelling requirements and final reporting. The programme has been developed collectively by the Project Partners and has undergone an iterative review process to ensure agreement on deliverability and responsibility.

The Project plan is assumed to commence immediately on notification of NIC success and is designed to complete in mid-2020. The GB GDNs will add their year one contribution to the NIC project bank account to bridge any gap between the January start date and delivery of NIC funding provision (April 2018) ensuring no delays to project execution. Whilst costs for Phase 2 – Field trials) are considered robust the final site selection is still to be determined (see Appendix C for detail on field trials). The programme team are confident that this will be achievable and the letter of support (Appendix J) from the combined authorities of the West Yorkshire areas confirms the regions commitment to ensuring project delivery.

6.1.2 Project management and governance
The aim of the Project structure is to manage and deliver the Project safely within budget and programme. It is designed to provide the Network Licensee the level of control required to meet the requirements of the Ofgem Governance Document, as well as the governance requirements of the Partners, specifically DNV GL and the Health & Safety Laboratory (HSL) who are the operators of the Spadeadam and Buxton sites respectively. As with any major project, governance will be in place to ensure progress is monitored via a regular review process by Project Partners throughout the delivery of the Project. The Project organisation is summarised in the management diagram in Appendix D.

The GB GDNs have a well-developed and proven collaboration agreement, which has formed the basis for previous NIC projects to date. This has already been reviewed by the primary Project Partners and will form the basis for this project.

The governance framework is in place to ensure appropriate oversight and control over key decisions and to delegate authority for scope delivery to a Steering Committee. The Steering Committee will comprise of representatives nominated by each of the collaborating GB GDNs and the primary project Partners. The Chair of the Steering Committee shall be the H21 Programme Director for NGN. Should the chair not be available they shall delegate to one of the other collaborating GB GDNs as appropriate.

The Steering Committee will meet on a quarterly basis to review Project progress reports, performance against budget, key Project risks and material issues. The rules of the Steering Committee will be set out in the Project Collaboration agreement, and are summarised in Appendix D.

The H21 Programme Director is accountable for the successful allocation of milestones and allocation of stage funding under the NIC allowance. The Project nominees from the other GB GDNs shall report progress to their own executive committees.

Project management is provided by a multi-disciplined project team, see Appendix D, Organogram, responsible for co-ordinating the day-to-day operations of the Project, coordinating and reporting to the Steering Committee, and acting upon decisions, with relation to budget management, and submitting requests for milestone completion and sanctions to progress to subsequent project stages. **Project Board** meetings of the participants will be held monthly.

Due to the nature of the H21 NIC project, testing will be required at Spadeadam and Buxton managed/overseen by DNV GL and the HSL respectively. To provide an appropriate level of governance and agreement of the respective testing plans DNV GL and the HSL will be required to review and agree each other's finalised master testing plan and testing regime. Furthermore, both Partners will also be permitted to have a presence in each other's respective testing operations to confirm that tests were undertaken in line with agreed methodology and ensure credibility of results.

The HSL will also participate in the QRA/modelling element of the Project and both HSL and DNV GL will collectively support the development of the master testing plan requirement for Phase 2 of the Project, Field Trials.

The project structure also includes a stakeholder/advisory board. The purpose of this board is to ensure appropriate levels of communication across key stakeholders, for example BEIS, the Health & Safety Executive (HSE), Local Authorities, Heating and Hotwater Industry Council and Institution of Gas Engineers & Managers (IGEM), are established with opinions and observations which can be disseminated back to the Steering Committee for consideration. The frequency and participants (which may change as the Project progresses) will be proposed by the H21 Programme Director and agreed via the Steering Committee.

6.1.3 Project Partners, contractors and team

The GB GDNs have constructed a team comprising experienced and expert companies and individuals. Additional company summaries and CVs of key individuals can be found in Appendix H.

Project Partners have been categorised as Primary Partners or support Partners. Primary Partners (DNV GL and the HSL) are undertaking and responsible for key aspects of the work. Support Partners are adding specific strategic advice to the Project team to ensure validity of results, value for money, support knowledge dissemination and provide general challenge and review to the Project Board and Steering Committee meetings.

This project is a true collaboration between all GB GDNs. **NGN** is the funding licensee and project sponsor. **Cadent, Scotland and Southern Gas Networks** and **WWU** are collaborating and co-funding GDNs. They all bring their expertise and experience relating to the gas network to the Project, and between them have undertaken numerous NIA and NIC projects in the past. The Projects primary and supporting Partners and their roles are summarised below.

DNV GL (primary Partner): DNV GLs UK gas consulting business has a common history with the GDNs since, like the GDNs, it was formerly part of British Gas. DNV GL still employs some of the staff responsible for the leakage testing programme developed and executed throughout the 1990s and, to date, have been invaluable in advising on the testing programme specifically avoiding unnecessary testing where possible. They are the operator of the Spadeadam Testing and Research facility, on the border of Cumbria and Northumberland, and have over forty years of experience carrying out hazardous testing at large scale, quantitative risk analysis and computer modelling. They will plan and oversee the experimental programme at the Spadeadam site, as well as providing a reviewing and support function at Buxton and the Phase 2 – Field trials. DNV GL will also have primary responsibility for the QRA and updating of the existing computer modelling platform used to extrapolate results across the GB gas distribution network asset base.

The Health & Safety Laboratory (HSL) (Primary Partner): One of the UK's foremost health and safety experimental research establishments. They understand the issues that the HSE need to see addressed in this project. This experience significantly de-risks the Project by ensuring that the relevant evidence base is understood from the outset, and ensures close and effective engagement with the HSE throughout the process. They will plan and oversee the experimental programme at their Buxton sites, as well as providing a reviewing and support function at Spadeadam, the QRA and Field Trials.

The following Partners are all considered Supporting Partners.

Alastair Rennie – YOEnergy Limited: Review role providing over 38 years' experience mostly Project Management of large or new issues, delivered to budget. Since 2000 he has worked on renewable energy options and in 2006 he helped found and then led the UK Hydrogen Association, and its merger, to found the UK Hydrogen and Fuel Cell Association. Concurrently a Director of the Carbon Capture and Storage Association, where he has led on technical issues such as HS&E, and has long advocated 'low cost, low carbon hydrogen'. He was a prime contributor to H21 LCG NIA.

Element Energy: One of the UK's leading low carbon energy consultancies. Through over fifteen years of work in the hydrogen sector, Element Energy has worked with all the major industrial companies in the UK's hydrogen sector, led numerous multi-stakeholder assignments, gained a deep understanding of the full spectrum of hydrogen technologies from generation, transport, storage and use, whilst also building a very extensive global network of stakeholders throughout the hydrogen sector.

Kiwa Gastec: Kiwa is a UK Notified Body under the Gas Appliance Directive and has developed close relationships with most UK gas appliance companies. They ran the BEIS Hyhouse project, an investigation of the comparative behaviour of 100% hydrogen and natural gas leaks in a two-storey building, and have carried out risk assessments on several hydrogen refuelling stations. Kiwa have been involved in H21 LCG and several high-profile hydrogen projects to date. They operate a gas-safe training centre and will bring a valued perspective on gas safety.

Radius Systems Limited: Radius have a unique historical position with 48 years of trading spanning the history of polyethylene pipe use in UK gas distribution. Through their technical staff, who individually can evidence between 20 and 39 years' experience, Radius will provide high quality support to the H21 NIC, both in terms of PE pipe systems and failure modes/mechanics. Additionally, Radius currently hold the presidency of the Plastic Pipes Group within the British Plastics Federation, ensuring an industry wide perspective is available to complement the single manufacturers viewpoint.

The National Physical Laboratory (NPL): NPL is the UK's national standards laboratory and is owned by BEIS. NPL Management Limited operates as a public corporation and is an internationally respected and independent centre of excellence in research, development and knowledge transfer in measurement and materials science. They will provide advice on the measurement techniques (specifically for the field trials) and support close and effective engagement with BEIS throughout the process.

6.1.4 Project delivery risk assessment and mitigation

The Project will be managed using a structured approach to project delivery risk. During the development of the Project a risk register has been drawn up as shown in Appendix F which identifies risk, risk management and mitigation plans.

A standardised approach is used for the Project, where risks are categorised and assessed in terms of likelihood and impact. Likelihood is assessed on a scale from 1 to 5, (from impossible to certain), and impact assessed between 1 and 5, (from low to disastrous). mitigation measures against each risk are identified and actions proposed. The risk is reassessed based on the mitigation measures being put in place. This tool will be used proactively to manage the Project throughout the delivery phase, with clear responsibility for each action and risk status. It will be updated regularly throughout the Project and will provide the basis for reporting.

The H21 NIC project risk is grouped into three main categories of risk; namely health and safety, technical delivery and project risks. The risk register has been developed using a 5x5 risk rating.

The health and safety risks are primarily around the construction, delivery and undertaking of the three test Phases 1A, 1B and 2. As these all involve practical and operational testing, the risks are potentially high, although with the necessary controls and mitigations in place, these will be managed to ALARP (as low as reasonably practical). It is important that onsite controls and management are effective in the delivery of the programme. All three locations for the testing will have their own management processes and procedures in place to allow safe operation of the tests.

Technical risks are associated with the Project, and therefore data quality is critical. Having the appropriate instrumentation available is a key factor and a risk. Some of the instrumentation is already in use for similar types of projects for measuring data but further investigation will be undertaken once the Project begins. There is a need for detailed design and planning of the sites and this has been undertaken in advance through an NIA project where the sites will be designed and approved through a design assurance process following the Industry guidelines.

Project risks includes the delivery, duration and cost of the Project. These risks will be managed throughout the duration of the Project, as outlined in Section 6.1.2 and Appendix D. One of the other risks is the engagement of stakeholders and the importance of stakeholder management through the Project, this will be supported with a knowledge dissemination strategy as defined in Section 8.

6.1.5 Interface with other innovation projects

The H21 NIC has been established as a direct result of the H21 LCG project and the subsequent 'Executing the H21 Roadmap' document. This NIC project sits centrally to unlocking a long-term future for low carbon energy (heat, light and transport) utilising hydrogen gas alongside growing low carbon electric.

It interfaces directly with existing NIC projects as well as numerous NIA projects focusing on hydrogen and wider gas industry issues, for example billing. These include:

BioSNG, i.e. the potential for bioHydrogen following a subsequent conversion to 100% hydrogen which could enhance the existing plants net energy production characteristics.

HyDeploy which will consider blending hydrogen into the existing gas grids. Whilst the H21 project is fundamentally different there will be safety and customer interface best practice which will be shared openly between the Projects.

Future of Billing, considering the changes to billing methodology necessary to facilitate adoption of new gases and blends more widely.

This H21 NIC will interact and complement directly the BEIS £25m 'Downstream of the meter' innovation programme. Designed to deliver within similar timescales, these two world-first innovation programmes will ensure all aspects of the outstanding critical evidence for a 100% hydrogen conversion to decarbonise heat is provided effectively and efficiently. This is essential to facilitate an optimised future policy decision on heat in the interests of gas customers.

Finally, this H21 NIC project will be centrally coordinated from the H21 project office established in Leeds City Centre in conjunction with Leeds City Council. This office has already established national and international links (Statoil, Australia, Eurogas, Hong Kong and Japan) via stakeholder engagement activities and hydrogen specific NIA projects including:

- H21 – Strategic Modelling Major Urban Centres.
- H21 – Domestic Metering.
- H21 – Alternative hydrogen production and storage methodologies.

These links will be utilised to ensure international best practice and benchmarking, knowledge dissemination, enhanced global lobbying and, hopefully leveraging additional funding, to support development of a live trial following the BEIS and H21 NIC programme completions.

6.2 Evidence of the measures a network Licensee will employ to minimise the possibility of cost overruns (direct benefits are not applicable to this project)

6.2.1 Budget development

A conservative approach has been taken to produce a robust cost plan for delivering the Project.

The starting point for the cost plan is the careful design of the overall programme. This ensures that not only are the technical activities accounted for, but important facets such as communications and consumer engagement are properly considered and costed. The programme and costs have been developed collaboratively and iteratively by all the Project Partner's, drawing on the significant amount of technical work from the H21 LCG and 'H21 – Keighley & Spadeadam Designs' NIAs as well as the specific and unique expertise and historical background from the Partners.

Collective development and agreement by all Partners was established on the minimum testing requirements which would be essential to solve the problem statement, i.e. Phases 1A, 1B and 2 and the detail thereof, (see Section 2 and Appendix C). Once this was finalised and agreed a detailed iterative costing exercise was undertaken to establish a bottom up cost breakdown based on levels of effort for individual activities. For Partners with existing pre-tendered framework rates these rates were used to build up costs. Rates for Partners not on existing framework agreements were established by benchmarking against past projects, e.g. the HSL rates on HyDeploy.

Costs associated with site construction costs at Spadeadam and Buxton were established utilising NGNs expertise to provide estimates against preliminary site designs which were also sense checked and agreed as appropriate with the respective site owner Partners. Costs for extraction of network assets (for Phase 1A) were established via an independent pricing exercise by NGN and Cadent which was subsequently compared to ensure consensus on costs. These estimates are based on business as usual practices within the GB GDNs and are considered minimum cost whilst ensuring achievable delivery.

Estimates for specialist or specific items, for example hydrogen supplied to site, were provided utilising the expertise and wider connections of the Project Partners and/or appropriate benchmarking against other network projects, for example site security for field trials.

The consolidated costs have been reviewed by the Project Partners. The detailed risk register for the Project has been reviewed to identify areas which require allowances to be made against specific activities. By these means, and through an internal review process, there is confidence that not only is the scope well defined and comprehensive enough to deliver the requirements of the Project but that the associated costs are robust.

6.2.2 Budget management

The Project will be carefully managed to ensure that it delivers to budget. This will be overseen by the Steering Committee.

The Project Manager will consolidate and track project costs from the Partners and subcontractors. These will be provided as part of the wider monthly project reporting process to the H21 Programme Director for sign off.

NGN already has in place the governance processes to manage a separate NIC account and provide the necessary traceability of invoices and payments made.

Budgets will be reviewed regularly by the Steering Committee, to give forward visibility of costs and the opportunity to address proactively potential deviations from budget.

6.3 A verification of all information included in the proposal (the processes a Network Licensee has in place to ensure the accuracy of information can be detailed in the appendices)

Data assurance activities have been performed to ensure the accuracy of the data provided in this submission is in compliance with the requirements of Ofgem's Data Assurance Guidance (DAG) document under Standard Special Condition A55: Data Assurance of NGN's Gas Transporter Licence.

Please refer to the separate NIC Bid 2017 Irregular Submissions template document which provides details of the DAG Risk Assessment performed and the detailed data assurance activities performed to comply with the DAG.

In addition to the DAG reporting process the following summarises the principle areas of bid development and the parties involved to verify and agree the requirements.

Scope: This was developed iteratively in conjunction with the Project Partners, building on the work undertaken in the H21 Leeds City Gate NIA.

Technical programme and budget: The overall technical programme was developed by the GB GDNs and collectively agreed across all Project Partners.

Phase 1A – Master testing plan (Buxton): Developed utilising asset selection methodology (as defined in Appendix C) and then agreed across the GB GDNs and Primary Partners.

Phase 1B – Master testing plan (Spadeadam): Developed by DNV GL and agreed with the GB GDNs and the HSL and, additionally supported via the 'H21 – Keighley & Spadeadam Designs' NIA.

Phase 2 – Field trials requirements: Defined and agreed across all Project Partners

6.4 How the Project plan would still deliver learning in the event that the take up of low carbon technologies and renewable energy in the Trial area is lower than anticipated in the Full Submission

This project is a world first and will provide valuable and entirely new learning for the UK and worldwide gas industry. Whilst the carbon savings and financial benefits to gas customers will only be achieved through a subsequent conversion to 100% hydrogen the learning is not dependent upon the take-up of the option.

The H21 NIC project will provide the critical safety evidence to unlock the significant benefits to UK gas customers, the UK economy and the global climate challenge. The benefits of such a conversion are extensive and can be quantified. However, they cannot be realised without this project to provide policy makers and gas customers with the confidence to make and support such a conversion decision.

6.5 The processes in place to identify circumstances where the most appropriate course of action will be to suspend the Project, pending permission from Ofgem that it can be halted

The project has been carefully planned and reviewed by the Partners for deliverability, so project suspension or termination is considered unlikely.

The progress on the Project will be constantly reviewed and assessed quarterly by the Steering Committee and at Project Board meetings. Other than for general project delivery reasons as identified below, the only additional foreseeable reason to stop the Project would be the identification of a 'show stopper' in relation to a 100% hydrogen conversion option. A 'show stopper' could be the identification of an increase in risk for 100% hydrogen relative to natural gas that would be considered unmanageable in terms of gas distribution of 100% hydrogen. This is considered highly unlikely by all project Partners.

More generally, the Steering Committee will have the power to suspend the Project if:

- Insufficient progress is being made compared to the Project plan.
- It cannot be delivered within its budget and additional funds cannot be raised.
- Risks are identified which cannot be mitigated and make delivery of the Project objectives unlikely.

After any suspension, Ofgem will be approached to discuss and agree termination of the Project. Under the terms of the Project collaboration agreement, specific provisions are defined for dealing with termination of the work in this event.

Section 7. Regulatory issues

The network licensees will not require a derogation, licence consent, licence exemption or change to current regulatory arrangements to deliver the Project. The Project team has considered the following as part of the Project design to confirm the accuracy of this statement.

Regulations/Uniform Network Code (UNC): The H21 Leeds City Gate project identified in Section 8 (p268) the extent of the deviations required to both the Gas Act and UNC should a full conversion to 100% hydrogen take place. The key points were:

1. The Gas Act:

Section 48 of the Gas Act defines gas:

> "gas" means—
>
> (a) any substance in a gaseous state which consists wholly or mainly of—
>
> (i) methane, ethane, propane, butane, hydrogen or carbon monoxide;
>
> (ii) a mixture of two or more of those gases; or
>
> (iii) a combustible mixture of one or more of those gases and air; and
>
> (b) any other substance in a gaseous state which is gaseous at a temperature of 15°C and a pressure of 1013.25 millibars and is specified in an order made by the Secretary of State.

This means that a hydrogen network could be included in the scope of the Gas Act.

2. The Uniform Network Code/Gas Transporters Licence:

The Gas Transporter Licence is issued under Section 7 of the Gas Act and permits the conveyance of gas. Under their licence each Transporter must conform to the Uniform Network Code (UNC). The UNC is limited in scope to natural gas and does not include hydrogen. Although this definition could be changed a major review of the UNC would be required to identify any consequential impacts.

The H21 NIC will not convert any part of the distribution network which supplies natural gas to customers, and will therefore not be 'transporting' hydrogen gas. The Phase 2 – Field trials will be managed under a safety management system developed as part of the Phase 1A and 1B work. They will be temporary in nature with no effect on customers, therefore the Gas Safety (Management) Regulations, the UNC and the Gas Transporters Licence are unaffected. No change will be required to the licence.

Consumers: No live trials are included in the Project, and so there will be no interruptions to gas supplies or other impacts on consumers. These field trials will be undertaken on in-situ abandoned mains with no customer connections. The purpose of these trials is to confirm the results of the evidence gathered in the background testing.

The H21 NIC will not affect 'Downstream of the meter' and will not affect customers' gas supply.

Industry policy and procedures: The project is designed to increase knowledge of what constitutes good practice, which will later inform the development of industry policies and procedures for hydrogen. Good practice will be observed in the design and execution of the test programme. The test equipment designs will be independently design assured using the principles of the gas industry's G17 process. Task risk assessment and safe control of operations procedures will be observed at all test locations to ensure safe systems of work are involved. All Partners have management systems which are independently certified under ISO 9001, OSAS 18001 and ISO 14001 for quality, safety and environmental performance, which will be applied in full during the execution of the work.

The H21 NIC will solve the problem statement and allow progression of a policy decision on hydrogen for heat and live trials (upstream and downstream of the meter). Live trials would require changes to regulations and industry procedures, including the Uniform Network Code documents, secondary legislation, e.g. GCoTER – Gas Calculation of Thermal Energy Regulations, and a range of other industry specific documents. Whilst these amendments are out of scope of the H21 NIC project, coupled with the BEIS led 'Downstream of the meter' programme, they will provide the significant evidence required to allow these amendments to take place.

Furthermore, other existing NIC projects such as HyDeploy, Future Billing Methodology and the Opening up the Gas Market (completed) will add further evidence and, as importantly, establish the methodology for amending these documents in future.

Health & Safety Executive (HSE): The HSE do not own the safety case for GB GDNs. These are owned by the GDNs themselves. The HSE ensure compliance with this safety case. However, any significant change to the safety case, such as to convert the GB gas distribution network to 100% hydrogen, must be justified with evidence to the HSE and BEIS. The process for such significant changes is currently being progressed and developed as part of the SGN Oban project. As a primary Partner to the Project, the HSL have a direct link to the HSE ensuring that open communication with this critical stakeholder is efficient and effective.

ofgem RIIO NIC NETWORK INNOVATION COMPETITION

Section 8. Customer impact

A fundamental part of the rationale for undertaking the Project is to develop the critical evidence to allow for a deliverable policy decision on heat to be made in the early 2020s. A GB gas distribution network conversion to 100% hydrogen to decarbonise heat would cause minimal disruption in the homes and the highways for gas customers when compared with viable alternatives.

The H21 NIC has three phases which will have different levels of impact on customers. No phase will have any significant impact on customer's gas supplies. The specific type of customer impact per phase is summarised below with a detailed explanation thereafter.

- **Phase 1A – Background testing.** Could have a minor impact on a very limited number of customer supplies when removing network assets.
- **Phase 1B – Consequence testing.** No customer impact.
- **Phase 2 – Field trials.** No impact on customers gas supplies. However, a customer engagement plan will be developed to ensure customers in the surrounding area are aware of what works are being undertaken.

8.1 Phase 1A – Background testing

Background testing will involve a strategic set of tests covering an appropriate range of assets and pipe configurations representative across the GB Gas Distribution Networks (GDNs). A cross section of these assets will be removed from the networks and transported to the HSL site at Buxton. Controlled testing with natural gas and 100% hydrogen will then be undertaken. These tests will provide the quantitative evidence for changes to background leakage levels in a 100% hydrogen network. The only element of this phase which could have an impact on customers will be the removal of network assets prior to delivery to the Buxton sites.

As part of the H21 NIC bid development a range of pipes and equipment has been identified and agreed as appropriate by all Partners, within the master test plan for Phase 1A (see Appendix C). These assets will need careful removal from the network by isolation under normal gas flow-stopping procedures. The samples will be carefully removed from the excavation to minimise disturbing the pipe, joints and other assets that may be present (e.g. valves). All the work activities to remove the pipe samples will be undertaken in accordance with GB GDN technical and safety procedures.

Most of the assets to be removed will be varying diameters of pipes with different joint configurations. To keep customer impact to a minimum these assets, where possible, will be isolated and removed as part of the Iron Mains Replacement Programme (IMRP) or Business as Usual (BAU) operations. For all the GB GDNs, customers are at the heart of the IMRP with a strong focus on minimising the amount of time that the customer is left without gas.

Removal of network pipes for testing will be designed to capitalise on existing planned projects in the 2017/18 and 2018/19 GDNs IMRP. These sites will be identified in collaboration with all the GB GDNs to ensure samples are removed with no additional impact on customer's gas supplies other than what would have already been the case under business as usual for the individual projects in question.

The IMRP covers Tier 1 mains (up to 8 inch diameter) and some Tier 2 mains (above 8 inch and below 18 inch in diameter). To isolate and remove mains which fall outside the IMRP (Tier 2 non-mandatory and Tier 3 mains which are 18 inch and above diameter), the Project team will try to select mains from across the GB GDNs which have been identified for replacement as part of BAU network processes under a cost benefit analysis. This will ensure that excavation and removal of these mains has no additional impact on customer's gas supplies other than what would have already been the case under BAU for the individual projects in question.

There may be some Tier 2/3 mains identified in the Master Testing Plan (MTP) which are not identified in the 2017/18 or 2018/19 replacement programmes across any GB GDNs. If this is the case, in the first instance, consideration will be given to changing the diameter of main selected for testing to a similar size main that has been identified in one of the GDNs replacement programmes. If this is not possible and/or could affect the validity and confidence in the tests an appropriate main will be identified which will have the lowest customer impact possible. It should be noted that, for the length of main which will be removed for testing, it is highly unlikely that this will affect more than one customer connection.

All GB GDNs have a strong focus on customer service which includes keeping customer time off gas to a minimum. GB GDNs have well established processes to minimise additional customer impacts when undertaking work on the network. It is normal practice that as part of the IMRP and BAU operations customer and stakeholder mitigation plans are developed to ensure impacts are minimised as much as possible for the work activities. These plans focus on the following general areas, but are not limited to:

- Traffic – traffic flow/volumes, management systems in place, bus routes and emergency routes.
- Land uses – private roads etc.
- Education – nurseries, schools and universities nearby.
- Public services – hospitals, ambulances, fire stations, crematoriums etc.
- Business and commerce – types of businesses, commercial, retail outlets etc.
- Type of house/private/public.
- Special event/consideration.
- Residential areas.

It is important to identify the level of community engagement which will be required for the type of works to be undertaken and to ensure the engagement process is continuous and appropriate. For Phase 1A the H21 NIC project will utilise already well-established practices and leverage planned work programmes to keep customer impacts to a minimum.

8.2 Phase 1B – Consequence testing

Consequence testing will involve the quantification of risk associated with background leakage as determined in Phase 1A, failure leakage (for example mains fracture, 3rd party damage) and operational response, i.e. repairing leaks. This means establishing what the consequence of leaking hydrogen will be for different scenarios with different potential sources of ignition when compared to natural gas. This phase of testing will have no impact on customer gas supplies and will require minimal customer liaison as part of the test due to the remote location of the Spadeadam site.

These tests are designed to provide validation information and data to enhance the knowledge and the behaviour of hydrogen compared to that of natural gas. A series of tests have been developed based on the existing research and operational knowledge of natural gas. Some of these tests will include modelling releases of hydrogen, ignition and explosion of various scenarios. It is due to this nature of testing that DNV GL Spadeadam Research and Testing Centre has been chosen for the location. It is a remote site with a comprehensive array of engineering and scientific equipment and facilities specifically designed for these types of activities.

DNV GL Spadeadam Research and Testing Centre have established stakeholder and customer management processes which will be in operation during any testing. This includes liaising with the RAF staff for overall site control and local residents as part of the daily plans.

8.3 Phase 2 – Field trials

Field Trials will involve tests on in-situ mains and some above ground assets (for example district governors), the purpose of which is to confirm the results of the evidence gathered in Phase 1A. These tests will not be undertaken on live mains or downstream of the meter and will not affect customer's gas supplies. Extensive liaison with Local Authorities, as well as a comprehensive customer engagement plan will be required to inform neighbouring residents of the works being undertaken.

The H21 NIC team have been working closely with the West Yorkshire Combined Authority to identify demolished/derelict sites where mains networks still exist. Derelict/demolished sites have been identified as the most suitable sites for field tests as the network assets still exist but will have been isolated from the network and do not impact end use customers. Using these types of sites will ensure no customer impact and a safe, but 'real-life' environment for carrying out field testing.

Final site identification and subsequent design/enabling work will be undertaken throughout 2018 in preparation for the field trials in 2019. To date several sites have been identified and assessed against the parameters identified in Section 2. Ultimately the site selected for field testing will represent the best value for money in terms of cost, range of assets available, surrounding land use and level of customer impact. The selected site will be provided to the H21 NIC project under legal agreement between the council and the networks for the duration of the trial.

The field trials will be carried out under a well-developed safety management system supported by the evidence from Phases 1A and 1B. A customer/stakeholder engagement plan will be developed and approved by the Steering Committee to ensure customers in the surrounding area are fully aware of the work being undertaken.

Section 9. Project Deliverables

The following project delivery criteria are based on a project commencement date of January 2018.

Ref:	Project Deliverable	Deadline	Evidence	NIC Funding Request (%)
1	Contractual agreements signed	28/02/18	Signed contractual agreements between all GB GDNs and Primary Partners.	5%
2	Phase 1A contract award of Phase 1A site build (Buxton)	02/04/18	Signed contracts (following tender) for build of background testing facilities at Buxton.	5%
3	Phase 1A/B Completion of Master Testing plan	01/06/18	Completion and agreement of final Master Testing Plan (MTP) schedule for background testing and consequence testing.	15%
4	Phase 1A Completion of build works	01/09/18	Completion of site build at Buxton and delivery of a minimum of 75% of network assets measured against MTP.	25%
5	Phase 2 Legal agreement for site.	24/12/18	Legal agreement signed between parties for field trials site.	10%
6	Phase 1B Completion of testing	31/03/19	Completion of consequence testing at Spadeadam.	10%
7	Phase 2 Completion of field trials	24/12/19	All testing completes measured against field trials MTP.	20%
8	QRA and modelling completion	30/4/20	Completion of updated QRA results and modelling for hydrogen scenarios following results from Field trials.	5%
9	Report and results	01/08/20	Report and results issued at conference event.	5%
10	Comply with knowledge transfer requirements of the governance document	End of Project	1. Annual Project progress reports which comply with the governance document. 2. Completed close down report which complies with the requirements of the governance document. 3. Evidence of attendance and participation in the annual conference as described in the governance document.	N/A

Section 10. List of appendices

Appendix A. Benefits Table

Method	Method name
Method 1	Baseline scenario taken as option one from Section 11 of the H21 LCG report

<u>Gas NIC – financial benefits: Cumulative Financial Benefits (NPV terms; £m)</u>

Scale	Method	Method Cost	Base Case Cost	Notes			Cross-references	
				2030	2040	2050		
Post-trial solution *(individual deployment)*	Method 1	N/A	N/A	N/A	N/A	N/A	N/A	An incremental 100% hydrogen conversion of the GB gas distribution networks could only be undertaken with significant scale and a policy decision. The scenario presented in the H21 report could be considered a 'minimum' initial policy position i.e. $^1/_3$ of the gas network. The scale in the scenario is reasonable but initial urban centres converted could change from those suggested. For example, the 'Northern Power House' could be used instead of the major cities across the UK. With subsequent policy extending to other areas.
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	N/A	N/A	N/A	N/A	N/A	*N/A*	
GB rollout scale *If applicable, indicate the number of relevant sites on the GB gas distribution network.*	Method 1	App B (B4)	App B (B4)	5,505	32,457	48,250	*circa $^1/_3$ gas conns*	*All assumptions in Appendix B (Section B4) summarised further in bid Section 3.4.1 & 4.1.4.*

Gas NIC – carbon and/or environmental benefits: Cumulative Carbon Benefits (tmCO2e)

Scale	Method	Method Cost	Base Case Cost	Notes			Cross-references	
				2030	**2040**	**2050**		
Post-trial solution *(individual deployment)*	Method 1	N/A	N/A	N/A	N/A	N/A	N/A	An incremental 100% hydrogen conversion of the GB gas networks could only be undertaken with significant scale and a policy decision. The scenario presented in the H21 report could be considered a 'minimum' initial policy position i.e. $^1/_3$ of the gas network. The scale in the scenario is reasonable but initial urban centres converted could change from those suggested. For example, the 'Northern Power House' could be used instead of the major cities across the UK. With subsequent policy extending to other areas.
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	N/A	N/A	N/A	N/A	N/A	*N/A*	
GB rollout scale *If applicable, indicate the number of relevant sites on the GB gas distribution network.*	Method 1	App B (B3.3)	App B (B3.3)	1.5	83	363	*circa $^1/_3$ gas conns*	*All assumptions in Appendix B (Section B 3.3) summarised in bid Section 3.5 & 4.1.3*
Environmental benefits which cannot be expressed as tCO_{2eq}: The benefits have been calculated based on guaranteed CO_2 savings from heat alone. However, there would be significant benefits arising from the rapid uptake of hydrogen vehicles across cities with hydrogen gas distribution grids. These could be more significant than heat as hydrogen fuel cell vehicles not only remove carbon dioxide but also particulate matter and NOx. For the purpose of this H21 NIC bid trying to calculate this benefit was considered over complicated and held too much reliance on projected uptake of vehicles, however, the heat benefit savings are guaranteed. Additionally, fugitive methane emissions (25 times more detrimental to the environment than CO_2) from natural gas distribution network leaks (current leaks) would no longer pose an environmental threat from hydrogen gas distribution grids. Finally, for hydrogen converted areas, carbon monoxide risk would be eliminated entirely as it is not possible to get carbon monoxide poisoning from a hydrogen appliance.								

Appendix B. Justification of Financial and Carbon benefits

B.1. Strategic approach

The H21 – Leeds City Gate (H21 LCG) Network Innovation Allowance project assessed the feasibility of converting a major city's gas distribution network from natural gas to 100% hydrogen. The project was designed to be a 'blue print' study to prove that the GB gas distribution networks could be converted to 100% hydrogen. Specifically, it confirmed the following.

- The gas distribution network has sufficient capacity to convert to hydrogen, i.e. the pipes were big enough, with minimal upgrading.
- That a secure supply of zero carbon hydrogen could be provided to meet the annual and peak demands of the city. This would be achieved via Steam Methane Reforming (SMR) coupled with Carbon Capture and Storage (CCS).
- That intra-day (within day) and inter-seasonal storage could be managed alongside hydrogen production facilities (SMRs) using salt caverns developed in the salt deposits available across the UK and specifically in the north-east region.
- That the city could be converted incrementally with minimal disruption to customers. This would be undertaken in a similar fashion to the towns gas to natural gas conversion which occurred across the UK between 1966 and 1977.
- The overall costs for such a conversion and a recommendation for how that could be financed with minimal impact in customers' bills.
- How such a conversion could be undertaken incrementally across the UK over time which would provide the single biggest contribution to decarbonisation.

All the technology identified and developed in the H21 LCG project can be evidenced across the world today. The project suggests that an incremental conversion (i.e. one city then the next) to 100% hydrogen within the UK gas distribution grid is technically possible and economically viable.

Converting the GB gas distribution network to 100% hydrogen would provide large scale decarbonisation of heat with minimal disruption to existing customers versus alternative options. Alternative options can be considered to include electrification of heating, district heating and energy efficiency. Additionally, converting the gas distribution network to 100% hydrogen is an immediate and long term low carbon option as the system would provide a deep, system based level of decarbonisation from the day of conversion. Electrical heating options and district heat are only low carbon if the electricity or heat is decarbonised at source. This would not be likely from day one and there are many uncertainties around how or if this could be technically, economically or socially achieved.

The H21 LCG report provided detailed and robust analysis of the carbon savings associated with production of hydrogen via SMR coupled with CCS. This was chosen as the most credible source of economic, large scale and low carbon hydrogen supply based on international evidence. Most of the world's hydrogen is produced using this proven technology. In Port Arthur, America SMR plants have already been connected to CCS infrastructure.

A practical, incremental rollout scenario for 100% hydrogen conversion across the UK was presented in Section 11 of the H21 LCG report. As the H21 LCG project represents the most advanced document to date on UK gas distribution network conversion to 100% hydrogen the figures from this report have been used to develop the carbon and cost benefits up to (and beyond) 2050.

B.2. Evidence on counter factual success – all electric heating to date.

Until the H21 LCG project the options for decarbonisation of heat through gas distribution network grid conversion to 100% hydrogen had not been realistically considered. This has resulted in 'low carbon heat' options being focused on electric, predominantly through air source heat pumps, and, more recently, district heating. Neither approach comprehensively considered the energy systems. The H21 LCG project has started to fundamentally shift embedded opinions when considering large scale decarbonisation options. Additionally, it has articulated the complexity, scale and benefits of the GB gas distribution networks and the opportunity they present for large scale decarbonisation utilising technology evident around the world today, as well as galvanising support for the concept across the supply chain and political arena.

The recent work undertaken by Wales & West Utilities in the Bridgend Project highlighted some of the substantial barriers to delivery of low carbon heat via heat pumps. The requirement for high levels of capital outlay and substantial disruption means that consumers are not adopting these technologies despite current government incentives.

Some of the challenges around electric heating deployment in the UK were also extensively covered in the Committee for Climate Change 'Next Steps for Heat' report. Some points therein are provided below:

- The market for domestic heat pumps has flat-lined in recent years in existing homes at around 9,000 a year, despite the recent decreases in levels of support for domestic biomass. The latest RHI (Renewable Heat Initiative) projections aim to reach 16,000 a year by 2021, but there is no evidence of any acceleration in the rate of take up.
- To decarbonise heat supply (with heat pumps by 2050) it would need to run at over 1 million installations a year from the mid-2030s.
- For air-source heat pumps this (the slow uptake) is most likely due to the upfront cost barrier, low awareness, and the fact that the tariffs deliver lower returns for smaller properties.
- Heat pumps remain a niche option in the UK as previous policies have failed to deliver a significant increase in uptake. However, they are used widely in many other countries (e.g. Sweden and France) and are the primary low-carbon option for most UK buildings off the gas grid.

Whilst heat pump technology will undoubtable have a part to play in a low carbon future there are significant challenges. Additionally, heat pumps do not address industrial and commercial heat at approximately 40% of city based consumption (see H21 LCG) and are not appropriate for many UK properties. A UK gas distribution grid conversion to 100% hydrogen would resolve all these problems.

B.3. Carbon and environmental benefits

B.3.1. Baseline Scenario (Information based on Section 11 H21 LCG report)

A significant advantage of a 100% hydrogen conversion is that rollout across the UK can be achieved incrementally at a rate dictated by appetite for cost and carbon reduction. To provide some clarity on what a rollout strategy could look like Section 11 of the H21 LCG report provided an example of incremental conversion involving many major British cities/urban centres, covering around 30% of gas users. The example presented in the H21 LCG report (Option 1, p324) provided significant carbon benefits in a relatively short time whilst ensuring broad UK coverage to encourage wider benefits (transportation/ electrification).

The cities and major urban centres considered for conversion as part of this option include: Leeds (city), Teesside (greater area), Kingston upon Hull (city), Newcastle (greater area), Manchester (greater area), Sheffield (city), Liverpool (greater area), Edinburgh (city), Glasgow (greater area), Birmingham (greater area), Bristol (city), Cardiff (city), Aberdeen (city), Leicester (city), Luton (city), Oxford (city) and London (greater area). All other areas in this scenario could remain on a natural gas/biogas/hydrogen blended mix.

When considering an incremental conversion to 100% hydrogen there are many other advantages and environmental benefits that have not been factored into the analysis for the H21 NIC due to adding unnecessary complexity. However, they have been included below for completeness and consideration:

- The existing high pressure natural gas network will remain in place for large industrial users such as power stations. These industrial users can be converted onto the Hydrogen Transmission System (HTS) at the end of their asset life providing low carbon decentralised electricity generation.
- Fuelling stations can be built across the cities hydrogen grid which would allow a greatly accelerated decarbonisation of transport alongside electric vehicles.
- Converting some of the UK cities worst transport polluters to hydrogen (or initially natural gas) has a significant beneficial impact on air quality by removing NOx and particulate matter emissions from vehicles with no electrical alternative, for example garbage trucks.
- During or following conversion to 100% hydrogen the uptake of micro combined Heat and Power (CHP) by homeowners could have a huge impact on decarbonisation of electricity. This is because generating electricity locally removes the current electrical system efficiency losses. This results in less requirement for central generation and no loss of energy due to transporting electricity down cables.

B.3.2. Carbon intensity

The rationale for any natural gas to 100% hydrogen conversion programme must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with Kyoto Protocol, but quantifying this can be complex. When comparing the carbon emissions of any product or service it is vital to compare like with like, and to define the boundary conditions in a coherent fashion.

Commonly carbon emissions are compared at three different levels and for meaningful discussions it is vital to agree the concepts behind these. Without this, society can make erroneous decisions. These three levels are:

Scope 1: These are the direct emissions within the system boundary of the end user and hydrogen production facilities (typically from a boiler or vehicle). From stationary plant, they are usually evaluated at gm/kWh of fuel. For natural gas, they are typically 184 gm CO_{2eq}/kWh_{HHV} (Defra/DECC data set 2015). They usually make no allowance for the carbon dioxide emitted in (for example) liquefying the natural gas in Qatar, transporting it in refrigerated ships, storing it in LNG depots, re-gasifying it and compressing it into the National Transmission System. For the H21 system these include emissions associated with the production of hydrogen and carbon from the SMRs.

Scope 2: Typically allows for Scope 1 carbon emissions and for additional energy inputs to the system such as electricity from the grid. For the H21 system these include the electrical consumption of the plant and the compression requirements (both CCS and hydrogen).

Scope 3: Endeavours to capture the embodied carbon emitted in material inputs to the system, for example LNG refrigeration and transport of product.

Establishing the CO_2 emissions for H21 Leeds City Gate

H21 LCG used the Defra/DECC natural gas emission figure of 184.45 gm CO_{2eq}/kWh_{HHV} (Defra/DECC data set 2015, Scope 1 emission) emitted directly from the combustion of natural gas and a further 24.83 gm CO_{2eq}/kWh_{HHV} (Defra/DECC data set 2015, Scope 3 emission) by the natural gas supply system making a total of 209.28gm/kWh for the present natural gas supply. These factors were used to estimate what the emissions from the H21 LCG system were.

Scope 1 Emissions associated with the production of hydrogen and carbon dioxide at the SMR
The main emissions from the H21 system will come from the SMR plants which convert natural gas to hydrogen and capture approximately 90% of the carbon in the feedstock. The highest practical efficiency (HHV basis) of a simple SMR (without CCS) is circa 88%, with 11.2% of the energy potentially exported as steam and 76.8% of the energy exported as hydrogen.

Simulations carried out for the H21 LCG project of the basic SMR process (with CCS) indicate that 68.4% of the energy in the natural gas feedstock is retained in the hydrogen product on an HHV basis. The remaining 31.6% is released as heat, much of which is converted to steam but with some carried away in hot stack gases from the reforming furnace. When carbon capture is added most of the steam is required by the capture process and the stack gases are fully cooled by the capture process so that this heat is now rejected by the cooling system. However, the overall conversion efficiency remains the same.

The carbon footprint of the SMR+CCS has been evaluated as follows:

- The carbon footprint of the natural gas feedstock = 184gm/kWh.
- With no carbon capture capability and an efficiency of 68.4% = 269 gm/kWh (184/0.684).

90% of the carbon dioxide will be captured by the CCS system therefore the direct CO_2 emissions from this process are 26.97gm/kWh (Scope 1).

Scope 2 Emissions include the electrical consumption of the plant and the compression requirements (both CCS and hydrogen)
The system utilises electric power to drive pumps and fans for the carbon capture process and the large compressors which send the captured CO_2 to storage. The SMR plant could in principle generate this power from the waste heat produced by the conversion process. However, this requires additional equipment and the simplest concept is to import this power from the UK electrical grid. This would result in an additional emission of 18.49gm/kWh (DEFRA emission factor 2015).

The system requires a certain amount of hydrogen to be stored to ensure all demands in winter and during peak hours during the day are met. The additional emissions associated with this based on the proposed maximum storage pressures are 4.07gm/kWh (DEFRA emission factor 2015).

Total Scope 2 emissions are:

- Hydrogen/carbon production = 26.97 gm/kWh. (Scope 1).
- Electric requirements for SMR plant = 18.49gm/kWh.
- Electrical hydrogen compression requirements = 4.07gm/kWh.
- Total emissions = 49.53gm/kWh.

It is important to remember that this figure is based on the 2015 electricity grid carbon footprint, and sub optimised SMR+CCS performance to give a worst-case scenario. The final SMR+CCS design would give better capture and efficiency and the UK electric grid will continue to be decarbonised.

For this NIC bid the Scope 2 emissions have been used to quantify the carbon benefits. Adding Scope 3 emissions is contentious and potentially disproportionate based on the varying supply of LNG to the UK and conservative Scope 2 figures mentioned above.

Total yearly volume of captured carbon

The amount of CO_2 sent to disposal during a year of operation for the H21 LCG system are 1,440,000 tonnes per annum rounded to 1.5mtcarbon/year. The calculation can be seen in the table below:

	Unit	On site emissions
Natural gas	gm/kWh	184
Leeds design (average Year)	TWh/yr	5.94
Emissions CO_2	Tonnes/yr	1,093,000
SMR		
Conversion rate	%	68.40%
Natural gas to SMR	TWh/yr	8.68
Total CO_2	Tonnes/yr	1,600,000
% CO_2 to CCS	%	90%
CO_2 to storage	Tonnes/yr	**1,440,000**
CO_2 to atmosphere	Tonnes/yr	160,000

B.3.3. Project Volumes

The projected volumes are based on the baseline scenario taken as Option 1 from Section 11 of the H21 LCG report. The figures were calculated using the H21 LCG data and extrapolating this based on percentage populations for each major urban centre (Table 11.1 in the H21 LCG report). For example:

- Population covered in the H21 LCG figures = 0.66m.
- Population in Teesside (greater area) = 0.56m.
- Percentage difference = 15% (i.e. 85% of population in H21 LCG).
- Total carbon captured per annum H21 LGC = 1.5mtcarbon/year.
- Total carbon captured per annum in Teesside (greater area) = 1.28mtcarbon/year.

The H21 LCG report also gave an indication of timescales which may be considered reasonable for the conversion of the nominated cities. The following table summarises the results:

City	Population guestimate (In area to convert in millions)	Proportional variation from Leeds	Number of connections (customers)	Timeline		Carbon capture using proportional variation mtcarbon year	Cumulative Carbon capture per annum using proportional variation mtcarbon
				Year start	Year Finish		
Leeds	0.66	1.00	265,000	2026	2029	1.5	1.5
Teesside	0.56	0.85	225,250	2029	2032	1.3	2.8
Kingston Upon Hull	0.26	0.39	103,350	2029	2032	0.6	3.4
Newcastle	1.12	1.69	447,850	2032	2035	2.5	5.9
Manchester	2.41	3.65	967,250	2032	2035	5.5	11.4
Sheffield	0.56	0.85	225,250	2035	2038	1.3	12.6
Liverpool	1.71	2.59	686,350	2035	2038	3.9	16.5
Edinburgh	0.49	0.75	198,750	2036	2039	1.1	17.7
Glasgow	1.14	1.73	458,450	2039	2042	2.6	20.3
Birmingham	2.81	4.25	1,126,250	2039	2042	6.4	26.6
Bristol	0.44	0.67	177,550	2042	2045	1.0	27.6
Cardiff	0.35	0.54	143,100	2042	2045	0.8	28.4
Aberdeen	0.23	0.35	92,750	2042	2045	0.5	29.0
Leicester	0.34	0.51	135,150	2045	2048	0.8	29.7
Luton	0.21	0.32	84,800	2045	2048	0.5	30.2
Oxford	0.16	0.24	63,600	2045	2048	0.4	30.6
London	8.54	12.91	3,421,150	2045	2052	19.4	49.9
TOTALS	22.00	N/A	8,821,850	N/A	N/A	49.94	N/A

To calculate the cumulative carbon savings from the hydrogen conversion presented in this scenario the annual captured carbon figures for each city have been projected up to 2050. This is summarised in the following table.

City	Years to 2030	Total mtcarbon saved to 2030	Years to 2040	Total mtcarbon saved to 2040	Years to 2050	Total mtcarbon saved to 2050
Leeds	1	1.5	11	16.5	21	31.5
Teesside	0	0	8	10.2	18	23.0
Kingston Upon Hull	0	0	8	4.7	18	10.5
Newcastle	0	0	5	12.7	15	38.0
Manchester	0	0	5	27.4	15	82.1
Sheffield	0	0	2	2.6	12	15.3
Liverpool	0	0	2	7.8	12	46.6
Edinburgh	0	0	1	1.1	11	12.4
Glasgow	0	0	0	0	8	20.8
Birmingham	0	0	0	0	8	51.0
Bristol	0	0	0	0	5	5.0
Cardiff	0	0	0	0	5	4.1
Aberdeen	0	0	0	0	5	2.6
Leicester	0	0	0	0	2	1.5
Luton	0	0	0	0	2	1.0
Oxford	0	0	0	0	2	0.7
London	0	0	0	0	1/7th/year for 5 yrs	16.6
TOTALS		1.5		82.9		362.7

The carbon benefits are summarised up to 2050 in the following table.

	To 2030	To 2040	To 2050
mtcarbon saved	1.5	83	363

It is important to note that this scenario could be rapidly accelerated. The original towns gas to natural gas conversion converted the whole of Great Britain in 10 years which included 14 million customers (households) and 40 million appliances. The actual rate of conversion is dictated by the speed at which hydrogen production can be established and this could be three times as fast as the figures represented above provided the appropriate supply chain is established. This would give three times the benefit in terms of mtcarbon savings by 2050, i.e. **1,089mtcarbon.**

B.4. Financial benefits

When considering the financial benefits for gas customers one must consider the counterfactual. There is significant debate as to whether an all-electric decarbonisation solution for all UK energy (electric, heat and transport) is technically achievable especially within the timescales available. It is certainly unclear how an all-electric option, specifically for heat, would be physically achievable with the technology of today or socially acceptable given the poor adoption track record. However, if the UK is to meet its climate change obligations it is critical that a major change occurs.

Energy efficiency measures are important for all decarbonisation pathways but even with these it is likely that the large-scale decarbonisation of heat will require either a gas distribution network conversion to 100% hydrogen or conversion to all electric options or a combination of both. As stated in the Committee on Climate Changes recent 'Next Steps for Heat' policy report "Both heat pumps and hydrogen bring significant challenges, but to reduce heating emissions close to zero in the long term, extensive use of at least one of these options will be required…It is not possible at this stage to identify either heat pumps or hydrogen as the dominant solution, nor should either be ruled out".

The recent study by KPMG ‘2050 Energy Scenarios’ suggested significant differences in cost and deliverability between an all-electric and alternative gas options for decarbonisation. The all-electric option for decarbonisation was estimated to have a cost differential per consumer of over 2.5 times the gas alternative which is a £170-196bn difference overall. Additionally, practical obstacles for the all-electric option were considered high as opposed to low/medium for the all-gas option.

The KPMG report (p7 Executive Summary) provides an estimate of the differential cost to decarbonise heat between all-electric and hydrogen conversion options. These figures are summarised in the following table.

	Evolution of gas (predominantly 100% hydrogen networks)	Electric Future	Mid-point Scaling Factor
Incremental cost per consumer up to 2050	£4,500-£5,000	£12,000-£14,000	2.74

Using the 2.74 scaling factor, it is possible to work out a cost differential for customers to convert to an all-electric option versus 100% hydrogen conversion. This is summarised in the following table.

City	Population guestimate (In area to convert in millions)	Proportional variation from Leeds	Number of connections (customers)	Timeline		Cost per customer Hydrogen conversion (based on H21 LCG table 11.1) (£Ms)	Cost per customer Electric heating (based on KPMG report) (£Ms)	Cumulative savings (£Ms)
				Year start	Year Finish			
leeds	0.66	1.00	265,000	2026	2029	2,044	£5,593	£3,550
Teesside	0.56	0.85	225,250	2029	2032	1,542	£4,219	£6,227
Kingston Upon Hull	0.26	0.39	103,350	2029	2032	666	£1,823	£7,384
Newcastle	1.12	1.69	447,850	2032	2035	3,023	£8,272	£12,634
Manchester	2.41	3.65	967,250	2032	2035	5,939	£16,255	£22,950
Sheffield	0.56	0.85	225,250	2035	2038	1,331	£3,644	£25,262
Liverpool	1.71	2.59	686,350	2035	2038	3,978	£10,887	£32,172
Edinburgh	0.49	0.75	198,750	2036	2039	1,393	£3,811	£34,590
Glasgow	1.14	1.73	458,450	2039	2042	2,701	£7,391	£39,281
Birmingham	2.81	4.25	1,126,250	2039	2042	6,178	£16,908	£50,011
Bristol	0.44	0.67	177,550	2042	2045	1,170	£3,201	£52,042
Cardiff	0.35	0.54	143,100	2042	2045	841	£2,301	£53,503
Aberdeen	0.23	0.35	92,750	2042	2045	797	£2,181	£54,886
Leicester	0.34	0.51	135,150	2045	2048	797	£2,180	£56,270
Luton	0.21	0.32	84,800	2045	2048	611	£1,673	£57,332
Oxford	0.16	0.24	63,600	2045	2048	489	£1,337	£58,180
London	8.54	12.91	3,421,150	2045	2052	17,178	£47,014	£88,016
TOTALS	22.00	N/A	8,821,850	N/A	N/A	£50,676	£138,691	£88,016

The financial benefits are summarised up to 2050 in the table below

	To 2030	To 2040	To 2050
Hydrogen conversion	£3,585m	£22,616m	£50,676m
All-Electric (using 2.74 scaling factor)	£9,813m	£61,897m	£138,691m
Costs avoided for customers versus All Electric	£6,227m	£39,281m	£88,016m
Savings to gas customers versus All Electric (NPV)	£5,505m	£32,457m	£48,250m

As with the calculated carbon benefits it is important to note that this scenario could be rapidly accelerated. The actual rate of conversion is dictated by the speed at which hydrogen production can be established and this could potentially be three times as fast as the figures represented above provided the appropriate supply chain is established. This would give three times the benefit in terms of financial savings by 2050, i.e. **£145bn (NPV).**

Appendix C. Project Technical Description

C.1. Introduction

This H21 NIC project will provide quantified critical safety based evidence towards proving that a 100% hydrogen GB gas distribution network represents a comparable and manageable risk to that of the natural gas network. The project will achieve this through a strategically designed testing and quantification programme. This programme will be split into three primary phases:

Phase 1A – Background testing

Phase 1B – Consequence testing

Phase 2 – Field trials

Each phase of testing, agreed and designed by a consortium of leading industry partners, is critical to provide the evidence to support a detailed Quantitative Risk Analysis (QRA) and solve the problem statement. This QRA will then be used to evolve the existing computer modelling software (used for natural gas) to make it applicable for 100% hydrogen allowing meaningful extrapolation of results and the associated GB Gas Distribution Networks (GDN) assessment of risk. This appendix provides more technical detail on the Project and provides an overview of the detailed development work undertaken to date.

C.2. Phase 1A – Background testing

A strategic set of tests are being designed to cover the range of assets represented across the GB gas distribution networks. A cross Section of these assets will be removed from the networks and transported to the Health & Safety Laboratory (HSL) site at Buxton. Controlled testing against a well-defined master testing plan, (see Section C2.3), with natural gas and 100% hydrogen will then be undertaken. These tests will provide the quantitative evidence to forecast any change to background leakage levels in a 100% hydrogen network.

The background testing involves removal of network assets, building of a new testing facility at Buxton, testing the assets and quantification of results as set out in Section C.5. The following Sections explain how assets were selected, the preliminary design requirements for the site at Buxton and the master testing plan. These tests are essential to forecasting how the network may change (in terms of leakage) on day one following a 100% hydrogen conversion. In effect, would assets that previously didn't leak now leak when transporting 100% hydrogen and what are the consequences? A change to this background position could have a combination of three consequences:

- A safety impact, determined and quantified through Phase 1B.
- A commercial impact, i.e. the cost of lost gas if leakage substantially increases.
- An operational impact, e.g. a rapid increase in publicly reported gas escapes which could be a safety and/or logistics problem, difficulty in making new connections and diverting mains.

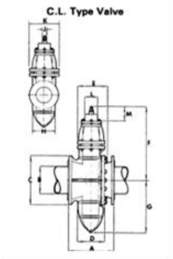
C.2.1. Gas distribution network assets

A critical aspect of the background testing element of the H21 NIC has been the selection of an appropriate range of assets to test from across the GB gas distribution networks. There are thousands of assets types (pipes, valves, fittings, repairs, pressure reduction equipment, etc) and configurations thereof across the GB gas distribution networks. The key challenge has been to select an appropriate range of assets to test which will prove an appropriate representation of distribution assets to allow meaningful extrapolation of results. These results also need to be confidently accepted as accurate, credible and robust by all stakeholders including the HSE, GB GDN Asset Directors, the Department for Business, Energy & Industrial Strategy (BEIS), the wider supply chain, scientific community, the public and all Project Partners.

A selection of photos and brief description of the different assets by category are provided in the following section to illustrate the large range of assets that could be selected for testing.

Valves and fittings

The below seven bar network consists of a variety of valve types and fittings used for different connection applications between mains and services. The following are examples of some of the valves and fittings used across the network.



Repair techniques

The GB GDNs must maintain the network and this includes repairing leaking mains/joints. Leaks can occur through a variety of causes, for example 3rd party damage, asset degradation, joint failures and fractures. The following images are examples of some of the range of repair techniques that exist across the below seven bar distribution networks.

Mains and joint types

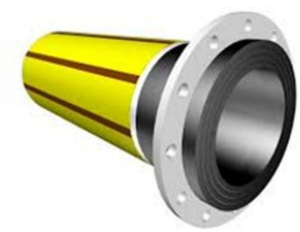
Over the last 35 years various iron mains replacement programmes have been in place. Since 2002, driven by the Health & Safety Executive (HSE) enforcement policy for the Iron Mains Replacement Programme (IMRP), all GDNs have been designing programmes to decommission all iron pipes fitting a defined diameter and risk profile within a 30-year period. The priority in which these iron pipes have been/should be decommissioned has been determined by use of a risk prioritisation model. This models the consequences of failure of iron mains within 30 metres of buildings and the consequent risk of injuries, fatalities and damage to buildings and thereby assigns a risk score to each main. It is designed to secure public safety whilst allowing efficiency, environmental, strategic and customer service factors to contribute to driving the programme and allowing sufficient flexibility to enable the Ofgem to incentivise innovation in risk management.

The current IMRP (Note: steel pipes are not currently included in the IMRP) uses a three-tier approach to iron mains replacement. Under this approach mains are categorised into diameter tiers as set out below:

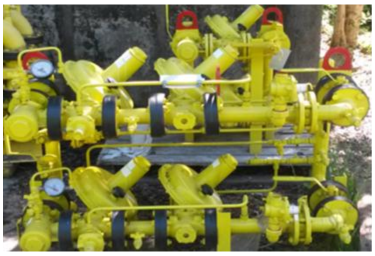
- Tier 1: 8 inches and below (approximately 80% of all iron pipes).
- Tier 2: above 8 inches and below 18 inches (approximately 15% of all iron pipes).
- Tier 3: 18 inches and above (approximately 5% of all iron pipes).

Tier 1: Iron pipe population at 8” diameter and below represents the most significant risk to the public. Each GB GDN operator will set a length of Tier 1 pipes to be decommissioned over the period of their approved programmes. This should be sufficient to ensure that all Tier 1 pipes within 30m of property will be replaced by the end of 2032 or earlier. **Tier 2:** Iron pipes scoring above a risk action threshold, set by the GDN operator, will be selected to receive appropriate attention over the period of the approved programme. The current replacement policy means there will still be iron pipes above 8” but below 18” within 30m of property after 2032. **Tier 3:** Iron pipes of 18" diameter and above are the least likely to fail of all those within 30m of buildings. Tier 3 pipes may still be subject to decommissioning where a cost benefit analysis justifies this. As with Tier 2 pipes this policy means that there will be Tier 3 pipes within 30m of property post IMRP.

Post 2032 Polyethylene (PE) mains will represent the largest population within 30m of property with a variety of jointing techniques and a significant range of ages. The remaining mains population, circa 10% throughout the network, will be metallic consisting of steel and a range of iron (cast, spun and ductile) at diameters from 2 to 48”. It is vital the background leakage position for these metallic mains, and more specifically their joints, are understood as they will still represent the highest network risk. A small sample of joint types is provided below which is by no means exhaustive.



District governors and service governors
Pressure differentials between different pressure tiers, e.g. 7bar to 2bar or 2bar to low pressure (typically 40 to 50mbar), are provided using a range of pressure reduction equipment in both above and below ground applications. The following examples are provided.



C.2.2. The asset selection process
The most significant asset group in terms of quantity, variability and risk within GDNs are the mains (pipes) in the ground and their associated range of joints and repairs. An extensive process of selection was used for these assets. Other assets, for example valves, fittings, connections, governors, were selected based on either:

- The identified sizes to test, i.e. valves, repair methods etc. The project will predominantly be testing those which have the same diameter to the mains for ease of testing application.
- Quantities of assets, e.g. the most common district governor configurations.
- Operational experience to identify a range of appropriate fittings, repair techniques and 'ad hoc' assets which could be considered high risk.

The extensive number of mains across the GB gas distribution networks of varying types and sizes with a variety of different jointing techniques make selecting an all-inclusive range to test challenging on such a limited budget. This H21 NIC with its £15m budget contrasts to a circa £40m budget for the leakage tests undertaken by British Gas throughout the 1990s. However, the GB GDNs have well established risk management methodologies developed and adapted over decades for identification of risk. They also have extensive asset records including leakage histories, material type, diameter, distance to building etc. coupled with extensive operation experience managing these assets.

Selection of mains and joints to test
To understand the background leakage position of the GB gas distribution network on day one of conversion to 100% hydrogen it is essential that tests are undertaken on a range of iron, PE and steel pipes of varying diameters and joint types. This will provide quantified evidence of the difference between hydrogen and natural gas and will help inform some of the tests in Phase 1B – Consequence testing, and will also allow extrapolation of results across the asset range.

If a policy decision was made to incrementally convert the UK gas network to 100% hydrogen it is unlikely that such a conversion would begin before the late 2020s. Furthermore, most conversion, due to the incremental nature, would be undertaken post completion of the IMRP in 2032. As such it is reasonable to design an asset testing regime which focuses on assets which will be in place post the IMRP. Since the 1970s almost all distribution mains replaced under business as usual and as part of the IMRP will have been with PE.

Post 2032, PE mains represent the largest population within 30m of property so a selection of these will be tested. However, there is already established evidence of PE's compatibility with 100% hydrogen and the jointing system is effectively a welded system providing a continuous permanent seal. The remaining metallic mains population is the highest risk for a change in background leakage levels due to its age and the mechanical nature of joining techniques. Circa 10% will still be metallic consisting of steel and a range of iron (cast, spun and ductile) at Tier 1, 2, and 3 diameters. It is vital the background leakage positions for these metallic mains and joints are comprehensively understood.

To determine an appropriate range of mains (and joint types) to test which would give credible results acceptable to all stakeholders three independent selection methods were used and then compared to produce a definitive list. The methods were:

- Operational experience.
- Analytical modelling utilising leakage data.
- Analytical modelling utilising risk data.

Method 1: Operational experience
The GB GDNs hold data relating to pipes and fittings in their respective asset repositories, e.g. SAP for NGN. This list of data was obtained for NGN mains and provided the following data; Pipe material types, pipe joint types, leaking component types, leakage causes and leakage corrective actions.

Led by a highly experienced Operational Manager, this list was reviewed by operational colleagues with over 250 years combined experience. As the range of pipe diameters in each material and joint type is extensive the sizes to be tested were selected based on leakage information from work records held against equipment in NGNs asset repository and the experience of the operational colleagues.

Method 2: Leakage data analysis
Led by a highly experience network analyst the SAP base leakage data from NGNs repair records for the period starting 2006 and ending 2015 was extracted and analysed. This was merged with a SAP extract of mains data which allowed the joint type to be added to the leakage data to create a master data spreadsheet in Excel. This merged table therefore contained data relating leakage cause to mains diameter, material, length and joint type plus additional data such as date of repair, gas in buildings etc.

The leakage data on its own provides an incomplete picture in that populations which have the greatest lengths may have the largest leakage totals but may not represent the mains with the highest/km leakage which is the useful metric. Therefore, the data was combined to provide a leaks/km figure for each material/diameter/joint combination.

Method 3: Mains risk score
Every metallic main within 30m of property has a risk score which provides an absolute value of the risk of an incident arising from the main. Factors which combine to produce the risk score include leakage history for the main, proximity to property, risk of mains fracture or corrosion, properties bordering the main are cellared and the background breakage history for mains in the adjacent area. All the GDNs use the mains risk scores to create projects suitable for the economic replacement of mains under the IMRP.

This selection method utilises the risk score to determine which mains combinations should be selected for testing by material and diameter only. Joint type will be indirectly reflected in the leakage history but will not be shown in the selections. Joint type is a primary focus of selection for the previous two selection methods.

As with the leakage data the risk data on its own provides an incomplete picture in that mains populations with longer lengths could have very low risk scores individually but could score artificially high collectively. Additionally, just considering an average risk could highlight very short lengths of mains with very high-risk scores artificially scoring high.

Following an initial assessment, a range of data analysis was undertaken to allow a variety of prevailing risk drivers to take precedence. These were then ranked, e.g. the top scoring risk main was number one, for a range of driving factors (e.g. average risk score). Finally, these ranks were added together to give an overall picture of the top risk mains as selected by different risk driving factors.

In addition to the NGN data the same analytical process was applied to data supplied by Cadent for their four Local Distribution Zones (LDZs) and a respective final ranking table was produced comparing the NGN and Cadent data.

Final mains selection
Following completion of the three methods of mains selection the results were then compared to produce a definitive set of mains/joints to test. This selection was then presented to all Project Partners and collaborating GDNs at a workshop held at the HSL site in Buxton. This ensured consensus in the approach and the final selection of mains/joints to test.

The final selection covers a range of Tier 1, 2 and 3 iron mains and a range of steel with varying types of joints and a range of PE of varying sizes and ages. Additionally, test samples, i.e. number of representative samples to test, were determined based on availability of the assets, i.e. Tier 1 would be readily available through the IMRP and would be the cheapest to extract, Tier 2 and 3 mains may require specific projects outside business as usual.

In addition to metallic mains, a sample of PE mains to test some more obscure mains have also been included if they are believed to have sufficient quantities and associated risk. An example of this would be mains which have been rehabilitated through phoenix and paltem lining. This technique was employed in the 1980s and involved inserting a thin liner into a host pipe and sufficient quantities will remain (based on current replacement methodology) to justify a test.

C.2.3. Master Testing Plan (MTP)
The MTP is being evolved as part of the 'H21 Keighley & Spadeadam Designs' NIA. The MTP details the specific testing requirement and methodology for each of the removed assets. It is being designed to ensure that the tests undertaken cover the required areas and solve the problem statement. The MTP is being designed in conjunction with the HSL lead technical scientists and will be independently reviewed by DNV GL to ensure consensus of approach.

To date a significant amount of development of the MTP has already been undertaken and it is likely that a range of static pressure tests (predominantly focusing on Low Pressure (LP) but including some Medium Pressure (MP) and Intermediate Pressure (IP)) and flow tests to obtain quantifiable differentials in background leakage position will be undertaken across the mains asset range.

Fittings and valves will be tested by installing/attaching them to a selected number of mains and/or by building of service type systems for specific tests. To test the effectiveness of repair techniques a selection of the mains excavated will have leaks simulated though joint manipulation and drilling of specific holes. These will then be repaired using a range of techniques to confirm the effectiveness of the repair on 100% hydrogen.

Finally, a select sample of district governors and service governors will be tested to confirm operability and leakage differential between natural gas and 100% hydrogen.

C.2.4. Buxton preliminary design
The 'H21 Keighley & Spadeadam Designs' NIA project was developed to determine the specific test and site requirements for upfront site design works for both background testing and consequence testing which will ensure the NIC can be quickly and effectively executed subject to successful award. If the NIC bid is unsuccessful this NIA is still a significant contributor to the H21 roadmap allowing network operators to understand the experimental testing and design build requirements which will be needed to fully understand the impact of hydrogen conversion on their assets.

The initial screening document for the H21 NIC recommended Keighley as the site selected for background testing. This NIA established Buxton as the preferred site based on multiple factors. These included its remoteness (for public safety), the HSL's previous experience of working with hydrogen, the ongoing costs and security of the site and proposed availability as an ongoing asset test facility site for the gas industry after the completion of the Project.

Facility requirements

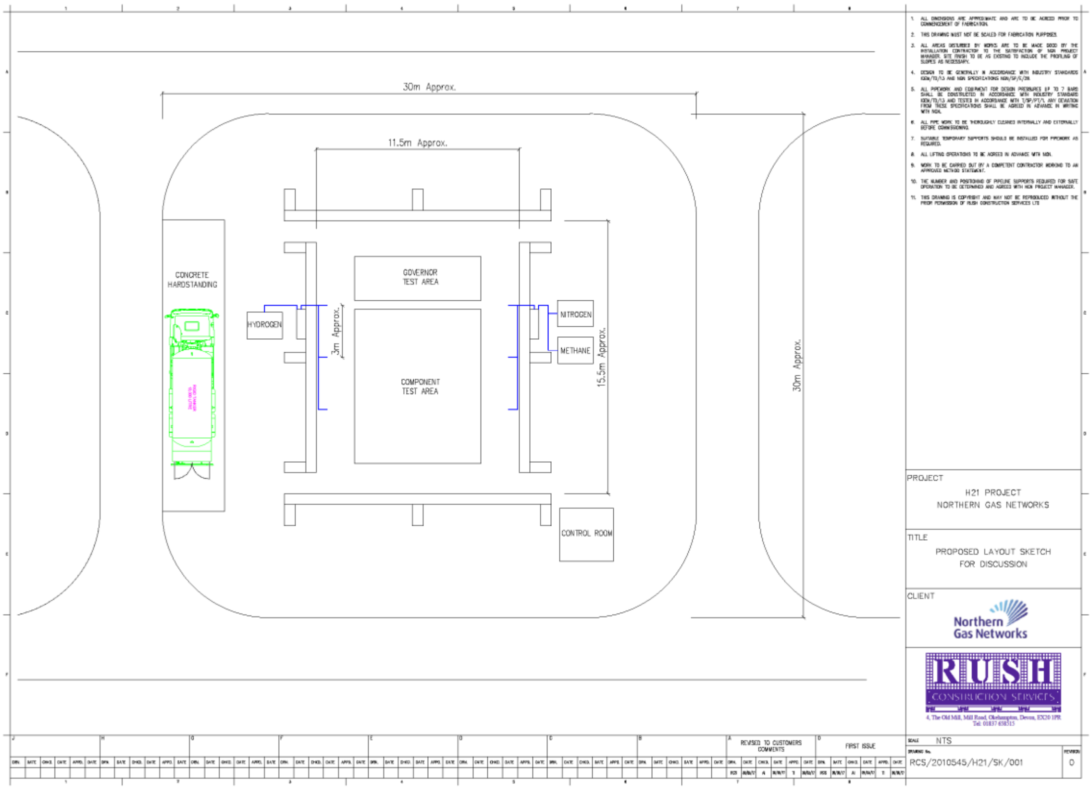
The background testing facility will be split in to three areas. Area one being an appropriately designed storage/set down area for the removed and delivered network assets (mains, repairs, valves etc.). Area two will be for storage of gas governors, the range of appropriate repair assets and testing facilitation materials, e.g. flexible hoses, gauges and cap ends. Area three will be the testing area where operational tests on each asset will be carried out. This area will include the testing bays, control room, and hydrogen/natural gas delivery and storage facilities.

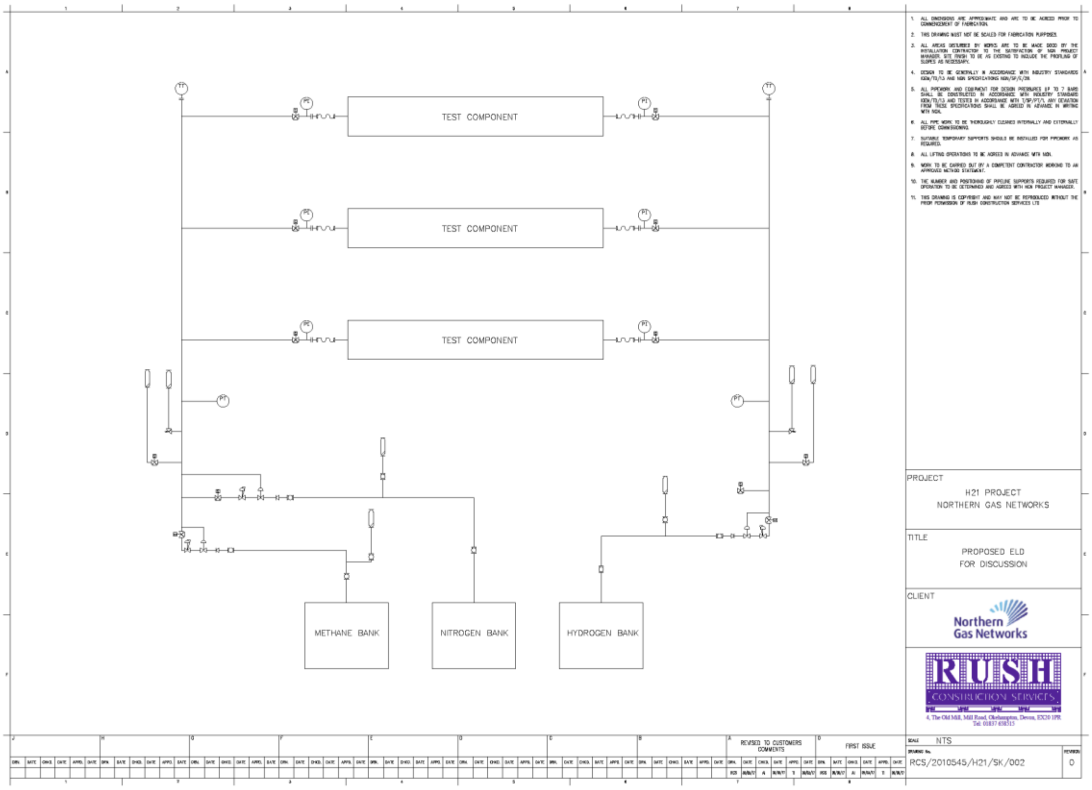
It is proposed to design a suitable test facility by creating four test beds for the recovered buried assets. The four test beds will be based on:

- Tier 1 – Iron and steel pipes with nominal diameters 8"/200mm and less.
- Tier 2 – Iron and steel pipes with nominal diameters greater than 8"/200mm but less than 18"/450mm.
- Tier 3 – Iron and steel pipes with nominal diameters of 18"/450mm or greater – up to 48" for Cadent assets.
- District governor testing and services connections and fittings.

The facility will be designed to enable testing for the different sizes, materials and equipment type of each of the mains tier ranges. Each of the assets will be of different diameters and lengths and the design of the connection between the hydrogen or natural gas supply used for the test and the asset on test would likely be via a flexible hose.

To ensure tests are not adversely affected by weather conditions a suitable cover will be included, which will enable more consistent results and limit the environmental effects on the measurements for gas release. The facility is being designed with a minimum ten-year lifetime to ensure value for money for gas customers with the ongoing ability to undertake additional tests as required in the medium term, e.g. by specialist equipment manufacturers. The additional cost is considered marginal for a more permanent facility and the HSL have agreed, in principle, a reduced ongoing rate for testing by the GB gas industry in recognition of the asset onsite.





As with any construction site design the ongoing safe operation of the site post construction is a critical requirement in the design process. This is developed by detailed hazard and operability (HAZOP) studies. Gas network assets are typically very heavy and are therefore difficult to move due to weight and size. A suitable lifting system will be developed to move the assets in to place from a storage facility to the test rig and vice-versa. A well-designed facility is considered critical to ensuring testing time is kept to a minimum to reduce cost onsite through reduced staff time and to ensure ongoing safe operation of the site whilst moving heavy assets into place.

Above ground governors will be tested both outside and within kiosks to determine both operational functionality and differential leakage between 100% hydrogen and natural gas. Other key design considerations include:

Gases supply: The facility at Buxton will be designed for both a hydrogen and natural gas supply to compare the differences between the two gases, with easy and safe transition between the two gases. There is currently no hydrogen onsite and so an adequate supply for testing will need to be brought in (see Section C.7). The type of onsite storage will be dependent on the volumes to be used. For smaller volumes, a bottle bank will be sufficient but for large volumes a tube trailer will be required. The volumes will be confirmed in the conceptual design stage and the detail design will include a suitable storage facility for the gases required for testing.

Control Room: A new control/monitoring room will be built within close proximity of the test facility. The control room will also house the control, test, monitoring and recording equipment for the site. The equipment required will be determined in the conceptual stage with the HSL.

Instrumentation: To enable the correct measurement of the results, the instrumentation for monitoring pressure, temperature and gas release will be designed by consultation between the H21 project team, the HSL and DNV GL to ensure that what is measured is appropriate to solve the purpose of the test.

Design process: The design will be undertaken by a designer with experience of working on natural gas facilities. In line with industry practice, the design will undergo a HAZOP when the detailed design is approximately 60% complete. Whilst the facility is not a live gas network, the design will be undertaken in the spirit of the gas industries established GL5/G17 process to provide an appropriate level of design assurance. Additional assurance requirements for the use of hydrogen will be supplied by Project Partners and the wider industry, e.g. the potential hydrogen suppliers. The design assurance will be conducted by DNV GL.

C.3. Phase 1B – Consequence testing (Spadeadam)

A strategic set of tests are being designed to allow quantification of risk associated with background leakage as determined in Phase 1A, failure leakage (for example mains fracture, 3rd party damage) and operational response, e.g. repairing leaks. This means establishing what the consequence of leaking hydrogen will be for different scenarios with different leakage rates and potential sources of ignition when compared to natural gas.

The master testing plan at Spadeadam is being developed based on decades of gas industry experience in destructive/consequence testing. This has drawn extensively on the unique expertise and extensive background which DNV GL can uniquely provide. Due to this expertise, tests at Spadeadam will only be undertaken using hydrogen. The equivalent tests on natural gas have already been undertaken throughout the sites history.

The tests at Spadeadam will involve development of new testing areas and utilisation of existing testing facilities. Tests will then be undertaken which will confirm the ground and air concentration levels associated with a range of hydrogen leaks, quantify the consequences of those leaks and determine the applicability of existing repair methods. Following testing, the well-established mathematical models for natural gas leakage, and consequences that form part of the FROST computer package, will be developed and modified for use with hydrogen before a final quantitative risk analysis. The following Sections provide more detail on these specific areas.

C.4. Spadeadam site benefits

The Spadeadam site has experience of extensive testing of this nature meaning it has assets and experience which are being leveraged to ensure value for money as part of the H21 NIC. These include:

Staff experience: Design and conduct of the experiments to provide the validation data for the existing natural gas models was predominantly conducted at Spadeadam. The staff of DNV GL have extensive knowledge, expertise and experience related to this experimental programme.

Site experience: Experience of recent similar test programmes, e.g.

- Investigating the above ground flammable limits from underground releases of natural gas in pressure ranges up to 40bar.
- Investigating the gas accumulation and explosion hazards associated with the storage of high pressure hydrogen in automotive filling stations.
- Investigating dosing the existing natural gas supply with 20% hydrogen.

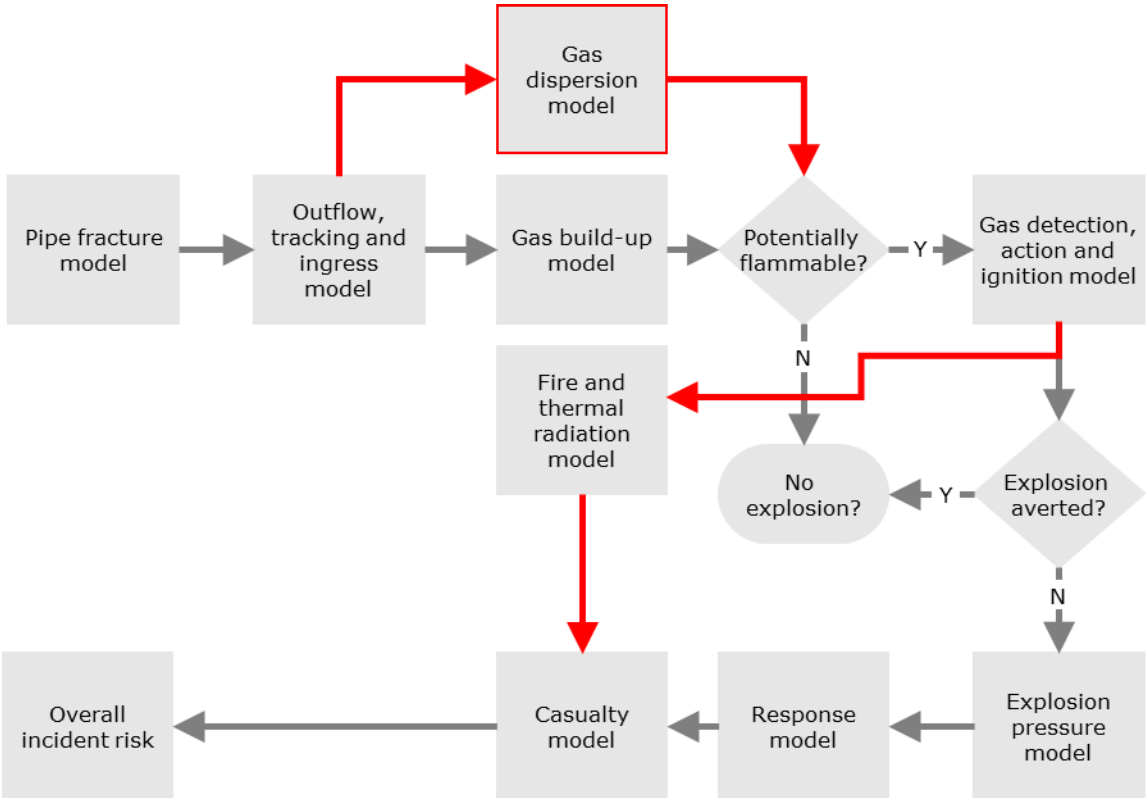
Existing facilities: As well as new building works, existing assets onsite will be utilised for the tests reducing overall cost. These include high pressure gas storage, existing test beds/assets and the extensive data acquisition systems required for the collation of data from the large volumes of instruments required to measure dispersion, accumulation and other process variables in experiments.

C.4.1. Development of the MTP

Currently risks associated with a gas releases from the pipeline network are quantified using a set of linked models to predict the following:

- The outflow of the gas.
- The dispersal and tracking of the gas if subsurface, either to the surface or into buildings.
- How it disperses or accumulates in the atmosphere.
- The likelihood of ignition if a flammable mixture is predicted.
- Explosion overpressure and thermal radiation from an ignited mixture.
- Response of buildings and structures from the fire/explosion.
- The probability of casualties from the fire/explosion/building collapse.

Some of these models are phenomenological and use an understanding of the engineering, physical and chemical formulae to model properties of the gas leak. Others are empirical and based on experimental and incident data. The models have been shown to be suitable within their scope of validation for natural gas releases against full scale experimentation and statistical analysis performed by DNV GL over the past 30 years. The introduction of hydrogen in place of natural gas takes the models outside their validated scope. The principles of the models are shown schematically in the following flowchart.



In terms of the consequences of a network release of hydrogen, it is necessary to quantify the overall risk from a release, and whether this risk is increased or decreased when compared to natural gas. To this end, hydrogen experiments will be conducted to validate the risk model for a 100% hydrogen network. Some elements of the risk model are likely to remain valid. For example, it can be assumed that the failure modes of the components of the network will be largely unchanged as it is not considered that hydrogen introduces new failure mechanisms, particularly for PE pipes and components at below 7bar. The most common cause of loss of containment on the PE pipes is substandard joint fusion which is unlikely to be affected by the introduction of hydrogen.

An overview of the current knowledge positions for each model and the proposed action to achieve a natural gas level knowledge position is shown in the following table. In cases where validation data is needed to prove the respective models perform well for hydrogen, it is likely that modifications to the models will be required to accommodate the different behaviour compared to natural gas. These modifications are contained within the scope of the analysis and modelling work package led by DNV GL and supported by the HSL. This base assessment is being used to develop the MTP.

Comparison of model positions

Model	Natural gas position	Hydrogen position	Action
Release rates	Known	Predictable	Need validation
Tracking/migration	Known	Same mechanisms	Need validation
Accumulation	Known	Some data	Expand Knowledge
Dispersion/flammability	Known	Likely lower risk	Validate
Ignition	Known	Assumed worse	Need data
Thermal radiation	Known	Some data	Need specific data for representative scales
Explosion	Known	Potentially more severe	Need data
Noise	Known	Potentially more severe	Obtain noise data
QRA	Known	Same routines	Use above and check

C.4.2. Spadeadam facility requirements

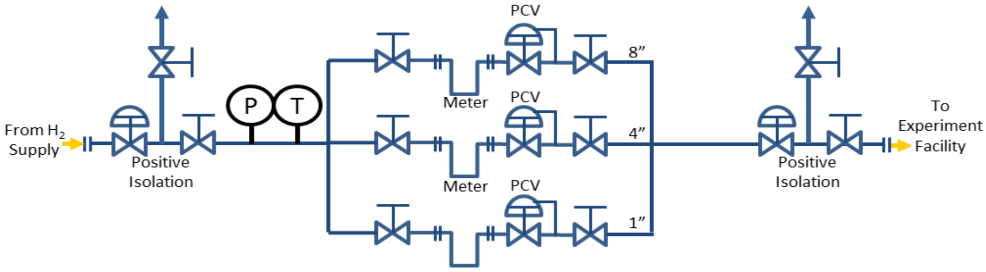
As with Phase 1A – Background testing, an MTP is being developed to satisfy the required measurements for a set of experimental variables. Throughout the experimental programme, modelling of release scenarios will be conducted to help design the most effective programme of experiments. This integrated approach will assist in the model validation process by quickly identifying where models do not give satisfactory results.

The Spadeadam MTP and site design is being developed as part of the 'H21 Keighley & Spadeadam Designs' NIA. The sites objectives include:

- Quantify risk of operating a 100% hydrogen network and compare and contrast with that of a natural gas network.
- Revalidate existing natural gas models for quantitative risk assessment of 100% hydrogen network operation.
- Obtain practical experience of operating 100% hydrogen network components at full scale in a safe and secure environment.

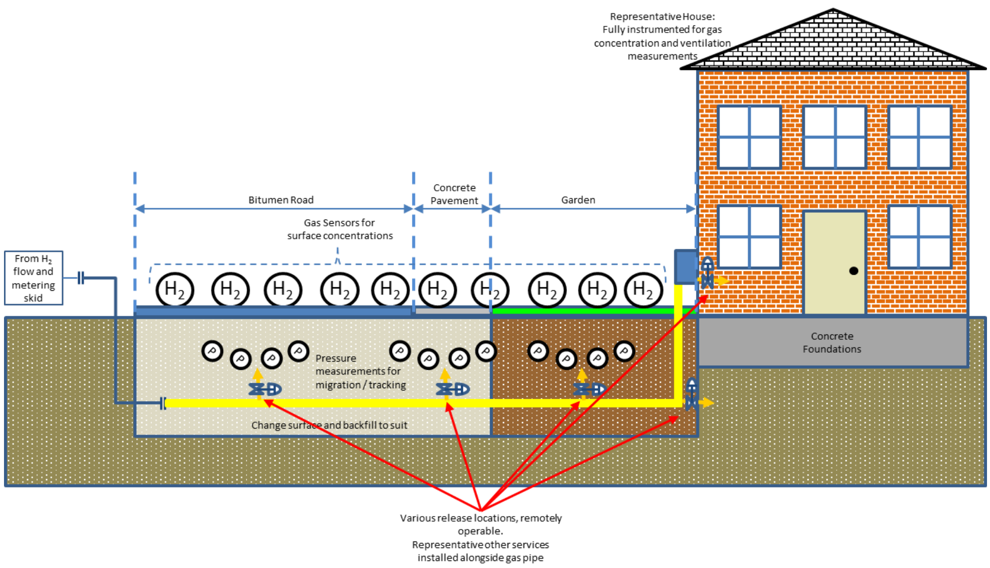
The following test descriptions explain the site-specific tests and facilities which will be used to achieve the objectives. The locations of these tests/test areas are identified on the site area map in Section C4.3.

Hydrogen delivery: All the experiments/tests require hydrogen to be released to atmosphere through various geometries at specified pressures and flow rates. To save on duplication of control systems DNV GL will design and build a mobile pressure control/metering skid capable of taking hydrogen feeds from cylinder packs and high-pressure reservoirs alike and controlling the flow through several streams of varying size complete with flow metering instrumentation. This will allow low and high flow rates to be accommodated at all the facilities described in the coming sections. The following schematic shows a concept sketch of a pressure control and metering skid.



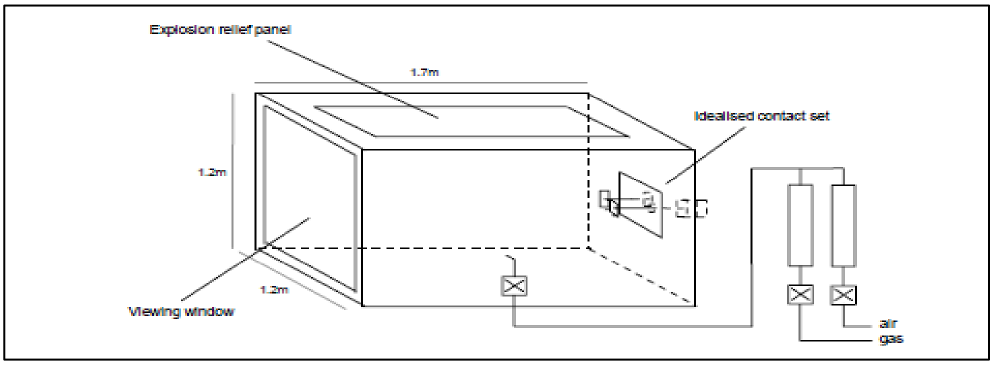
Hydrogen can be supplied to the skid from either a cylinder pack, road trailer or gas storage reservoir at pressures up to 150bar. Using a combination of the 8”, 4” and 1” Nominal Bore (NB) streams, all foreseeable flow rates can be supplied when used in conjunction with a variable supply pressure. After the completion of this experimental programme, this metering and control skid will form part of the maintained facilities available for gas testing by the gas industry. The skid will equally well accept natural gas or other gas mixtures.

Tracking, migration and accumulation facility: To accommodate the required experiments to verify the tracking, migration and accumulation of hydrogen, a facility will be developed on the Test Site West (TSW) area of the Spadeadam site. This facility will consist of a flattened, hardcore area measuring nominally 50m^2. Onto this area a mock-up of a standard service installation will be built in a domestic street setting. The following figure shows a design concept for this facility. Hydrogen supply to this facility will be via cylinder pack or road tanker trailer through the flow control/metering skid. The design is intended to be entirely customisable such that different configurations of service pipe, release location and building entry configuration can be investigated. The domestic street setting will include a minimum of two houses of differing building types (e.g. cellar versus no cellar, airtightness) and above and below ground governor kiosks for investigation of gas accumulation in network enclosures. DNV GL will contribute to the cost of construction of this facility, specifically the houses.



Adjacent to the 50m hardcore area for the migration, tracking and accumulation test facility, a small control building will be constructed to house the various data acquisition systems, gas analysers and personnel deployed on each experiment.

Ignition facility: Ignition potential testing of equipment and components will be conducted in an existing explosion chamber as shown below. Many ignition tests on various equipment/circuitry can be performed using this smaller chamber. During the last three decades, DNV GL has performed an extensive range of ignition tests on various equipment (mobile telephones, PDA's, battery operated tools, cameras and a host of domestic equipment, e.g. refrigerator compressors). These tests were conducted with ethylene and natural gas. The minimum ignition energy for hydrogen is approximately $^{1}/_{5}$ that of ethylene and many times lower than that of natural gas. To accommodate hydrogen, tests need only be performed on equipment and circuitry which has been shown not to provide enough spark energy to ignite natural gas or ethylene.



Explosion facility: An existing explosion facility on the TSW area of Spadeadam will be used to test the explosion consequences from gas accumulation in enclosures and buildings. This facility has been used to perform large vapour cloud explosions over the last eight years. And these tests will be executed utilising the hydrogen metering and control skid alongside the existing instrumentation, gas mixing and analysis systems already in place on this facility.

Dispersion and thermal radiation facility: Dispersion and thermal radiation data can be gathered using an existing facility where natural gas releases are normally conducted. In this facility, releases of hydrogen can be conducted at pressures up to 150bar and hole sizes up to 150mm diameter either above or below ground. This will allow for all possible scenarios for pipes up to 150mm in diameter to be simulated at full scale, including a full-bore rupture. Larger releases can also be accommodated by modification of supply pipework. A large, high pressure storage reservoir is available to store sufficient quantities of hydrogen for longer duration run times. Supply of hydrogen to the leakage source will be from the HP store via the mobile flow control and metering skid.

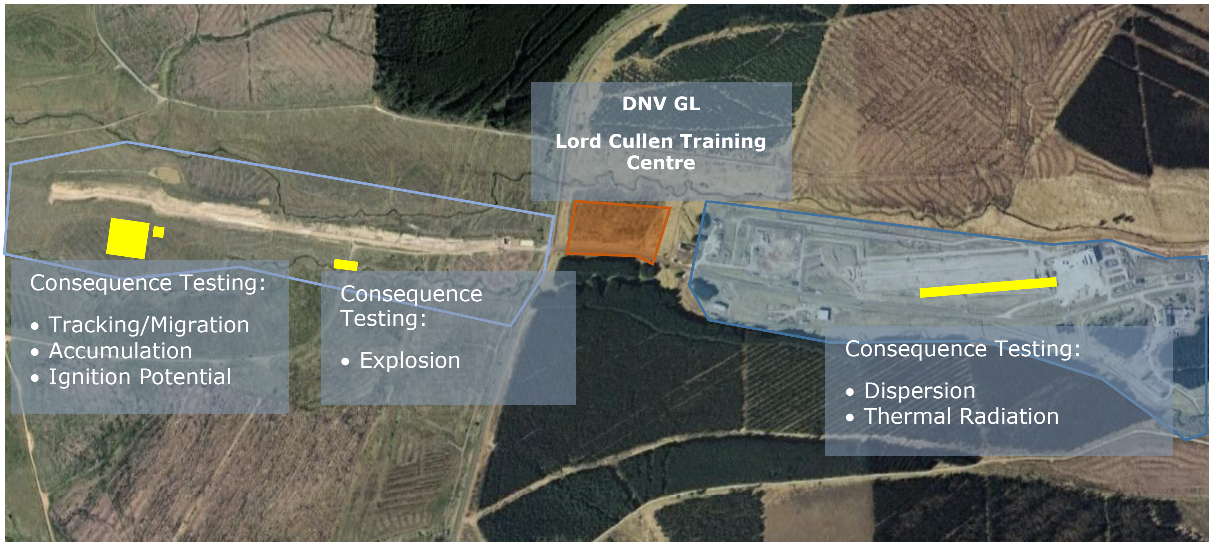
This facility includes a large, open, flat area on which dispersion or thermal radiation instrumentation can be deployed to measure the results of each experiment. Spadeadam has an array of Schmidt-Boelter type thermal radiation sensors and the ability to calibrate them onsite for each experimental programme in a black body furnace. Large scale measurements of gas dispersion are most cost effectively measured using oxygen depletion methods by interpretation of the signals recorded for oxygen sensors throughout experiments. This facility will also be used to measure the overpressure generated in the case of a delayed ignition hydrogen release by use of dynamic over-pressure sensors.

Longevity

All the modifications and additions to the Spadeadam site will provide a valuable testing and experimentation facility for GB GDNs operators and others for the foreseeable future. The facilities are all intended to be used with other gases and are over-designed for pressure to allow for future higher-pressure experimentation to be carried out. DNV GL will commit to the maintenance of these facilities for a period of five years after the completion of the experimental work packages. This means that further experimental programmes involving the sites can be conducted at considerably lower cost than if the facility needed to be built specifically. After completion of the initial experimental programme, it may be possible to utilise some of the facilities for the training of network operation personnel. Beyond the five-year period, costs to reinstate any of the facilities would be kept to a minimum.

C.4.3. Site layout

A satellite photograph of the DNV GL Spadeadam Testing and Research Centre is shown below detailing the general site layout and locations of the tests as described above:



C.5. Phase 2 – Field trials

Ultimately, to provide conclusive comparative safety based evidence for a 100% hydrogen conversion, field trials will be essential. These field trials will be undertaken on in-situ mains, the purpose of which is to confirm the results of the evidence gathered in Phase 1A, confirm the accuracy of the developed computer modelling package from Phase 1B and to evidence operational practices on a mains network.

It is important to note these tests will not be undertaken downstream of the meter and will not affect customers gas supply. Extensive liaison with Local Authorities, as well as a comprehensive customer engagement plan will be required. The H21 NIC team have already been working with Leeds City Council to identify suitable areas where trials can be conducted on abandoned gas network assets prior to any conversion to a network or appliances in customers property.

C.5.1. Why field trials are important

As with all controlled testing, definitive assessment can only be corroborated with in-situ testing. All H21 NIC Partners agree that in-situ testing is essential to solve the problem statement and provide the final evidence requirement. The field trials will confirm the results of the controlled testing undertaken in Phases 1A and 1B, i.e. that the results obtained and modelled in controlled conditions could be used to accurately predict and certify field conditions. Additionally, field trials will provide comprehensive evidence which will ultimately allow a live trial of 100% hydrogen involving both the network and the customer's appliances (note live trials with customers are not part of this H21 NIC).

Field trials could not be undertaken in the absence of controlled testing (Phases 1A and 1B). The safety case would not be in place and stakeholders and/or the GDNs could not have confidence that such trials could be managed safely. Furthermore, obtaining detailed measurement which could be subsequently used for quantitative risk assessment and modelling development by which to extrapolate results could not be undertaken in field trial conditions. The equipment required, controlled environment and range of assets would not be available.

In support of a future policy decision to incrementally convert the UK gas network to 100% hydrogen small live trials involving both the network and end user customers (appliances) will be essential. These trials are not part of the H21 NIC or the BEIS programme but the two programmes, when combined, will provide the evidence and safety case to progress to live trails. The original conversion from town gas to natural gas involved conversion of Canvey Island and Burton-on-Trent prior to any policy decision. This served two significant purposes. Firstly, it allowed the gas industry to understand the logistical challenges associated with conversion of appliances and equipment which also helped confirm conversion cost and timeline estimates. Secondly, it provided government with the consumer acceptability evidence required to provide confidence that a policy decision would be positively accepted, in the main, by the British public.

Following the H21 NIC and BEIS programmes, progression to a live trial will require agreement and confidence across multiple stakeholders. The key stakeholders will include the following:

- **The customers –** In areas identified for live trials customers would need absolute confidence that such a trial was safe. This would be provided by the H21 NIC specifically focusing on the field trials and by the BEIS programme.
- **Ofgem –** To undertake live trials the regulator would need to be confident that such trials were safe. This would be provided by the H21 NIC specifically focusing on the field trials and by the BEIS programme.
- **The GB GDNs –** The GB GDNs are entirely responsible for the safety case to transport natural gas. In a live trail, involving a real part of the distribution network, the GB GDNs would be responsible for the safety case for the 100% hydrogen trial within the network. To do this the network asset directors would need to be confident that the QRA, modelling and operational procedures were comprehensive and accurate. The asset directors agree that this could only be achieved through in-situ tests to corroborate results and gain some practical experience without impacting customers.
- The Health & Safety Executive (HSE) would need to be convinced that the safety case to progress with 100% hydrogen live trials is robust. These field trials provide the definitive evidence coupled with the BEIS programme of work.

C.5.2. Work to date and what is involved.

The H21 NIC team have been working closely with the West Yorkshire Combined Authority to identify demolished/derelict sites where mains networks still exist (see letters of support Appendix J). Derelict/demolished sites have been identified as the most suitable for field trials as the network assets still exist but will have been isolated from the network and do not impact end use customers. Using these types of sites will ensure minimal customer impact and a safe, yet still provide a 'real-life', environment for carrying out field trials.

Final site identification and subsequent design/enabling work will be undertaken throughout 2018 in preparation for the field trials in 2019. To date several sites have been identified and assessed against the parameters identified in Section 2. Ultimately, the site selected for field trials will represent the best value for money in terms of cost, range of assets available, surrounding land use and level of customer impact. The selected site will be provided to the H21 NIC project under legal agreement between the council and the GB GDNs.

Prior to progression to Phase 2 the H21 NIC must pass a critical stage gate. The Project Steering Committee (see Section 6, Governance) will only permit the Project to proceed if the results of Phases 1A and 1B provide credible evidence that there are no clear 'show stoppers' regarding 100% hydrogen gas grid conversion, i.e. that the QRA indicates the risk is manageable and, furthermore, that field trials will be safe.

Two examples of demolished/derelict sites identified to date are provided below:

As identified in the programme gantt chart the in-situ tests will require extensive enabling works to ensure mains soundness in addition to development of the temporary works design. During the tests, the sites will be fully isolated and made secure to ensure the sites can be managed within the safe control of operations parameters typically adopted by the gas industry. Measurement systems will be installed across the sites to obtain results which will be referenced against the predicted outcomes generated via the computer simulation modelling developed as part of Phase 1A and 1B. A district governor will be used to control hydrogen delivered to site confirming its operability. Finally, operational procedures will be carried out to repair hydrogen leaks, perform flow stopping and make new connections as part of the field trial confirming the network can be maintained safely under 100% hydrogen conditions. An extensive customer liaison programme will be developed for the chosen site for any customers in the surrounding area. Costs for the field trials have been estimated based on a breakdown of activities and cross referenced against typical gas industry activities and expert review. Contractors to undertake the site works will be engaged via either competitive tender or utilising existing GDN framework agreements.

C.6. Analysis and model development

The overriding objective of the Project is to provide the compelling safety based evidence for a 100% hydrogen conversion in the GB gas distribution networks; specifically, that the pipes and equipment in 2032 (i.e. following completion of the IMRP) will be as safe operating on either 100% hydrogen or natural gas. As part of this objective, a comparative QRA is required which can be used to evaluate the difference in safety risk to the public associated with supplying 100% hydrogen versus natural gas. The assessment will reflect both the layout of the existing distribution network within the selected isolation zone and the hazard assessment findings from the full-scale field trials conducted as part of the wider project. The risks calculated will cover the network up-stream of the meter only, i.e. the network up to and including the Energy Control Valve (ECV). Furthermore, an evaluation will be made of the risk posed by a 100% hydrogen gas network against a range of other options, to put the overall risks into context as well as comparing risk levels with other external risks faced by the public day-to-day.

C.6.1. Outline scope of work

The QRA is the process of obtaining a numerical estimate of risk by quantitatively estimating the likelihood of occurrence of specific undesirable events (the realisation of identified hazards) and the severity of the harm or damage caused, together with a value judgement concerning the significance of the results. The process of carrying out a QRA study for the supply of 100% hydrogen through the distribution network will result in an improved understanding of the level and significance of risks compared against those associated with the current supply of natural gas. This will inform decisions regarding the suitability of the network for hydrogen use and will also provide important information relating to the implementation of appropriate risk control and reduction measures.

The QRA will address the safety risks to the public (100% hydrogen versus natural gas) from leakage resulting from both normal operation of the network (e.g. component leakage) and 3rd party accidental interference (e.g. impact during construction work). The QRA will require the existing natural gas distribution QRA model to be modified first, to enable the necessary calculations to be performed for hydrogen. It is planned that this will be performed in stages to include:

Part A: Information gathering

- Literature review to identify existing knowledge to modify natural gas QRA model for hydrogen.
- Identification of hazards and scenarios pertinent to hydrogen transportation highlighting key differences from natural gas.

Part B: Preliminary QRA model for hydrogen and gap analysis

- Evaluation of modules and logic in natural gas QRA model to specify where changes may be required to reflect hydrogen service, including:
  a) Failure mode and frequency for pipelines and components.
  b) Gas release rate calculation (in-ground gas releases and releases direct to atmosphere).
  c) For gas releases direct to atmosphere – extent of gas dispersion in the atmosphere, probability of ignition (immediate or delayed) and fire hazards.
  d) For in-ground releases – extent of gas migration through the ground under different conditions, potential for gas ingress into buildings, build-up to flammable concentrations, detectability, ignition (immediate or delayed) and explosion hazards and their potential effects, potential for distributed fires due to gas migration to the surface.
  e) The possibility of explosion hazards arising from unconfined hydrogen releases or releases into confined or congested regions of above-ground installations will also be considered for possible inclusion in the model.
- Modify existing QRA models and logic for hydrogen using existing knowledge or judgement.

Part C: Preliminary risk analysis and risk evaluation

- Definition of network parameters for QRA, including pressures, pipeline sizes, proximities, etc., based on the original H21 Leeds City Gate area.
- Estimation of risk (combining likelihood and consequences), applying judgement and cautious assumptions to identify the key areas of sensitivity and uncertainty that impact on risk.
- Preliminary evaluation of significance of initial risk results (comparison of hydrogen versus natural gas, comparison against risk tolerability criteria, evaluation of risk reduction options, etc.).
- Specification of experiments and model development required to address key uncertainties.

Part D: Refine QRA model and risk results for hydrogen and consider mitigation options

- Evaluation of data from Phase 1A and 1B and validation/modification of hydrogen QRA models and methodology as appropriate in the light of the results.
- Revised estimation of risk (combining likelihood and consequences), using the newly developed hydrogen QRA methodology and evaluate significance of risk results (comparison of hydrogen versus natural gas and risk tolerability versus criteria).
- Identify options and effectiveness of measures for risk reduction in the light of the refined results.

Part E: Extrapolation of QRA Results across GDNs

- Survey of GDNs to establish the appropriate network parameters to allow the risk results for the H21 Leeds City Gate area to be extrapolated across the whole of the GB gas distribution networks.
- Estimation of societal risk for the whole of the GB gas distribution networks for both natural gas and 100% hydrogen (with mitigation options applied if required) for direct comparison.

Part F: Utilisation of QRA model to predict outcome of the field trials

- Using the FROST model to predict concentration levels of hydrogen within the Phase 2 – Field trials area based on known leaks, soil types and ground covering etc.
- Validation of predictions following the field trials work in Phase 2.

Part G: Comparison of hydrogen network with alternative energy supply options

- Literature review and data collection (e.g. accident statistics from internal and external sources).
- Critical comparison of hydrogen versus natural gas risks (including health effects/carbon monoxide poisoning).
- Critical comparison of hydrogen versus expanded electricity supply risks.
- Comparative review of overall safety and health risks associated with different energy supply options, comparison of those risks against risk tolerability criteria for the public (from UK HSE), and comparison against risk levels from other hazards faced by the public daily. The objective of this final stage will be to put the overall risk levels into context and into layman terms using graphical representations to communicate the key findings.

Parts A to F will be led by DNV GL with extensive knowledge and expertise in relation to the legacy gas industry data and risk methodologies, with support from ERM, who will lead Part G.

C.7. Hydrogen supply options for H21 NIC

To ensure value for money for the trials a detailed review of the most appropriate methods of hydrogen production has been undertaken. For the H21 NIC testing programme the hydrogen supply costs will be dependent on hydrogen gas volume, supply mode, purity/grade and time required for supply. Consideration has been taken of the onsite logistics of supplying the hydrogen to the test site. With the aggressive timeline for the proposed works, a reliable and cost-effective supply mode is critical for the successful delivery of the Project.

The industrial grade hydrogen (typically >99.98%) supplied by any of the industrial gas companies, e.g. BOC (member of the Linde Group), Air Products or Air Liquide, is of adequate purity for the testing programme. The hydrogen in the UK comes from several production methods including from by product, steam methane reforming and electrolysis. Liquid hydrogen supply is available as well as compressed gas but this adds additional costs not typically required except for very high demand applications and/or high purity specification requirements.

Compressed hydrogen is available in a range of cylinders ranging from small portable composite cylinders (e.g. BOC's Genie) through to 40ft tube trailers. The unit price of the gas decreases with volume purchased, though the monthly rental for the cylinder increases with size. The following table gives indicative list prices for cylinder rental and the cost of the hydrogen contained in the cylinder. Costs are dependent on supply volume.

Cylinder type	Volume	Size/weight	Container rental per month (approx.)	Price range	Approximate price/m³ (excl. rental)
B steel	1.48m³	140mm diameter x 850mm/16kg	£6.90	£30 – £40	£23
G20 composite	4.98m³	20mm diameter x 662mm/22kg	£14	£45 – £55	£10
K Steel	7.21m³	230mm diameter x 1,460mm/65kg	£10	£50- £65	£8
WK (MCP) steel	108.15m³	840 x 1290 x 1,810mm/1,500kg	£180	£700 – £750	£6.70
Tube trailer	Circa 3,500m³	40ft trailer circa 30t	£1,500	£1,400 – £2,400	£0.55

For longer term applications with high volumes, the leasing of either onsite storage (that is topped up on demand), or onsite production could be considered. However, for the purposes of the H21 NIC programme this mode of supply is not cost effective.

In addition to the supply of the cylinders, consideration will be given to the local logistics of getting the hydrogen from the cylinder to the test site. Single cylinders can be wheeled around in a suitable trolley, whereas Multi Cylinder Pallets (MCPs) weigh around 1,500kg so require a fork lift truck, and finally trailers which require a tractor unit. A regulator and local distribution pipework may also be the best solution for repeated testing in one location, though this would need to be considered under the relevant Regulations and Codes of Practice (e.g. PER 1999, PSSR 2000 and BCGA CP 4). Depending on the final site design and testing programme an assessment will be made of the most appropriate supply and distribution mode. Once the locations and test programmes have been reviewed then further details, recommendations and price negotiations with suppliers will commence.

C.8. Social science

Currently there is considerable uncertainty about how communities and individuals would respond to the prospect of using 100% hydrogen in the GB gas distribution network and potentially in their homes, businesses and vehicles, what barriers may exist and what perceptions of hydrogen may already be in place. Furthermore, a great deal hinges on how the core practices of cooking, heating and mobility would respond to the introduction of hydrogen as a replacement for current fuels.

Despite hydrogen holding great potential, public perceptions of hydrogen are currently only guessed at by the research and industry community. It is also well established in research and applied contexts that public engagement with new technologies can be a complex process in which outcomes are not always predictable. This is amplified yet further where there are perceived to be possible risks to safety and where long-held norms about the 'look and feel' of the materials of daily life are being challenged – both of which may be true of hydrogen. If hydrogen is to play a role in the future energy system then the ways in which members of the public understand it and how these perceptions affect its integration in to everyday activities need to be determined.

Research Aims

As part of the H21 NIC a programme of social science research will be funded to ensure that some of these issues are confronted and new knowledge generated. This program of work aims to:

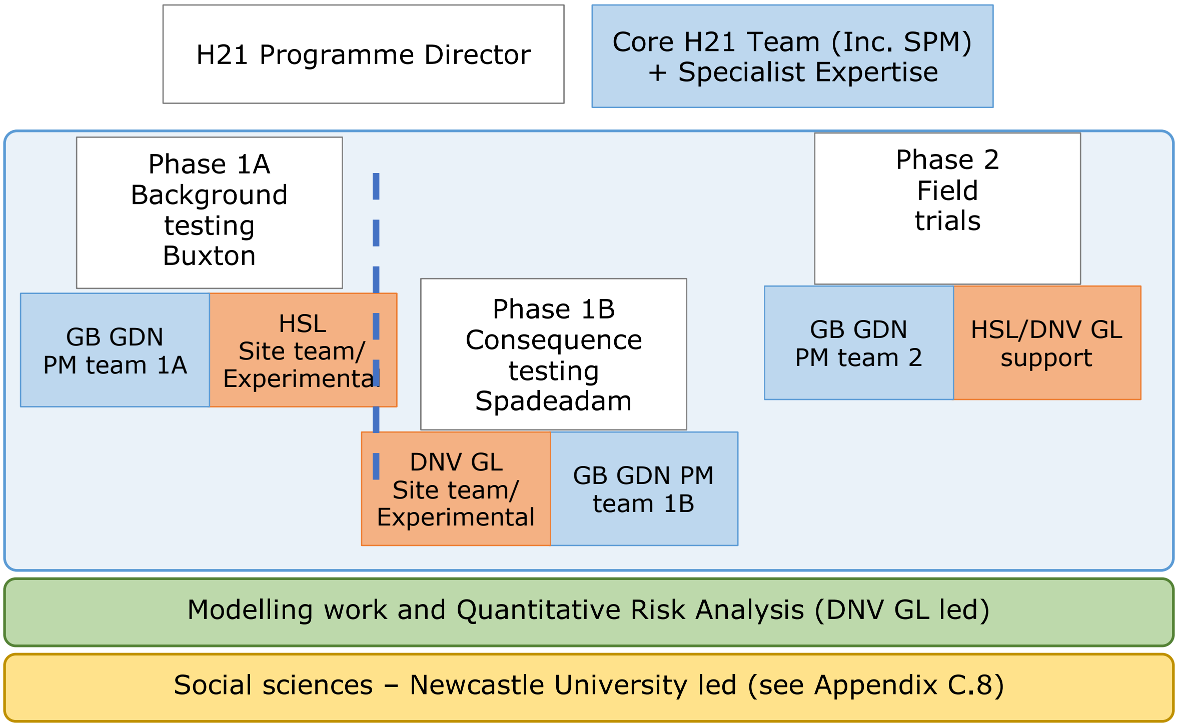
- Generate insight into baseline public perceptions of the safety of hydrogen and other energy technologies/vectors including how they vary by a range of socio-demographic and geographic variables.
- Generate insight into how people respond to the possibility of using 100% hydrogen in the three-key, gas-fuelled social practices (heating, cooking, travelling), including how they vary by a range of socio-demographic and geographic variables.
- Understand how public perception of the safety of hydrogen evolves across the range of socio-demographic and geographic variables when considering the H21 NIC evidence.
- Build a hydrogen research network of social scientists across the UK who may then become involved in the delivery of the proposed research activity or who may play advisory roles in the development of a body of research, data and expertise around the opportunities and challenges of hydrogen.

The programme of work will draw on the growing energy research literature on social practices that has gained considerable traction in recent years in both academic and policy communities through the work of Elizabeth Shove and others (Ropke and Christensen, 2013; Shove, 2010, 2012; Shove et al., 2012; Shove and Walker, 2010).

This research will leverage the existing relationship and work to date undertaken for the HyDeploy project led by Newcastle University. It is anticipated that relationships will be developed across the academic landscape ensuring appropriate coverage across GB GDNs. Ideally, connections will be made between academic institutions across the major urban centres used to extrapolate the carbon and financial benefits as defined in Appendix B.

Appendix D. Project governance and organogram

Project management is provided by a multi-disciplined project team responsible for co-ordinating the day-to-day operations of the Project. This will include management of contractors and programme, coordinating and reporting to the Steering Committee, acting upon decisions with relation to budget management, submitting requests for milestone completion, sanctions to progress to subsequent project stages etc. Project Board meetings of the participants will be held monthly. A summary of the proposed management structure for the Project is shown in the following diagram.



The core team will be made up of a Senior Project Manager and commercial functions reporting directly to the H21 Programme Director. They will be engaged via Northern Gas Networks (NGNs) professional services framework and will produce monthly reports summarising the progress of the Project in accordance to the standing agenda of the Steering Committee. A copy of the monthly report will be circulated to each member of the Steering Committee with the written notice for the relevant meeting by the Senior Project Manager. All other sub-teams will report back to the Senior Project Manager who will ensure appropriate communications are delivered throughout the Project

The GB Gas Distribution Networks (GDNs) team for Phase 1A will have a Buxton Project Manager responsible for overseeing design, construction, facilitating the testing and managing the budget for the Buxton sites. In addition, they will be responsible for co-ordinating removal and delivery of network assets for testing.

The GB GDNs team for Phase 1B will have a Spadeadam Project Manager responsible for overseeing design, construction, facilitating the testing and managing the budget for the Spadeadam site. This Project Manager will also be responsible for delivery of the Phase 2 – Field trials design and enabling work.

The H21 Programme Director is accountable for the successful allocation of milestones and allocation of stage funding under the NIC allowance.

The Steering Committee will meet on a quarterly basis and comprises representatives nominated by each of the collaborating GB GDNs and the primary Project Partners. The Chair of the Steering Committee shall be the H21 Programme Director for NGN. Should the Chair not be available they shall delegate to one of the other collaborating GDNs as appropriate.

The role of the Steering Committee is to assure delivery of all the activities undertaken on the Project to scope, time and budget and to provide overall direction of the work. Members may participate via teleconference, video conference or other technological means when necessary. Should a nominated member become unable to attend the member may appoint an alternate. Any alternate attending for a period of more than two months is to be approved by the Chair.

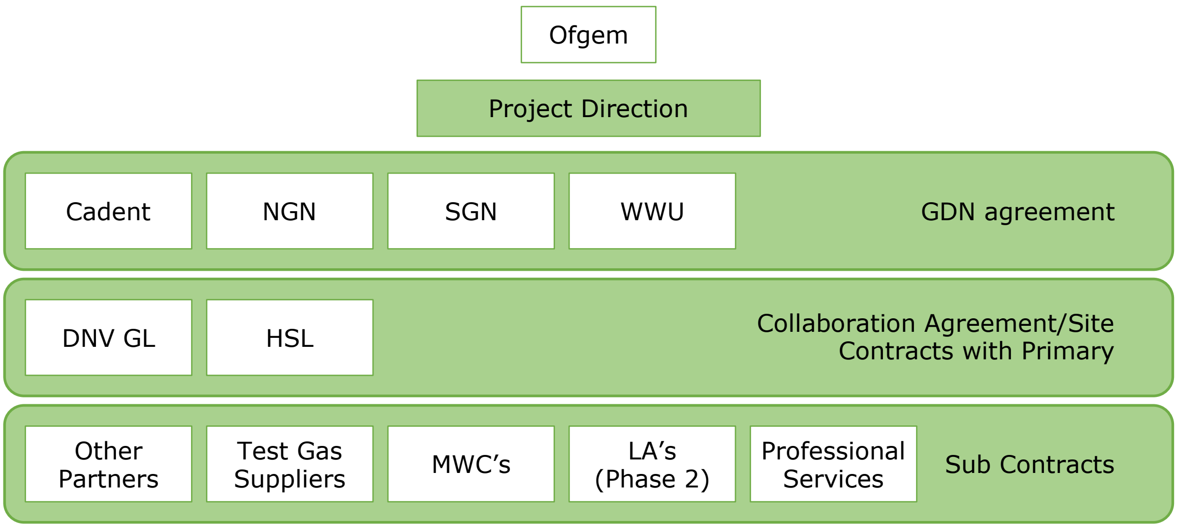
The Steering Committee shall provide assurance on:

- Safety and environmental management – incidents, lost time injuries, any breaches of environmental controls etc.
- Progress against deliverables and plan – mitigation of issues arising, review of open issues, sanction for closing open issues.
- Review of subsequent plans for coming six-month period and potential to accelerate activities or manage issues arising.
- Evidence of project task completion and review of achievement of research outcomes.
- Review progress against budget, risks register (proposed inclusion or removal of, change in impact/probability), communications plan etc.
- Evidence of project milestone progression as appropriate.

Meetings of the Steering Committee will be convened with at least twenty-one days written notice in advance. That notice must include a standing agenda and additional agenda items on request of any project Partner. Minutes of the meetings of the Steering Committee will be prepared by the Senior Project Manager and sent to each of the parties within fourteen days after each meeting.

Each Steering Committee Partner will have one vote. Decisions will be taken by a simple majority (in a tied vote, the H21 Programme Director will have a casting vote), except where a decision necessitates a change to the Project plan or a change to the allocation of any funding or change to any contribution. In any of those cases, any decision must be unanimous and may only be made where the representatives of all the Partners are present.

Contractual Arrangements: The GB GDNs have a well-developed and proven collaboration agreement, which has formed the basis for three NIC projects to date. This has been reviewed by the Project Partners and will form the basis for this project. A summary of the proposed contractual arrangements is shown in the following diagram.

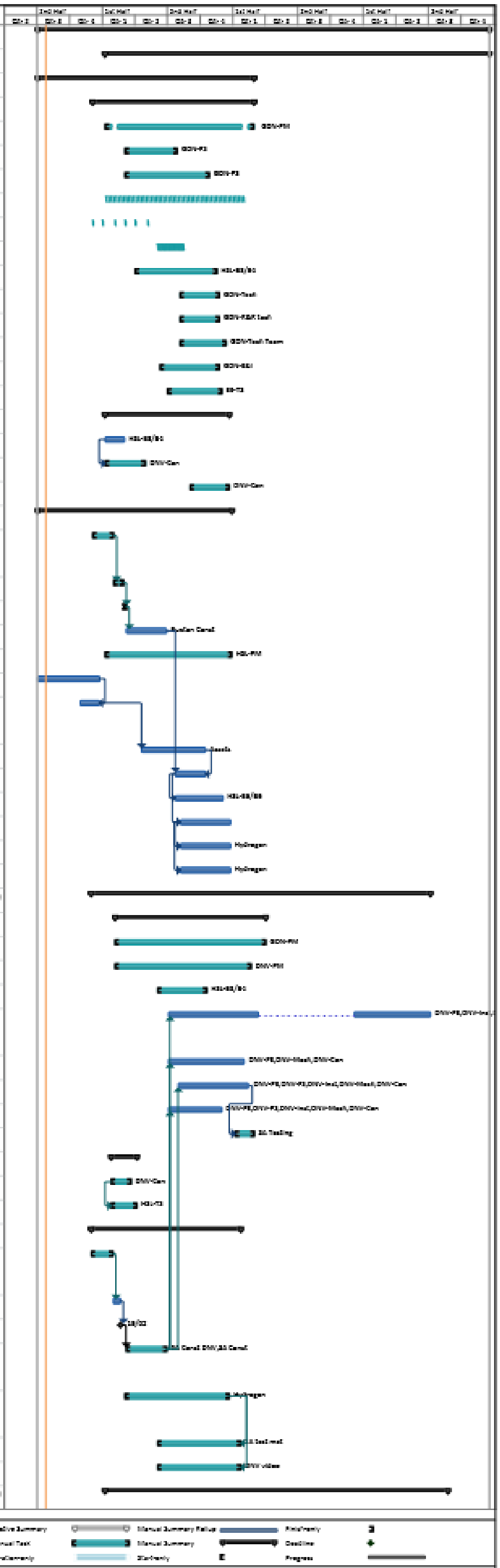


ofgem

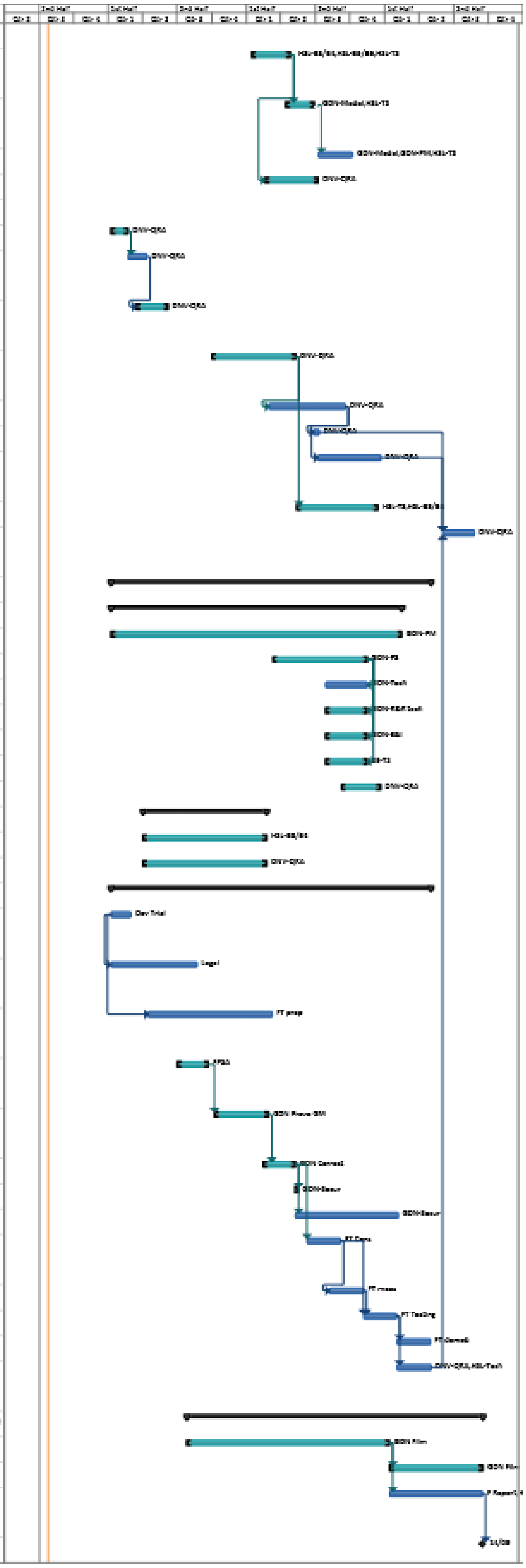
RIIO NIC NETWORK INNOVATION COMPETITION

Appendix E. H21 NIC programme

Task Name	Duration	Start	Finish
H21 Programme	**890 days**	**Mon 03/07/17**	**Fri 18/12/20**
Core Team	**758 days**	**Mon 08/01/18**	**Fri 18/12/20**
PHASE 1A:TESTING (BUXTON SITE)	**425 days**	**Mon 03/07/17**	**Thu 28/02/19**
PACKAGE MANAGEMENT	**315 days**	**Mon 04/12/17**	**Thu 28/02/19**
Project Manager A (GDN)	273 days	Mon 08/01/18	Thu 28/02/19
Project Supervisor (GDN) Construction	103 days	Mon 05/03/18	Sat 28/07/18
Project Supervisor (GDN) Asset Collectic	167 days	Mon 05/03/18	Fri 26/10/18
HSL Project Manager	**276 days**	**Thu 11/01/18**	**Thu 31/01/19**
HSL Test Scientist - Prep	**107 days**	**Mon 08/01/18**	**Fri 08/06/18**
HSL Test Scientist - Testing	**125 days**	**Mon 04/06/18**	**Fri 23/11/18**
HSL Technical Oversight and QA	162 days	Mon 02/04/18	Fri 16/11/18
GDN Maintenance technician	80 days	Mon 06/08/18	Fri 23/11/18
GDN R&R technician	80 days	Mon 06/08/18	Fri 23/11/18
Testing facilitation team	93 days	Mon 06/08/18	Wed 12/12/18
GDN E&I Support	120 days	Mon 11/06/18	Fri 23/11/18
Specialist technical support	110 days	Mon 02/07/18	Fri 30/11/18
EXPERIMENTAL DESIGN	**247 days**	**Mon 08/01/18**	**Fri 21/12/18**
HSL Test Plan	40 days	Mon 08/01/18	Fri 02/03/18
DNV GL Support and Assurance 1	80 days	Mon 08/01/18	Mon 30/04/18
DNV GL Support and Assurance 2	80 days	Mon 03/09/18	Fri 21/12/18
SITE ACTIVITIES	**382 days**	**Mon 03/07/17**	**Fri 28/12/18**
Tender Return Period (8 weeks minimum) - tender produced in NIA	40 days	Mon 04/12/17	Wed 31/01/18
Tender Appraisal	20 days	Thu 01/02/18	Wed 28/02/18
Contract Award	5 days	Thu 01/03/18	Wed 07/03/18
MWC - Build - Site modifications	78 days	Thu 08/03/18	Thu 28/06/18
HSL Contractor Management	250 days	Mon 08/01/18	Fri 28/12/18
identification of Assets	125 days	Mon 03/07/17	Fri 22/12/17
Detailed final costings using network workforce contractors	40 days	Mon 30/10/17	Fri 22/12/17
Excavation of assets as required	125 days	Fri 20/04/18	Mon 15/10/18
Delivery to HSL site	60 days	Tue 24/07/18	Mon 15/10/18
HSL Logistics / Workshops / Cranage	95 days	Tue 24/07/18	Mon 03/12/18
Asset Testing	100 days	Tue 07/08/18	Mon 24/12/18
Hydrogen Supplied to site	100 days	Tue 07/08/18	Mon 24/12/18
Testing on Natural Gas	100 days	Tue 07/08/18	Mon 24/12/18
PHASE 1B: TESTING (Spadeadam)	**663 days**	**Thu 30/11/17**	**Mon 06/07/20**
PROJECT MANAGEMENT	**296 days**	**Mon 05/02/18**	**Tue 02/04/19**
Project Manager B (GDN)	296 days	Mon 05/02/18	Tue 02/04/19
DNV GL Project Manager	267 days	Mon 05/02/18	Wed 20/02/19
HSL Independent Testing Witness	100 days	Mon 04/06/18	Fri 19/10/18
Tracking / Migration / Accumulation Experiments	515 days	Wed 04/07/18	Mon 06/07/20
Ignition Testing	150 days	Wed 04/07/18	Fri 01/02/19
Explosion Experiments	140 days	Wed 01/08/18	Fri 15/02/19
Dispersion / Thermal Radiation Experime	107 days	Wed 04/07/18	Thu 29/11/18
Additional Testing (As Defined by 1A)	40 days	Mon 07/01/19	Fri 01/03/19
EXPERIMENTAL DESIGN	**51 days**	**Thu 25/01/18**	**Fri 06/04/18**
Experimental Masterplan	40 days	Thu 25/01/18	Wed 21/03/18
Experimental master test plan approval	52 days	Thu 25/01/18	Fri 06/04/18
SITE ACTIVITIES	**290 days**	**Thu 30/11/17**	**Tue 22/01/19**
Tender Return Period (8 weeks minimum) - tender produced in NIA	40 days	Thu 30/11/17	Mon 29/01/18
Tender Appraisal	15 days	Tue 30/01/18	Mon 19/02/18
Contract Award	0 days	Mon 19/02/18	Mon 19/02/18
MWC - Build - Site modifications / test preparation (EFFORT AND DIRECTS)	79 days	Thu 08/03/18	Fri 29/06/18
Hydrogen Supplied to site (incl. bulk store hire)	207 days	Mon 05/03/18	Fri 21/12/18
Testing on hydrogen (materials)	164 days	Mon 04/06/18	Tue 22/01/19
DNV Videography	164 days	Mon 04/06/18	Tue 22/01/19
QRA Analysis and modelling	**674 days**	**Mon 08/01/18**	**Mon 24/08/20**



Task Name	Duration	Start	Finish
PHASE 1A			
Compile Data, Analyse Results, Comparisons & report	75 days	Mon 14/01/19	Fri 26/04/19
Develop modelling to extrapolate results for leakage across GDNs	54 days	Mon 15/04/19	Mon 08/07/19
Quantify commerical leakage position	65 days	Tue 09/07/19	Mon 07/10/19
DNV GL Review of Leakage Analysis	99 days	Tue 19/02/19	Mon 08/07/19
PHASE 1B			
A: Information Gathering	33 days	Mon 08/01/18	Wed 21/02/18
B: Preliminary QRA Model for Hydrogen and Gap Analysis	36 days	Thu 22/02/18	Thu 12/04/18
C: Preliminary Risk Analysis and Risk Evaluation	57 days	Thu 15/03/18	Wed 06/06/18
D: Refine QRA Model and Risk Results for Hydrogen and Consider Mitigation	156 days	Mon 01/10/18	Fri 10/05/19
E: Extrapolation of QRA Results across GD	144 days	Fri 01/03/19	Wed 18/09/19
F: Utilisation of QRA Model	10 days	Thu 27/06/19	Wed 10/07/19
G: Comparison of Hydrogen Network with Alternative Energy Supply Options	120 days	Mon 08/07/19	Fri 20/12/19
HSL Assurance	155 days	Mon 13/05/19	Fri 13/12/19
Revision of QRA Required following Phase 2 Field Trials	60 days	Tue 02/06/20	Mon 24/08/20
PHASE 2: Field Trials	**594 days**	**Mon 08/01/18**	**Fri 01/05/20**
PROJECT MANAGEMENT	**540 days**	**Mon 08/01/18**	**Fri 14/02/20**
Project Manager A (GDN)	540 days	Mon 08/01/18	Fri 14/02/20
Project Supervisor (GDN)	179 days	Mon 11/03/19	Fri 15/11/19
GDN Maintenance technician	80 days	Mon 29/07/19	Fri 15/11/19
GDN R&R technican	80 days	Mon 29/07/19	Fri 15/11/19
GDN E&I technician	80 days	Mon 29/07/19	Fri 15/11/19
Specialist Technical Support	80 days	Mon 29/07/19	Fri 15/11/19
DNV GL QA	75 days	Mon 09/09/19	Fri 20/12/19
EXPERIMENTAL DESIGN	**229 days**	**Mon 02/04/18**	**Fri 22/02/19**
HSL Support and Assurance	229 days	Mon 02/04/18	Fri 22/02/19
DNV GL Support and Assurance	229 days	Mon 02/04/18	Fri 22/02/19
SITE ACTIVITIES	**594 days**	**Mon 08/01/18**	**Fri 01/05/20**
Development and identification of appropriate field trial areas	38 days	Mon 08/01/18	Wed 28/02/18
Confirm legal agreement for access with Las	160 days	Mon 08/01/18	Wed 22/08/18
Develop temporary works design for site testing	230 days	Mon 16/04/18	Fri 08/03/19
Safety management - FPSAs. Design assurance	60 days	Mon 02/07/18	Fri 21/09/18
Prove gas mains 'soundness' test for identified sites	100 days	Mon 08/10/18	Wed 27/02/19
Correct mains / services as required	60 days	Thu 14/02/19	Thu 09/05/19
Secure Site (Herras Fencing)	7 days	Thu 09/05/19	Fri 17/05/19
Site Secutiry (CCTV/Secuity guard)	190 days	Fri 10/05/19	Tue 04/02/20
Construct site (governor, H2 injection points, temp works etc)	64 days	Mon 10/06/19	Thu 05/09/19
Install measurement equipment	64 days	Thu 08/08/19	Tue 05/11/19
Conduct Testing	60 days	Wed 06/11/19	Fri 31/01/20
Site demobilisation	62 days	Mon 03/02/20	Wed 29/04/20
Review and compare results to phase 1A/B and computer predicted	65 days	Mon 03/02/20	Fri 01/05/20
Dissemination of Results	550 days	Fri 27/07/18	Wed 16/09/20
Filming	375 days	Fri 27/07/18	Mon 13/01/20
Final Film Production inc animations etc	175 days	Tue 14/01/20	Wed 16/09/20
Develop Detailed Report (Graphic design, printing, etc)	20 days	Tue 14/01/20	Mon 14/09/20
Hold Launch Event(s) for results.	0 days	Mon 14/09/20	Mon 14/09/20



Appendix F. Risk register

Category	Project Phase	Risk ID	Risk Description	Impact of Risk	Impact (Low to High) 1-5	Likelihood (Unlikely to likely) 1-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Health & Safety	1a		Failure of the pressure system.	Possible safety issues.	5	2	M	Testing and operating procedures and design approval by competent person and competent operatives.	Incorporate knowledge into processes and include into any plans and procedures.	5	1	L
Health & Safety	1a		Possibility of flammable build up under and above ground .	Safety issue.	5	5	H	Good knowledge of ground dispersion from natural gas work and exclusion zones will be enforced. Strict control of ignition sources.	Incorporate knowledge into processes and include in any plans and procedures.	5	1	L
Health & Safety	1a		Possibility of flammable build up in kiosks.	Safety issue.	5	5	H	Good knowledge of ground dispersion from natural gas work and exclusion zones will be enforced. Strict control of ignition sources.	Incorporate knowledge into processes and include into any plans and procedures.	5	1	L
Health & Safety	1b		Hydrogen storage facilities failure.	Possible safety issues.	5	2	M	Designed by competent person, testing and process procedures developed, safe control of operations.	Following procedures and inspection and monitoring.	3	1	L
Health & Safety	1b		Failure of pressure system.	Possible safety issues – fatality.	5	3	H	Testing and operating procedures and design approval by competent person and competent operatives.	Following procedures and approvals.	5	1	L
Health & Safety	1a/b/2		Lack of necessary emergency response for site work.	Safety issue.	5	2	M	Test conducted in accordance with site procedures.	Training of emergency teams.	5	1	L
Health & Safety	1a/b/2		Conflict with other site activities.	Safety issue.	5	2	M	Close liaison with other site users and test exclusion zones.	Following site procedures.	5	1	L
Health & Safety	2		Specifying appropriate equipment. Risk of mixing hydrogen and natural gas.	Mixing performance key to safety of system.	4	2	M	Careful spec, full HAZOP and safety mechanisms built in and decommissioning of system through NGN/PM/GL/5/G17 process.	Following procedures for operations.	4	1	L
Health & Safety	1a/b/2		Robustness of instrumentation.	Safety risk if critical technologies do not operate effectively.	3	2	M	Use of approved and tested equipment.	Ensure equipment is approved.	3	1	L

Category	Project Phase	Risk ID	Risk Description	Impact of Risk	Impact (Low to High) 1-5	Likelihood (Unlikely to likely) 1-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Health & Safety	1a/b/2		Construction/fabrication/installation.	Safety issue.	5	3	H	Specific site procedures and risk assessment operated in accordance with site activities.	Following site procedures and safe control of operations process.	5	1	L
Health & Safety	2		Hydrogen storage and facilities failure.	Possible safety issues.	5	3	H	Designed by competent person, testing and process procedures developed, safe control of operations.	Following procedures and inspection and monitoring of facility.	5	1	L
Health & Safety	2		Access to site, vandalism.	Possible safety issues.	4	2	M	Site protection processes in place.	Follow procedures and monitoring of site.	4	1	L
Health & Safety	2		Risk of mixing hydrogen and natural gas.	Safety issue.	5	3	H	Detailed process for commissioning and decommissioning.	Adoption of safe control operations.	5	1	L
Health & Safety	2		Risk of hydrogen entering the adjacent gas network during trials.	Safety issues.	5	2	M	Detailed process for commissioning and decommissioning of system.	Adoption of safe control of operations and approvals.	5	1	L
Technical	1a		Wrong selection and management of network asset fittings.	Possible delays in testing programme.	4	2	M	Review of Master Testing Plan (MTP).		4	1	L
Technical	1a/b		Suitable site design for the site and suitable location and supply of hydrogen.	Site does not provide the right process.	5	3	H	Site designed and verified for the testing regime including 3rd party review.	All equipment is approved.	5	1	L
Technical	1a/b		Suitable process in place to ensure that no gases are mixed.	Mixture of hydrogen and natural gas.	4	2	M	Procedure developed with gas segregation policy in place.		4	1	L
Technical	1a		Suitable design of lifting process is developed and adopted to lift equipment and fittings around site.	Possible delay in testing and safety risk.	4	2	M	Careful spec, HAZOP and safety aspects built into the design and managed through NGN/PM/GL/5/G17 process.		4	1	L
Technical	1a		Selection and purchasing of the correct instrumentation and equipment monitoring and recording of tests i.e. pressure, temperature, gas release and including video recording.	Possible delay in testing programme.	4	1	L	Careful spec, HAZOP and safety aspects built into the design and managed through NGN/PM/GL/5/G17 process.		4	1	L
Technical	1a/b/2		Appropriate number of tests completed to gain enough accurate data.	Devalued deliverable.	4	3	M	MTP developed in association with Project Partners.	Develop MTP prior to project initiation.	2	1	L
Technical	1a/b/2		Suitable type and amount of instrumentation for monitoring the testing.	Lack of instrumentation = lack of data to demonstrate network performance.	4	2	M	Agree appropriate amount of instrumentation from design and third-party review.	Detailed design.	2	1	L

Category	Project Phase	Risk ID	Risk Description	Impact of Risk	Impact (Low to High) 1-5	Likelihood (Unlikely to likely) 1-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Technical	1a/b/2		Variability in quality of test gases used.	Incorrect data collected.	4	1	L	Only use accredited suppliers.	Test gases before use.	3	1	L
Project	1a/b		Adverse weather affects project schedule.	Costs/schedule.	4	2	M	Summer schedule for testing/fixed priced.		2	1	L
Project	1a/b/2		Variation in the cost of hydrogen/materials.	Cost implication.	3	2	M	Fixed price purchasing preferred.	Potential of more than one supplier.	1	1	L
Project	2		Identification and authorisation for suitable field trial locations.	Schedule and costs.	4	2	M	Working with Leeds City Council to find suitable sites.	Close engagement during the Project stage.	1	1	L
Project	2		Poor collaboration on Project.	Project schedule.	4	2	M	Active project management by Programme Director.	Regular interaction on Project at all levels.	1	1	L
Project	1a/b/2		Project delivery slippage.	Impact on Project completion and milestones.	4	2	M	Active project management for all aspects and regular project updates.		2	1	L
Project	1a/b/2		Stakeholders not informed of project delivery.	Impact on Project success.	3	3	M	Active stakeholder engagement, regular Steering Group meetings and stakeholder sessions.	Development of stakeholder engagement strategy.	2	1	L

Appendix G. Cost summary

The table below summarises the total costs for the three-year H21 NIC programme split in line with the organogram presented in Appendix D. For a detailed breakdown of activities see the gantt chart presented in Appendix E.

Work package	Total
Core team	
Project management – core team	£2,298,540
Risk	£176,436
Sub total	**£2,474,976**
Phase 1a – Background testing (Buxton site)	
Project management	£797,340
Site activities	£3,756,825
Risk	£841,733
Sub total	**£5,395,898**
Phase 1b – Consequence testing (Spadeadam)	
Project management	£403,860
Site activities	£2,375,182
Risk	£328,449
Sub total	**£3,107,491**
Analysis and modelling	
Analysis and modelling	£974,632
Risk	£141,856
Sub total	**£1,116,488**
Phase 2 – Field trials	
Project management	£522,000
Site activities	£1,844,415
Risk	£296,979
Sub total	**£2,663,394**
Dissemination of results	
Dissemination of results	£338,600
Risk	£75,220
Sub total	**£413,820**
Total including DNV GL £284,000 contribution	**£15,172,067**
Total excluding DNV GL £284,000 contribution	**£14,888,067**

These costs are associated entirely with delivery of the three-phase testing programme

Test phases	NIC totals	ISP totals
Phase 1a – Background testing sub total	£6,511,113	£7,000,000
Phase 1b – Consequence testing sub total	£3,734,448	£4,000,000
Phase 2 – Field trials sub total	£4,926,506	£4,000,000

Appendix H. Project Partners

H.1. Gas distribution networks

There are eight Gas Distributions Networks (GDNs), each of which covers a separate geographical region of Great Britain. Across England, Scotland and Wales there are over 282,000km of gas pipes supplying over 21.5 million gas customers. These eight networks are and managed the following companies:

- Northern Gas Networks Limited (NGN) – North East England (including Yorkshire and Northern Cumbria).
- Cadent – West Midlands, North West, East of England and North London.
- Wales & West Utilities Limited (WWU) – Wales and South West England.
- SGN – Scotland and Southern England (including South London).

Dan Sadler: H21 Programme Director

A Chartered Engineer with 17 years industry experience. Dan started on British Gas's Graduate Training programme progressing to Project Manager for high pressure gas pipelines and pressure reduction stations. In 2008, he joined Rhead Group, a professional services consultancy, in the role of as Divisional Director for Energy (UK). Dan joined NGN in 2012 as Head of Investment Planning and Major Projects following supporting the network in their RIIO-GD1 regulatory submission.

After undertaking several highly strategic roles within NGN, Dan was seconded throughout 2016 to the UK governments' Department for Business, Energy and Industrial Strategy (BEIS), advising across policy teams on all gas industry and wider energy related topics. Dan was the originator and Project Manager of the high profile H21 Leeds City Gate project. Since returning to NGN in 2017 he has taken up the role of H21 Programme Director.

Damien Hawke: Future Networks Manager

A Chartered Engineer with over 17 years Gas Industry experience. Damien joined Cadent and its predecessor companies as a Graduate Trainee in 2000 and has held numerous positions across the group, specialising in operational and commercial leadership roles and delivering significant change projects. He has a degree in Chemical Engineering from the University of Leeds.

Ian Marshall: Green Gas Development Manager

Ian joined WWU in 2011 as a Graduate Engineer having recently completed a Master's Degree in Mechanical Engineering with a focus on sustainable energy systems at the University of Southampton. After completing his 2-year Graduate Development Programme Ian joined the <7bar Asset Management where he took on responsibility for managing the WWU Shrinkage and Leakage model and the technical standards for gas carrying assets. Ian also has an array of experience as Project Lead on many Network Innovation Allowance funded innovation projects. Recently appointed to the System Operations team as the Green Gas Development Manager Ian is now responsible for promoting and developing the potential to utilise green and non-conventionally sourced gases within the UK. As part of this role Ian has taken up position on the recently formed IGEM Hydrogen and Gas Quality Working group and will be working with industry to address the required changes to allow widespread adoption and deployment of green and non-conventional gasses.

Colin Thompson: Investment Strategy Manager at SGN, based in Edinburgh

In his 27-year career in the gas industry Colin, a Chartered Engineer with the Institution of Gas Engineers and Managers, has experience covering network infrastructure, customer service, industry codes, commercial services and network strategy.

His primary role revolves around the future of the gas network to develop unconventional gas distribution such as biomethane, where SGN have successfully connected over 30 projects. As Chair of the Energy Networks Association Gas Futures Group he works closely with the other gas networks to shape understanding and build acceptance of the role and importance of gas networks in delivering the integrated, affordable, low carbon energy system that the UK economy and consumers need.

DNV GL
DNV GL is an independent organisation with dedicated technical and risk professionals in more than 100 countries. DNV GLs purpose is to safeguard life, property and the environment. Serving a range of industries, with a special focus on oil and gas sectors. DNV GL has undertaken research and development for the UK gas industry for the past forty years, a large part of this expertise came from the British Gas Research and Development business.

DNV GL has a world-wide reputation for understanding and investigating hazards associated with the energy and chemical processing industries and undertaking safety-related product testing. Their knowledge is combined with well-established and validated risk and consequence assessment techniques, to offer consultancy services to customers supporting safe and cost-effective operations for a wide range of potentially hazardous activities that they undertake.

DNV GL's unique Spadeadam Testing and Research centre features some of the world's most advanced destructive and non-destructive test facilities.

Dr Mike Acton
Mike has worked for over 25 years at DNV GL (formerly British Gas Research and Technology and subsequently Advantica) on safety and environmental issues in the oil and gas industry. A strong background in physics, including a doctorate for studies of brittle fracture behaviour, provides a firm foundation for understanding hazard and risk analysis techniques and their application to solve practical problems. He joined British Gas shortly after the Piper Alpha disaster in the UK North Sea, and immediately became involved in ground-breaking work to understand the explosion and fire hazards offshore, and to identify methods of mitigating the risks. He has since been responsible for major experimental programmes to study jet fire hazards for high pressure gas and other fuels and involved in many large-scale experiments to study the hazards associated with high and low pressure underground pipelines, including full-scale experiments in Canada to study gas transmission pipeline ruptures.

Dr Gary Tomlin
Gary is a Chartered Engineer with over 30 years' experience in the gas industry, working in both the natural gas and LPG market sectors. He has expertise in fire and explosion, gas storage, distribution, utilisation, emergency service provision and the investigation of incidents. Gary manages the DNV GL Spadeadam Testing and Research Centre and has been a member of the DNV GL incident investigation team since 2008, having investigated over 100 fatal and non-fatal gas related incidents including fire, explosion, BLEVE and carbon monoxide poisoning. In this role, he has provided expert support in relation to several incidents in both criminal and civil litigation.

Gary started his career with British Gas, working in both utilisation and distribution, before moving to join CORGI, leading a team assessing the competence of registered gas businesses and installers.

Andy Cummings
Andrew has over 31 years' experience in the gas industry and is currently a Principal Consultant with DNV GL. He recently took up a very prestigious role as President of the Institution of Gas Engineers and Manager for 2016-2017. In his role, he is responsible for delivery of high profile gas and engineering consultancy projects to national oil & gas companies. In addition, he has responsibility for business development, technical and commercial proposal writing.

He has recently worked on a high-profile project in Qatar to provide consultancy for the repositioning of the Qatar Petroleum's Health Safety & Environment Directorate to become the HSE Regulatory Authority for the Petroleum Industry in the State of Qatar, this focussed on benchmarking other petroleum regulatory authorities and developed a plan for Qatar to manage major hazards in the petroleum industry.

Health and Safety Laboratories (HSL)
HSL is one of the world's leading providers of workplace health and safety research, training and consultancy, employing staff across a wide range of disciplines. HSL have been developing health and safety solutions for over 100 years and have a long track record in hydrogen experiments both in nuclear applications and the safe use of hydrogen as a new fuel. At their Buxton site they have developed considerable expertise in safely carrying out testing to establish baseline measurements, as is required within this programme of work.

Input into Regulations, Codes and Standards: Over the last 15 years HSL has undertaken and been part of a major experimental and research programme into the hazards and risks associated with retailing hydrogen. Since 2004, through Dr Stuart Hawksworth, HSL have represented the UK on the International Energy Agency Hydrogen Implementing Agreement Safety Task 37. This is a network of hydrogen experts from all over the world whose overall goal is to reduce or eliminate safety-related barriers to the widespread commercial adoption. HSL is also a member of the International Association for Hydrogen Safety (IAHS Hysafe) and was a founding member of the HySafe Network of Excellence in 2004.

Catherine Spriggs
Catherine has over 15 years' experience of working on complex projects in the business, science and construction sectors, varying in value from tens of thousands of pounds to hundreds of millions of pounds. She joined the HSL in 2012 and works in the Major Hazard team managing scientific research projects for commercial clients predominantly in the energy, defence and aerospace sectors.

Phil Hooker:
Phil has spent 25 years in the process industry in various technical roles including process technology, quality and, for the last 10 years, in process hazards. Since joining HSL in 2009 Phil has been involved in hydrogen research including ignition by corona discharges, spontaneous ignition due to releases from pressurised storage, the behaviour of liquid hydrogen spills, and the dispersion, deflagration and jet fire characteristics of hydrogen gas in enclosures. Phil was a contributing author of the HSE Research Report HSE RR1047 on hydrogen addition to natural gas.

Element Energy:
One of the UK's leading low carbon energy consultancies. Through over fifteen years of work in the hydrogen sector, Element Energy has worked with all the major industrial players in the UK's hydrogen sector, led numerous multi-stakeholder assignments gaining a deep understanding of the full spectrum of hydrogen technologies from generation, transport, storage, and use, whilst also building a very extensive global network of stakeholders throughout the hydrogen sector.

Hamish Nichol
Hamish is a Senior Consultant with extensive experience across the hydrogen and gases sector. In all aspects of the commercial management, through to operational management and project engineering. Hamish is an affable professional who creates innovative business from strong relationships supported by deep technical understanding. Since joining Element Energy, Hamish has led the JIVE project which is the largest hydrogen fuel cell bus project to date, set to deploy over 140 hydrogen buses across Europe. This is an EU funded (H2020) project with 23 Partners in nine countries. Additionally, Hamish leads on other hydrogen and specifically gas projects utilising his technical, engineering and commercial experience.

Environmental Resources Management (ERM)
ERM is a leading global provider of environmental, health, safety, risk, social consulting services and sustainability related services.

Kevin Kinsella
Kevin has broad risk and process safety experience in the gas industry (over 30 years) and has carried out major international projects for clients in the UK, Europe and Middle East. He has completed detailed risk assessments and safety cases for both upstream and downstream facilities assisting with both new projects (concept and FEED stage) and operations. Much of this work has involved developing safety cases for completely new, and sometimes novel, facilities working with clients to ensure successful submission to HSE and managing these submissions through the regulatory acceptance process.

Kevin initially worked for British Gas Research and Development Division (Midlands Research Station) and was involved in developing quantitative risk models for gas releases into domestic and commercial premises and gas transmission and distribution pipelines.

Specialist Technical Support

Alastair Rennie – YOEnergy Limited
Review role providing over 38 years' experience of mostly project management of large or new issues, delivered to budget. Since 2000 he has worked on renewable energy options and in 2006 he helped found then led the UK Hydrogen Association and its merger to found the UKHFCA. Concurrently a Director of the CCSA, where he has led on technical issues such as HS&E, and has long advocated 'low cost, low carbon hydrogen'. Alistair was a prime contributor to H21.

Mark Crowther: Kiwa
Mark has 35 years' experience in the energy sector and has a wide knowledge of energy use (biomass, gas, oil and coal) from industrial to domestic scales of operation.

Mark spends around 50% of his time on commercial consultancy work as Technical Director of Kiwa Ltd with particular interest in the validation of carbon emission reduction by improved energy efficiency and the use of novel technologies.

Mark is particularly enthusiastic to use hydrogen as a low carbon vector in the heating, transport and process industries and led the Hyhouse project where substantial volumes of hydrogen and natural gas were released into a two storey Scottish farm house.

He has lectured to DECC (including the late Prof McKay) and provided technical support to major pieces of work by the Climate Change Committee, DECC, and KPMG (for the IEA).

Appendix I. Stakeholder engagement

#	Description	Location	Dates
A	Department for Business Energy and industrial Strategy – Various departments but the main interfaces included		
1	Science team	London	2016
2	Heat Policy team	London	2016
3	Carbon Capture and Storage team	London	2016
4	Shale Gas team	London	2016
5	Home Energy team	London	2016
6	Industrial Heat team	London	2016
7	DECC School – Designed and presented a DECC School to internal DECC colleagues	London	Mar-16
B	Ofgem		
1	Futures team	London	2016
2	Innovation team	London	2016
3	Key conferences	London	2016
C	Conferences/round tables/other key meetings		
1	Fleishmann Hillard (Chris Davis) – Round table based on H21, included members of the European Commission, and gas networks from across Europe (Poland/Ireland), Hydrogen Europe (Jorgo Chatzimarkakis), IPHE (Tim Karlson), Eurogas (Tim Cayton) etc.	Brussels	Aug-16
2	H2FC Conference (European Commission Building) – Dan Sadler was part of a panel session on city based innovations	Brussels	Nov-16
3	ZEP (Zero Energy Panel) – Carbon Capture and storage (Luke Warren) – Dan Sadler presented and took questions in a 1.5-hour window (with leaders from across the 10 large producers (Shell, Total, BP, Statoil, etc.) and various other stakeholders	Brussels	Jul-16
4	ZEP – Green hydrogen – Dialled into various meetings and supplied support and information for their recommendations document	Brussels	Aug-16
5	Meeting with the Marie Donnelly – Director General, Energy at the European Commission. 3-hour private meeting to discuss H21.	Brussels	Aug-16
6	Meeting with Sir Mark Walport and his Chief Scientific Advisor – presentation to Sir Mark and eight of his CSAs at his Brown Bag Breakfast meeting to brief them on H21	London	Sep-16
7	Tees Valley Collective – various meetings throughout 2016 to keep them updated on H21 and how to influence government policy	Tees Valley	2016
8	Leeds City Council – various meetings throughout 2016 to keep them updated on H21 and how to influence government policy	Leeds/London	2016

ofgem RIIO NIC NETWORK INNOVATION COMPETITION

#	Description	Location	Dates
9	Lord Oxburgh's Parliamentary Review on CCS (including Lord Oxburgh, Chris Davis, Ian Temperton) – Dan Sadler met with Lord Oxburgh three times at the House of Lords and his wider team, this led to a significant change to his final document incorporating the H21 work and recommending the Heat Transformation Group	London	April/ May/ June
10	BEIS – Carbon Capture and Storage Conference – presentation on H21	London	Jun-16
11	IChemE – Conference on Energy – presentation on energy position and H21	London	Oct-16
12	Sky News Australia interview – See NGN website	London Studio	Feb-17
13	H21 Launch Event – over 225 people attended	London	Jul-16
14	All Energy Conference – Presented on H21	Glasgow	May-16
15	SHFCA Conference – Presented on H21	St Andrews	Aug-16
16	Scottish Government – round table – presented on hydrogen options for Scotland (led workshop) and presented separately on H21	Edinburgh	Dec-16
17	Innogy Telecon – Innogy own gas networks in Czech Republic and Germany – telecon to advise on H21	Leeds T-Con	Jan-17
18	Unison – meeting with Senior Policy Officer (Matt Leyland) to discuss H21 and job impact	London	Oct-16
19	Statoil – Various meeting with Senior Team at their London office, this has led to the 'H21-alternative hydrogen production and network storage options NIA project'	London	Sept to Dec 16
20	The Royal Society – Hydrogen Embrittlement Conference – keynote presentation on H21	London	Jan-17
21	Northern Powerhouse Conference	Manchester	Feb-22
22	Oxford University – Energy Colloquium – presentation on H21	Oxford	Jan-17
23	Synergy – round table – presentation on H21	London	Jan-17
24	Global Council (Geoffrey Norris) – round table event	London	Jan-17
25	IPPR North (Darren Baxter) meeting at BIES in December 2016 then in January 2017 in Manchester to advise on their report	London/Manchester	Jan-17
26	IGEM – Hydrogen Conference – Presentation on H21	Kegworth	Feb-17
27	APPG CSS (Luke Warren) – presentation on H21	London	Feb-17
28	DoT/OLEV presentation on H21 to all Senior team	London	Dec-16
29	DoT (Leo Dando Ledenis) – Tees Valley – meeting on Tees Valley opportunity	Leeds	Feb-17
30	IET Hydrogen Workshop looking at barriers to hydrogen deployment	London	Feb-17
31	UKOPA – H21 presentation	Leeds	Feb-17

#	Description	Location	Dates
32	Worcester Bosch exploration day – a day at WB factory to discuss the opportunity for hydrogen appliances with the Senior team	Worcester	Feb-17
33	Leeds Council – H21 briefing to elected Councillors	Leeds	Mar-17
34	Association of Meter Operators – H21 presentation	Kenilworth	Mar-17
35	HHIC (Steve Sutton) – briefing to top 10 boiler manufacturers CEOs on H21	Kenilworth	Mar-17
36	Carbon Connect – various meeting to advise and inform on latest publication	London x3	Aug 16 to Mar 17
37	H2 Supergen Conference (Nigel Brandon) – presentation on H21, Dan Sadler is also on the H2 Supergen Advisor Board	Belfast	Oct-16
38	ESC/ETI – presentation and Q&A on H21	Birmingham	Oct-16
39	APPG for Energy Studies (Ian Liddle-Granger MP)	London	Feb-17
40	Committee on Climate Change – part of the Advisory Board for their reports in 2016	London	2016
41	Innovate UK (Harsh Prashad) – part of the Advisory Board for the Hydrogen Roadmap work	London	2016
42	UCL – part of Advisory Board for the HYVE Project	London	2016
43	Imperial College – part of Advisory Board on 3rd white paper with the Sustainable Gas Institutes (Nigel Brandon)	London	2016
44	Leeds University (David Glew) – Energy Colloquium meeting – presentation on H21	Leeds	Feb-17
45	West Yorkshire Combined Authorities – Civil Hall meeting with elected Councillors to discussion H21	Leeds	Mar-09
46	National Infrastructure Commission Update on H21	London/Leeds	March/April 17
47	As part of the preparations for this bid, DNV GL delivered a technical seminar at their Spadeadam Testing and Research site entitled 'Developing and Operating a Safe Hydrogen Network' in April 2017 that was attended free of charge by over eighty people from industry and academia. This included a keynote on H21 and talks from two other leading industry players, interspersed with full scale demonstrations	Spadeadam	Apr-17
48	EUA/Network Engineering & Equipment Group (NEEG) Meeting	Sheffield (ITM)	Apr-17
49	Meeting with Green Alliance to present H21	London	Apr-17
50	Welsh Assembly – Hydrogen Reference Group. Presentation on H21 at a day workshop with multiple stakeholders	Swansea	Apr-17
51	Cheung Kong Group Technology Conference 2017 – including H21 presentation to all CKI group companies covering a global community	Hong Kong	May-17

#	Description	Location	Dates
	including Australia, Europe, Canada, Hong Kong, South Africa and New Zealand		
52	Hong Kong and China Gas – A lunch meeting with the Hong Kong and China gas board to brief them on the H21 projects and its applicability in the China context	Hong Kong	May-17
53	Cleveland Institute of Engineers – lecture at Teesside University to a range of stakeholders	Teesside	May-17
54	Frontier Economics – BEIS project event – advising on regulatory and market barriers to hydrogen conversion	London	May-17
55	Trondheim Carbon Capture and Storage conference – keynote speaker H21	Norway, Trondheim	Jun-17
56	H21 Presentation to Eurogas Steering Committee	Brussels	Jun-17
57	H21 Presentation to GERG Steering Committee	Brussels	Jun-17
58	Support to BEIS on BEIS Supplier Day (launch of their £25m Downstream of the meter programme. This included presenting on the H21 NIC bid and taking questions on the BEIS programme (as part of D Sadler's former seconded BEIS role helping to design the programme)	London	Jun-17
59	NEPIC Conference – Keynote speaker – H21	Teesside	Jun-17
60	Australia two-week trip including 25 presentations in eight days to a range of stakeholders including regulators, safety committees, gas network operators, local and national governments, etc.	Australia (Adelaide, Melbourne, Perth	Jul-17
61	7th World Hydrogen Conference – keynote speaker H21	Prague	Jul-17
62	Westminster Energy, Environment & Transport Forum Keynote Seminar: Assessing the future of heating and cooling policy: priorities for decarbonisation, innovation and efficiency – H21 presentation	London	Jul-17

ofgem

RIIO NIC
NETWORK INNOVATION COMPETITION

Appendix J. Letters of Support

LEEDS CITY REGION ENTERPRISE PARTNERSHIP

TEES VALLEY COMBINED AUTHORITY

Rt Hon. Greg Clark MP Secretary of State
Department for Business, Energy & Industrial Strategy

Rt Hon. Sajid Javid MP Secretary of Sate
Department for Communities and Local Government

Dear Secretaries of State,

Firstly we would like to congratulate you on your recent appointments to Cabinet as Secretary of State for the Departments of Business, Energy & Industrial Strategy and Communities and Local Government.

As a group of Leaders of Councils and Local Enterprise Partnership's in the Leeds City Region and Tees Valley, we would like to take the opportunity to draw your attention to a new joint project between the LEPs and the energy industry, which has the potential to transform northern industry and provide an effective solution to the country's challenge to decarbonise heat.

The H-21 project, launched by Northern Gas Networks and DECC's Chief Scientific Advisor in July, demonstrated the technical and commercial feasibility of a bold new vision for converting the gas network in the UK's major cities to hydrogen, starting with the build out of hydrogen production facilities in the North East and conversion of the City of Leeds. Delivery of this vision would cut carbon emissions associated with heat by 80% and independent research by the Energy Networks Association has demonstrated that this solution would represent a £214bn saving compared to electrifying heat supply to UK homes and business.

We believe that, as well as providing a solution to the country's challenges of energy supply, value for money and decarbonisation, the project would act as a cornerstone investment for the growth of industry and manufacturing in the North. Delivery of the project would provide the infrastructure required to decarbonise industry in Yorkshire and the North East, safeguarding jobs and developing a sector fit for the future. The new hydrogen production facilities required would build on the extensive energy and hydrogen production sectors across the region, opening the sector up to new entrants, providing jobs and boosting the commercial case for investment in low carbon technologies such as energy from waste and biogas. The expertise and infrastructure for chemical production would be ideally placed to develop new products and materials utilising carbon arising from the hydrogen conversion process. Finally, as the first place in the world to have hydrogen 'on tap' Yorkshire and the North East would offer a truly unique proposition to business locally and across the globe developing the next generation of hydrogen cars, trains, and appliances. With the largest manufacturing sector in the UK and our academic institutions already leading the world in energy research and development, we believe our offer would be unparalleled.

As you begin to form your strategies for energy, industry and local government in the north we would value the opportunity to discuss with you the part that H-21 can play in the future growth of the UK. We look forward to meeting you when your busy diaries will allow.

Yours sincerely

Cllr Judith Blake Leader, Leeds City Council	Roger Marsh Chair, Leeds City Region LEP	Cllr David Budd Chair, Tees Valley Combined Authority	Paul Booth Chair, Tees Valley LEP

Leeds City Region Enterprise Partnership
1st Floor West, Wellington House, 40-50 Wellington Street, Leeds LS1 2DE
Tel: 0113 348 1818

Leeds CITY COUNCIL

Councillor Lucinda Yeadon Deputy Leader of Leeds City Council and Executive Member of Environment and Sustainability
Leeds Civic Hall Leeds
LS1 1UR

Civic Tel 0113 247 4708
Civic Fax 0113 247 4046

lucinda.yeadon@leeds.gov.uk

Nick Hurd MP
Minister of State for Climate Change and Industry
1 Victoria Street London
SW1H 0ET

15th December 2016

Dear Nick

It was good to meet you at the Clean Energy & Cities Ministerial Roundtable on 29 November.

As was mentioned, Leeds and Teeside are actively supporting the Northern Gas Network H21 proposal to convert the existing natural gas network in Leeds to hydrogen. The main alternative at present is to switch heating to electric heating which would require a quadrupling of electricity generation capacity and would leave the national gas network as a stranded asset. Supporting Northern Gas Networks' plans to convert existing gas pipes to hydrogen could reduce carbon emissions from the region by over 11% by 2030. Without an intervention of this size, it is difficult to see how the government can remain on track to deliver against the Climate Change Act to reduce carbon by 80% by 2050.

The economic rationale for the H21 Enabling Roadmap has been reviewed by the Regional Economic Intelligence Unit (REIU) at Leeds City Region. The headlines are as follows:

- The economic value of the jobs created or supported directly would be around £7 million annually (based on a 5 year time line between 2017-2021).
- Over the 5 years of the project this would have a life time economic value of £35 million (this is a constant price estimate based on 2011 prices).
- There is economic growth potential for other hydrogen suppliers linked to the network in the future.
- The project relies on carbon capture and storage for which economic uses for waste carbon could be found in the future.
- There would be new market opportunities for a new generation of household and industrial gas appliances and all of the associated supply chain benefits in manufacturing, retail and installation.
- Hydrogen fuelled vehicles are another potential growth area with significant environmental benefits in terms of air quality and for which there is a global market.

Leeds and Teeside are liaising closely on this matter and feel that a positive Government response to this proposal would be enhanced by actively including local stakeholders at an early stage in any decisions. This would add value, for example, by demonstrating that local stakeholders are supportive and moreover that other sources of funding (such as City Deal, Devolution and Local Growth Fund being identified in Teeside, potential for ERDF in Leeds and sources of research funding being pursued through University of Leeds) could be levered in. We are actively establishing a consortium of local partners to be based in Leeds, ready to respond to other sources of funding and also to lead the implementation of the H21 Roadmap.

Representatives from both regions wrote to the relevant Government departments in August 2016 (see attached letter), but have yet to receive a comprehensive response and I would be grateful for any assistance you can provide to secure this.

I am aware that the Energising the North report is due to be launched at Portcullis House in London on 17th January with likely attendance by the Andrew Percy (Minister for Northern Powerhouse) and Greg Clark (Secretary of State for Business, Energy and Industrial Strategy). I would be grateful to have a meeting with you in the New Year to discuss this report.

I look forward to hearing from you.

Yours sincerely

Councillor Lucinda Yeadon

www.leeds.gov.uk switchboard : 0113 222 4444

WEST YORKSHIRE COMBINED AUTHORITY

West Yorkshire Combined Authority
Leeds City Region Enterprise Partnership
1st Floor West
Wellington House
40-50 Wellington Street
Leeds LS1 2DE

7th June 2017

Dear Dan Sadler,

WYCA SUPPORT FOR H21 NIC BID

I am writing to you in my capacity as Head of Economic Policy for the West Yorkshire Combined Authority (WYCA). WYCA brings together the public and business sectors of the Leeds City Region into one collaborative partnership and with the joint vision of achieving good growth in the City Region.

Our Strategic Economic Plan (SEP) sets out our ambitions for the City Region and how they will be achieved. A key ambition set out in the SEP is for a resilient, zero carbon energy economy.

The City Region is already collaborating with the Northern Gas Network (NGN), Leeds City Council and Tees Valley Local Economic Partnership to explore NGN's exciting H21 Leeds City Gate project. There is wide spread political backing for this project and we are excited about its potential to not only contribute significantly to ensuring long term energy affordability, but to our local, and indeed the national carbon emission reduction targets and also the potential transformational impacts on the economy in terms of job creation, growth and innovation. We hope to establish the first commercial hydrogen economy in the world and place our region on the map, making it the first port of call globally for hydrogen technologies /region of excellence.

The objective of the H21 Network Innovation Competition (NIC) bid is to provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the UK gas distribution network. Specifically, that the pipes and equipment will be as safe operating on either 100% hydrogen or natural gas. This could ultimately support policy decisions for a UK hydrogen conversion with potential to save £100bns versus alternative solutions. The H21 NIC project will provide comprehensive, quantified evidence across the range assets within a three-year timeframe 2018 to 2020.

We understand that there will be a requirement in phase 2 of the H21 NIC project to undertake field trials on a 'real' section of the network that has been previously isolated from customers. We also agree that this stage of the project will be vital to confirm the results of phase 1A (background testing) and phase 1B (consequence testing) providing all stakeholders with the assurance that results obtained in controlled environments can be effectively modelled and used to predict outcomes in a real world setting. The field trial is likely to be carried out on a currently 'derelict/demolished' brownfield piece of land with good retained gas network assets still in place, and no plans for development until 2020 onwards.

WYCA recognises the importance of the H21 NIC bid and specifically the field trails and will support the H21 NIC team to work through existing regional planning channels to identify potentially suitable sites on which to undertake this important work.

Kind regards,

D.Walmsley

DAVID WALMSLEY
Head of Economic Policy, West Yorkshire Combined Authority

ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Y Gyfarwyddiaeth Cymunedau
Cyngor Bwrdeistref Sirol Pen-y-bont ar Ogwr
Swyddfeydd Dinesig
Stryd yr Angel
PEN-Y-BONT AR OGWR
CF31 4WB

Ffôn: 01656 643643
Ffacs: 01656 668249

Gwefan: www.bridgend.gov.uk

Cyngor Bwrdeistref Sirol Pen-y-bont ar Ogwr
BRIDGEND County Borough Council

Communities Directorate
Bridgend County Borough Council
Civic Offices
Angel Street
BRIDGEND
CF31 4WB

Telephone: 01656 643643
Fax: 01656 668249

Website: www.bridgend.gov.uk

Direct line / *Deialu Uniongyrchol:* 01656 643179
Ask for / *Gofynnwch am* : Mike Jenkins
Our Ref / *Ein cyf:*
Your Ref / *Ein cyf:*
Date / *Dyddiad:* 21st June 2017

Dan Sadler
Programme Director, H21
St George House
40 Great George Street
Leeds LS1 3DL

Dear Dan,

I am writing to confirm the strong support of Bridgend County Borough Council for the H21 Leeds City Gate project. We believe that the H21 Leeds City Gate Project has demonstrated an innovative approach to support decarbonisation of the UK economy at least cost to energy consumers an could play a role in our County Borough wide decarbonisation plans.

The UK, as with most other countries around the world, recognises the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of their level in 1990. Climate change is one of the most significant technical, economic, social and business challenges facing the world today. Following the completion of the H21 Leeds City Gate project there has been growing interest in the opportunity to decarbonise the gas network by converting to 100% hydrogen, a solution that appears to be technically and economically viable.

The objective of the H21 Network innovation Competition (NIC) bid is to provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. Specifically that the pipes and equipment will be as safe operating on either 100% hydrogen or natural gas. This could ultimately support policy decisions for a UK hydrogen conversion with potential to save £100bns to the UK vs alternative decarbonisation strategies. The H21 NIC project will provide comprehensive, quantified evidence across the range of below seven bar assets within a three year timeframe 2018 to 2020. We believe this project is a critical step to realising the potential for hydrogen reuse of the gas network.

Do not hesitate to get in touch if you require anything further.

Yours sincerely

M.P. Jenkins

Michael Jenkins
Team Leader Sustainable Development

Corporate Director – Communities
Cyfarwyddwr Corfforaethol – Cymunedau
Mark Shephard

---

green alliance...

25 May 2017

To whom it may concern

Supporting hydrogen for decarbonised heat pilots

Green Alliance believes that the next big challenge in meeting the fifth carbon budget is heat. The Government's is making good progress on electricity, by phasing out unabated coal plants by 2025 and building renewables, but electricity still represents only a fifth of the UK's final energy consumption with heating and transport constituting the rest.

Unlike in electricity and transport, where clean options are increasingly operating in the market, very low carbon heat solutions need to be tested. We believe the UK needs to trial specific technologies to understand their real world implications, potential routes to market, and customer acceptability, to discover a least cost pathway for decarbonisation.

Hydrogen heat is one potential solution. The attractiveness of being able to repurpose the existing gas grid, use gas or hydrogen to store large quantities of energy for use during the winter, and the technical robustness of both carbon capture and storage (CCS) and steam methane reformation suggest it merits support for a large scale trial.

The H2 Leeds city gate project provides an advanced blueprint of how hydrogen could decarbonise heating in Leeds. Supporting this as a pilot to test hydrogen's technical and socioeconomic outcomes could provide a potential breakthrough in tackling the heat sector. We think a smart trial should include significant building efficiency measures, so that consumer bills for hydrogen heat can stay relatively flat, compared to natural gas. We have seen estimates that suggest heat demand will need to be cut by 30% - a readily achievable goal for most buildings.

Yours faithfully,

Dustin Benton

Acting policy director
dbenton@green-alliance.org.uk
020 7630 4522

Disclaimer – Green Alliance does not hold any relationship, fiscal or otherwise, with the project proponents of the Leeds city gate and neither have we assessed the outcomes claimed by the project. But we strongly believe it to be amongst the few proposals that have the potential to move to a demonstration stage.

UKHFCA

Dan Sadler
Programme Director (H21)
St George House
40 Great George Street
Leeds
LS1 3DL

UK Hydrogen and Fuel Cell Association
108 Lexden Road
West Bergholt
Colchester
Essex
CO6 3BW

Tel: +44 (0) 1206 241360
Email: c.greaves@synnogy.co.uk

7th June 2017

H21 Network innovation Competition (NIC) bid

Dear Dan

We are writing in regard to the H21 Network Innovation Competition bid which, we understand, seeks to *"provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. Specifically that the pipes and equipment will be as safe operating on either 100% hydrogen or natural gas. This could ultimately support policy decisions for a UK hydrogen conversion with potential to save £100bns vs alternative decarbonisation strategies. The H21 NIC project will provide comprehensive, quantified evidence across the range of below seven bar assets within a three year timeframe 2018 to 2020".*

The UK Hydrogen and Fuel Cell Association (UK HFCA) works to ensure that fuel cell and hydrogen energy can realise the many benefits offered across economic growth, energy security, carbon reduction and beyond. Through the breadth, expertise and diversity of our membership, we work to trigger the policy changes required for the UK to fully deliver the opportunities offered by these clean energy solutions and associated elements of the supply chain.

We have a particular focus on ensuring that the role for hydrogen and fuel cells across the whole energy system is optimised, recognising and building on synergies across heat, transport, power and beyond. A robust evidence base is critical to delivering progress in this regard, and to facilitating the development of appropriate policy frameworks. Accordingly, we are supportive of projects and initiatives which contribute to the evidence base, and would be delighted to see this bid succeed.

Best regards

Celia Greaves, Executive Officer, UK Hydrogen and Fuel Cell Association
on behalf of Amanda Lyne, Chair of the UK Hydrogen and Fuel Cell Association

UK Hydrogen and Fuel Cell Association
Registered in England No 5806226; VAT No.:886387949
Registered Office: 108 Lexden Road, West Bergholt, Colchester, CO6 3BW

ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Scottish Hydrogen & Fuel Cell Association

H21 Programme Director
H21 Project Office
St George House
40 Great George Street
Leeds
LS1 3DL

9th June 2017

Letter of Support from the Scottish Hydrogen and Fuel Cell Association

for the H21 proposal to Gas Network Innovation Competition

Dear Dan

The Scottish Hydrogen & Fuel Cell Association (SHFCA) confirms its support for the proposed project to build directly on the work undertaken as part of the 'H21 Leeds City Gate' (H21 LCG) NIA project.

This project will be led by Northern Gas Networks and includes Scotia Gas Networks, a SHFCA member, as one of the consortium partners.

The objective for this further work is to provide compelling safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. It will determine if the pipes and equipment in use by 2032, following completion of the REPEX programme, will be as safe operating on either 100% hydrogen or natural gas. The project will provide comprehensive, quantified evidence across the range of below 7 bar assets. and will be carried out within a three year time frame between 2018 and 2020.

This is a critical programme of work which will inform key policy decisions for a UK hydrogen conversion, for the wider roll-out of hydrogen as a low carbon heat vector. This approach could offer very significant cost savings as compared to alternative decarbonisation strategies, with the potential to offer a solution which is also much less disruptive for many UK consumers.

The UK has committed to substantial carbon savings; heat contributes to a third of its current emissions. Delivering low-carbon heat via a 100% hydrogen conversion appears to be a technically credible, lower cost, large scale decarbonisation solution than alternatives. However, there is a critical safety based evidence gap which must be quantified by the UK gas industry to progress the option.

The proposed project will provide a comprehensive testing, measurement and quantified risk assessment which will be undertaken across a strategically selected range of below 7 bar gas network assets. These tests will be split into three phases including background testing, consequence testing and field testing.

The move towards low carbon solutions for our energy supply is one of the most important aims for our society, and this will require practical solutions for low carbon heat, combined with suitable energy storage at large scale to meet seasonal heat demand if we are to achieve the substantial decarbonisation of our energy systems by 2050. With the ongoing challenges of meeting carbon reduction targets SHFCA believes that the proposed project could potentially underpin the large scale deployment of hydrogen for low carbon heat.

SHFCA promotes and develops expertise in fuel cells and hydrogen technologies, and supports the development of businesses and markets in this sector through regular events and activities, bringing together the expertise and experience of specialised fuel cell companies, systems integrators, power generation companies, and energy consultants to identify key market opportunities. We also work closely with academic institutions, development agencies, and Local Authorities and have particular interests in the area of 'integrated energy systems, and the opportunity for hydrogen to be deployed as a 'clean energy vector' that can bridge between power, heat, and transport energy networks.

SHFCA would also like to offer our assistance with knowledge transfer and dissemination activities for key findings, for example through any joint workshop events or facilitating access to industry and other stakeholders where this would be of help.

I look forward to close working between SHFCA and your project team, and wish you all success with your proposal.

Yours sincerely,

Nigel Holmes

Chief Executive, Scottish Hydrogen and Fuel Cell Association

Scottish Hydrogen & Fuel Cell Association Limited Energy Technology Centre
Rankine Avenue
Scottish Enterprise Technology Park
East Kilbride G75 0QF
Tel: 01355 593570
Fax: 01355 593580
Website: www.shfca.org.uk

CCSa
Carbon Capture & Storage Association

6th Floor
10 Dean Farrar Street
London SW1H 0DX

t +44 (0)20 3031 8750
f +44 (0)20 7222 4253
e info@ccsassociation.org
www.ccsassociation.org

7th June 2017

Dan Sadler
Programme Director, H21
St George House
40 Great George Street
Leeds LS1 3DL

Dear Dan,

I am writing to confirm the strong support of the Carbon Capture and Storage Association (CCSA) for the H21 Leeds City Gate project. The CCSA believes that the H21 Leeds City Gate Project has demonstrated an innovative approach to support decarbonise of the UK economy at least cost to energy consumers.

The UK, as with most other countries around the world, recognises the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of their level in 1990. Climate change is one of the most significant technical, economic, social and business challenges facing the world today. Following the completion of the H21 Leeds City Gate project there has been growing interest in the opportunity to decarbonise the gas network by converting to 100% hydrogen, a solution that appears to be technically and economically viable. All the technology to convert the UK gas distribution network to hydrogen can be evidenced across the world today (steam methane reformers, salt caverns, hydrogen appliances). However, the primary obstacle to progressing with such a decarbonisation pathway is the lack of quantitative safety evidence.

The objective of the H21 Network innovation Competition (NIC) bid is to provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. Specifically that the pipes and equipment will be as safe operating on either 100% hydrogen or natural gas. This could ultimately support policy decisions for a UK hydrogen conversion with potential to save £100bns to the UK vs alternative decarbonisation strategies. The H21 NIC project will provide comprehensive, quantified evidence across the range of below seven bar assets within a three year timeframe 2018 to 2020. We believe this project is a critical step to realising the potential for hydrogen reuse of the gas network.

Do not hesitate to get in touch if you require any further support from the CCSA.

Yours sincerely

Luke Warren
Chief Executive

President: Lord Oxburgh KBE
Registered in London
Company number [illegible]

Energy Networks Australia

14 July 2017

Letter of support

NGN-H21 Network Innovation Competition Bid

To Whom It May Concern

Energy Networks Australia is the national industry association representing the businesses operating Australia's electricity transmission and distribution and gas distribution networks. Member businesses provide energy to almost every household and business in Australia.

On behalf of the gas industry, we recently produced *Gas Vision 2050*, which demonstrates a plausible pathway to decarbonise the Australian gas sector by 2050. It relies on three transformational technologies: biogas, carbon capture and storage and hydrogen, which are all technically proven but need to be widely deployed. This vision is supported by the gas industry.

Following the launch of the vision in March 2017, we organised a conference to explore progress being made to achieve this vision. Dan Sadler – from the H21 Leeds city gate project - was the international keynote speaker at our conference. His presentation was well received and many of the speakers have expressed interest to follow up and collaborate with the H21 project.

Australia's gas distribution businesses are actively engaged in demonstrating decarbonisation of gas. Australian industry-led activities include:

- Energy Networks Australia has funded a study by the Energy Pipelines CRC to identify the technical and regulatory issues for injecting hydrogen and renewable gases into distribution and transmission networks.
- Australian Gas Networks is piloting an advanced electrolyser technique to produce hydrogen and to inject this hydrogen into the gas distribution network.
- Jemena is proposing a pilot project for producing hydrogen through electrolysis and injecting it into the distribution network as well as using it for vehicles.
- ActewAGL is developing a biogas project that aims to convert organic waste streams to biogas in an anaerobic digestor and to inject the produced gas into the ACT's gas distribution network.
- The Australian Standard *AS/NZS4645 – Gas Distribution Networks* has been reviewed and updated this year. One of the conclusions from this review is that there is a lack of quantitative and scientific knowledge to support the introduction of new fuels into the networks, such as hydrogen. The proposed NIC bid also notes this lack of quantitative data and aims to provide quantitative data for the safety case of hydrogen in distribution networks.

Energy Networks Australia www.energynetworks.com.au
Unit 4, 110 Giles St, Kingston ACT 2604 P: +61 6272 1555 E: info@energynetworks.com.au
Energy Networks Association T/A Energy Networks Australia
ABN: 75 106 735 406

1

Interest in hydrogen extends beyond the gas industry. Australian governments are actively involved in pursuing options for hydrogen.

- In South Australia, the government has announced $9 million of funding towards its hydrogen roadmap in June 2017 and this will involve producing hydrogen from renewable energy and using it in a demonstration in the Adelaide bus fleet.
- The ACT Government is also progressing a hydrogen project as part of its renewable energy strategy. The pilot involves up to 20 vehicles that will be purchased by the ACT government and fuelled by hydrogen produced from renewable energy.
- The Victorian government and Kawasaki Heavy Industries are investigating options of using Victoria's brown coal asset base to produce hydrogen and export that to Japan to power its vehicle fleet.

There is a close linkage between the work being carried out in Australia and that being completed in the UK. While there is a prime facie case for hydrogen to play a critical role as part of complementary energy systems during decarbonisation, there are a range of technical and commercial issues that need to be further evaluated.

To this end, the Gas Committee of Energy Networks Australia is supporting a proposal for a new Future Fuels Cooperative Research Centre. A proposal was submitted to Government on 12 July 2017 for a new collaborative research centre focussing on future fuels, such as hydrogen, biogas and syngas. The intention is for this centre to run for 7 years with approximately $80 million of funding provided by industry, government and research organisations. The Centre will support the Australian pilot and demonstration projects and create even stronger collaboration opportunities with UK initiatives, such as the H21 Leeds project.

Energy Networks Australia supports the bid by Northern Gas Networks - H21 to 'provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network'. The timing of this proposed project creates excellent opportunities for collaboration with the Australian R&D and demonstration projects.

If you have any questions or require any assistance, please do not hesitate to contact Dr Dennis Van Puyvelde, Director - Gas on dvanpuyvelde@energynetworks.com.au or +61 (0)2 6272 1548.

Yours sincerely,

JOHN BRADLEY
Chief Executive Officer

2

GERG

the european gas research group
INNOVATION FOR EUROPE'S ENERGY FUTURE

The European Gas Research Group Avenue
Palmerston, 4
Brussels 1000 Belgium
Telephone: +32 475 80 29 22 www.gerg.eu

20th June 2017

H21 Programme Director H21 Project Office
St George House
40 Great George Street Leeds
LS1 3DL

H21 Application to the Network Innovation Competition: letter of support

GERG, the European Gas Research Group, is a research and development organisation that provides both support and stimulus for the technological innovation necessary to ensure that the European gas industry can rise to meet the technological challenges of the new century. It was founded to strengthen the gas industry within the European Community and it achieves this by promoting research and technological innovation.

Established as a network to enable exchange of information between a select group of specialist R&D centres to avoid duplication of effort, it has grown steadily to around 30 members whilst retaining and expanding its original aims. Its priorities are networking, technical information exchange, and the promotion and facilitation of collaborative R&D.

We recognise that the UK has committed to challenging low-carbon targets, and that heat contributes to a third of its current emissions. The UK has world class gas networks with enormous potential for future adaptation and energy storage provision. Adaptation of this grid to allow the injection of hydrogen provides a customer focused solution to the decarbonisation of low carbon heat. Delivering low carbon heat via a 100% hydrogen conversion appears to be a technically credible, lower cost, large scale decarbonisation solution than alternatives, with the potential to offer a solution which is a so much less disruptive for many UK consumers. However, there is a safety based evidence gap which must be quantified by the UK gas industry to progress the option. The proposed H21 NIC project provides a critical step to informing key policy decisions for a UK hydrogen conversion, and for the wider roll-out of hydrogen as a low carbon heat vector.

The objective for this further work is to provide compelling safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. It will determine if the pipes and equipment in use by 2032, following completion of the REPEX programme, will be as safe operating on either 100% hydrogen or natural gas. The project will provide comprehensive, quantified evidence across the range of below 7 bar assets, and will be carried out within a three year time frame between 2018 and 2020.

This is a project we are particularly interested because GERG and its European member companies have been leading a number of important initiatives which establish road maps for introduction of hydrogen into our natural gas networks. Projects include HIPS (hydrogen in pipeline systems), HIPS NET, and the European Power to Gas Platform. We work closely with policy makers at European level to ensure that the potential for the use of existing gas networks in providing a vital route to a decarbonized future energy system is recognized, and that appropriate Innovation actions are initiated to enable this set of future options. The H21 concept is already attracting major interest at a European level. The proposed H21 NIC project will make an enormous advance on the current state of international knowledge in this area, is very much a first of its kind, and will help to inform and steer future policy decisions on the direction of the future UK and European energy system.

GERG is prepared to participate on an advisory panel to ensure that key stakeholder views represented by our members are present in the delivery of the programme and its outcomes, and also to provide resources and facilities to disseminate and promote this project at the European level.

GERG is therefore glad to express its support to the bid by NGN and look forward to contributing to the programme of work.

Yours Sincerely,

Robert Judd
Secretary General, GERG

Australian Gas Networks

Australian Gas Networks Limited
L6, 400 King William Street
Adelaide, SA 5000 Australia
PO Box 6468, Halifax Street,
SA 5000 Australia
+61 8 8227 1500
info@australiangasnetworks.com.au
australiangasnetworks.com.au

Wednesday, 12 July 2017

To Whom It May Concern,

Australian Gas Networks Limited (AGN) is one of Australia's leading gas infrastructure businesses. AGN, together with its sister companies Dampier to Bunbury Pipeline and Multinet Gas, own approximately 3,500 kilometres of transmission pipeline and 34,000 kilometres of natural gas distribution networks which serve approximately 2 million customers. We are active across the country with assets in Victoria, South Australia, Western Australia, Queensland, New South Wales and the Northern Territory.

Like many businesses in Australia and around the world, we are currently focussed on exploring ways to minimise our carbon footprint. Natural gas as an end user fuel is currently a relatively low carbon choice, with a carbon dioxide contribution of around a quarter of Australian mains electricity.[1] However, we are interested to explore opportunities to further reduce the carbon intensity of our network, and accordingly are particularly interested in any technology that would allow a low-emission gas source to be distributed via our natural gas network.

Work on this concept is already underway in Australia. For example, in March 2017 the gas industry released *Gas Vision 2050* which details the decarbonisation journey of gas over time, outlining the use of low-emission fuels such as hydrogen and biogas.[2] Separately, individual businesses are also pursuing pilot plants such as AGN's pilot hydrogen production facility which will use excess renewable electricity to electrolyse water, with the small volumes of hydrogen produced from this process injected into our network.

Whilst work on gas network decarbonisation is underway in Australia, it is at a much earlier stage than that underway in the United Kingdom and to this extent, AGN and the wider Australian energy industry closely follows the leading work being carried out in the United Kingdom.

By way of example of the level of interest in Australia, in late June Dan Sadler from Northern Gas Networks was the key note speaker at Energy Networks Australia's 2017 Gas Seminar (speaking about the Leeds H21 project). As part of Dan's Australian trip, AGN also facilitated meetings on Leeds H21 and decarbonisation through hydrogen more generally, between Dan and 25 separate groups (including regulators, governments, consumer representatives, appliance manufacturers, distribution businesses and transmission businesses).

Dan's visit was extremely well received with attendees noting that they found the work underway in the United Kingdom and its potential implications for Australia very interesting and considered that it brought a new perspective to the current energy debate.

From an AGN perspective, we believe that Australia faces similar challenges to the United Kingdom in terms of decarbonising gas, electricity and transport, and that our natural resources (natural gas, coal and renewable electricity) lend themselves well to the production of hydrogen. Consistent with this, we are focussed on applying learnings and outcomes from the Leeds H21 case study to our Australian networks. This includes continuing to engage with key industry participants and scoping out the potential to decarbonise our networks, likely using a similar approach to the Leeds H21 project.

In Australia we are watching the development of the H21 concept with interest and are very supportive of the H21 NIC bid. We see this as a key requirement to move this opportunity for low/zero carbon energy forward across the globe. Please contact either myself or Krissy Raman if you would like to discuss this letter further.

Yours sincerely,

Craig de Laine
General Manager Strategy and Regulation, Australian Gas Networks

[1] Department of the Environment and Energy, *'National Greenhouse Accounts Factors'*, August 2016, pages 12 and 18.
[2] Energy Networks Australia, Australian Petroleum Production and Exploration Association, Australian Pipelines and Gas Association, Gas Energy Australia, Gas Appliance Manufacturers Association of Australia; Gas Vision 2050; March 2017. Available here: http://www.energynetworks.com.au/gas-vision-2050.

Australian Gas Networks

ACN 078 551 685

ATCO Gas AUSTRALIA

81 Prinsep Road, Jandakot, WA, 6164
Postal: PO Box 3006, Success WA 6964
P +61 8 6163 5000 www.atcogas.com.au

Friday, 14 July 2017

To Whom It May Concern,

NETWORK INNOVATION COMPETITION (NIC) BID – NORTHERN GAS NETWORKS

ATCO Gas Australia (**ATCO**) is a wholly owned subsidiary of the ATCO Australia Group. ATCO owns and operates the vast majority of Western Australia's gas reticulation network, serving approximately 740,000 end users via the Mid-West and South West Gas Distribution System (regulated by Western Australia's Economic Regulation Authority, ERA). Australia is an important strategic market for future growth and investment. In addition to the WA gas distribution network, the ATCO Australia group also includes businesses that operate within the electricity sector through the ownership and operation of gas fired power stations in Karratha (wholly owned) and Adelaide (co-owned).

The ATCO Australia Group is part of the world wide ATCO Group of companies with more than 8,000 employees and assets of approximately $20 billion. ATCO's companies are engaged in pipelines and liquids (natural gas transmission, distribution and infrastructure development, energy storage, and industrial water solutions); electricity (electricity generation, transmission, and distribution); retail energy; and structures and logistics.

ATCO is committed to minimising our carbon footprint through investing in reliable and affordable energy solutions. While our natural gas pipelines currently contribute approximately a quarter of the carbon as that produced by Australian mains electricity, we are currently investing in technology that would enable low-emission gas sources to be distributed via our natural gas network.

This orientation is consistent with the position of the broader gas industry in Australia, which released Gas Vision 2050 in March 2017. This paper details the decarbonisation journey of gas over time, outlining the use of low-emission fuels such as hydrogen and biogas. ATCO is also working with our customers to improve reliability and affordability through innovative solutions such as our GasSola product. GasSola combines solar PV, battery and micro gas generation to optimise the residential customer's energy bill.

Whilst work on gas network decarbonisation is underway in Australia, it is at a much earlier stage than that underway in the United Kingdom and to this extent, ATCO and the wider Australian energy industry closely follows the leading work being carried out in the United Kingdom.

By way of example of the level of interest in Australia, in late June Dan Sadler from Northern Gas Networks was the key note speaker at Energy Networks Australia's 2017 Gas Seminar (speaking about the Leeds H21 project). As part of Dan's Australian trip, Australian Gas Networks (**AGN**) facilitated meetings on Leeds H21 and decarbonisation through hydrogen more generally, between Dan and 25 separate groups (including ATCO, regulators, governments, consumer representatives, appliance manufacturers, distribution businesses and transmission businesses).

ATCO's view is that Australia faces similar challenges to the United Kingdom in terms of decarbonising gas, electricity and transport, and that our natural resources (natural gas, coal and renewable electricity) lend themselves well to the production of hydrogen. In this regard, Dan's visit was timely and well received where the work underway in the United Kingdom may have significant implications and benefits for Western Australia and the broader national energy supply chain.

Therefore, ATCO is focussed on insights and outcomes from the Leeds H21 case study through the development of our *Energy Roadmap 2030 for Western Australia*. One of our *Energy Roadmap* scenarios includes assessing the feasibility of transitioning to hydrogen including how a *Perth H21* may evolve.

ATCO will be keen observers of the development of the H21 concept are very supportive of the H21 NIC bid: this process is a critical enabler of progressing towards a net zero carbon future.

Yours sincerely,

Pat Donovan
President ATCO Gas Australia

ALSTOM TRANSPORT UK

The Place
175 High Holborn
London WCIV 7AA
Phone 44 (o) 20 7438 9230
Fax: 44 (o) 20 7438 9290
www.transport.alstom.com

ALSTOM

Dan Sad er
Programme Director (H21)
St George House
40 Great George Stree: Leeds
LSI 3DI

16th June 2017

Dear Dan

Alstom is a tier 1 supplier in the rail industry globally with products and services touching the entire value chain: ranging across the manufacture of trains and other vehicles, maintenance & service, infrastructure; signalling and control systems.

Around the world, Alstom's customers are generally local authorities, cit ies and regions, or t ran sp ort operators/owners. Alstom has developed a strategy and is actively involved in a number of initiatives and pro jects with the objective to decarbonise public transport systems. An important part of this st rat egy is Alstom's Hydrogen Fuel Cell train, iLint, launched in Germany in September 2016. This launch generated a huge interest in the UK from local, regional and national authorit ies.

The UK, as with most other countries aro und the world, recognises the chall enge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of their level in 1990. Climate change is one of the most significant technical, economic, social and business challenges facing the world today.

Follo wing the completion of the H21 Leeds City Gate project ther e has been growing interest in the opportunity to decarbonise the gas network by converting to 100% hydrogen, a solution that appears to be t echnically and econom ically viable. All the technology to convert the UK gas distribution network to hydrogen can be evidenced across the world today (steam methane reformers, salt caverns, hydrogen appliances). However, the primary obstacle to progressing with such a decarbonisation pathway is the lack of quantitative safety evidence.

The objective of the H21 Network Innovation Competition (NIC) bid is to provide compelling, quantified safety based evidence for a 100% hydrogen conversion in the below 7 bar UK gas distribution network. Specifically, that the pipes and equipment will be as safe operating on either 100% hydrogen or natural gas. This could ultimately support policy decisions for a UK hyd rogen conversion with potential to save £100bns vs alternative decarbonisat ion strategies. The H21 NIC project will provide comprehensive, quantified evid ence across t he rang e of below seven bar assets within a three year time frame 2018 to 2020.

This development will benefit the growing hydrogen economy of the UK facilitating growth in all sectors through the development of a greater hydrogen infrastructure. Alstom is pleased to support the H21 project and in particular the NIC bid to OFGEM as one of the innovative solutions that could help to create a robust hydrogen infrastructure in the UK, helping us in turn to deliver a low carbon transportation system for the twenty first century.

Yours sincerely

Mike Muldoon
Head of Strategy
Alstom UK & Ireland

BUILDING OUR INDUSTRIAL STRATEGY GREEN PAPER JANUARY 2017

Introduction

This is a joint response from Leeds City Council, West Yorkshire Combined Authority and Tees Valley Combined Authority to the Industrial Strategy Green Paper focussing on hydrogen based heat decarbonisation and specifically the opportunities afforded by the H21 Leeds City Gate project. This is an aspect of the Industrial Strategy that all three organisations are collaborating on and have corresponded on with Ministers (see attached letters to Greg Clark & Sajid Javid, August 2016 and to Nick Hurd, December 2016). Each organisation will be submitting additional responses to the Industrial Strategy as a whole.

Background

The need to reduce carbon emissions is a global and a national priority, and the UK is committed to reducing carbon emissions by 80% of the 1990 levels by 2050. As the UK transitions to a low carbon economy there are numerous scenarios that could play a part in the future UK energy mix. Heat, provided almost exclusively by natural gas, currently contributes over 35% of the UK's energy needs and is seen as an important transitional fuel as the UK moves to a low carbon economy.

Through the 'H21 Leeds City Gate' Project, Northern Gas Networks has been examining a scenario where gas and the gas networks play a direct role in reducing carbon emissions via the creation of Hydrogen from Natural Gas (Methane). Hydrogen, at point of use, leaves no carbon footprint - the combustion of hydrogen with oxygen results in water and heat.

The outcome of the project is confirmation that the UK gas neworks can transport the same amount of energy using hydrogen as they currently do with natural gas with the same level of energy security for customers The recommendations are that the gas network in Leeds (and parts of Bradford, Harrogate Kirklees and Wakefield) should be the first to convert from natural gas to 100% hydrogen in an incremental UK-wide roll-out strategy. Use of hydrogen as a fuel produces zero CO2 emissions at point of use, improves air quality and eliminates carbon monoxide risk. The main elements of the project include:-

- Four steam methane reforming plants built in Teesside, fitted with 90% carbon capture that would convert natural gas into hydrogen.
- The construction of a pipeline to transport the captured carbon from Teesside into the North Sea.
- Salt storage caverns for hydrogen built in Teesside, some of which may be repurposed existing caverns in the area.
- A Hydrogen Transmission system (a pipe) that will transport the hydrogen from Teesside to Leeds.
- Minor upgrades to the gas network infrastructure within Leeds, which generally already have the capacity to convert to 100% hydrogen.
- Conversion of gas appliances to consumers.

The Leeds area is recommended as the first to convert due to its geographical and geological position as well as its large energy demand creating an efficient and large market for initial conversions. This would be the start of an incremental UK roll-out for hydrogen conversion which can be designed to be as fast or slow as required depending on appetite for cost and carbon reductions.

This project has gained national and international recognition as a potential realistic and deliverable pathway to the decarbonisation of heat across the UK. The project has proved, via a desktop exercise, that the current low pressure (below seven bar) gas network in the UK is sufficiently sized to convert to hydrogen. If the hydrogen economy is to commence in the UK it is likely, and indeed geographically necessary, that Leeds would be the first city to convert.

In the short term, the project would deliver new jobs and research capabilities. In the long term it would represent a mainstream supply of zero carbon energy bringing with it significant opportunities for job creation, inward investment, manufacturing and reduced energy costs.

Industrial Strategy

The Green Paper includes only one reference to hydrogen which we feel does not reflect the potential significance of the opportunity that it represents to the UK's future industrial strength. In our region, H21 provides an exciting opportunity for Government, business and researchers to work together to develop competitive opportunities. We welcome the proposed review on the opportunities for growth from the energy sector and the opportunities for the UK. In particular, and as a cost effective solution, we would stress the importance of exploring the potential opportunities associated to a future Hydrogen gas grid (including roles for Steam Methane Reformation and Carbon Capture & Storage (or similar)). transport and decentralised / centralised electrical generation as proposed in the H21 Roadmap and associated documents and reports. Others are already exploring these options: For instance, it has recently been reported that the Port of Rotterdam is working on two ambitious options (covering capturing and storing all CO2 from the port factories and development of renewable fuels such as hydrogen from wind energy).

The H21 Roadmap (section 10 of the H21 report) presents all of the work required to de-risk a hydrogen for heat decarbonisation strategy and enable a national policy decision to be taken in the early 2020's.

The economic rationale for this Roadmap has been reviewed by the Regional Economic Intelligence Unit (REIU) at Leeds City Region employing analysis derived from the Regional Econometric Model, (REM), a model of the regional economy that has been developed in partnership with Experian. The work of the REIU has explored the breadth and scale of the economic impacts and outcomes that could be realised through the 5 year programme of work set out within the H21 Roadmap.

- We estimate that the economic value of the jobs created or supported directly would be around £7 million annually (based on a 5 year time line between 2017-2021).
- Over the 5 years of the project this would have a life time economic value of £35 million (this is a constant price estimate based on 2011 prices).
- The 133 direct jobs would support the creation of 15 further indirect FTE's – a mix of some additional supply chain jobs and jobs associated with sectors such as retail (through extra spending of the people employed by the project).
- The Capex of the project will give rise to some construction jobs not captured in the project job numbers of anywhere up to 150 construction FTE's

However, these clear short term economic benefits are dwarfed by the scale of the impact that might be achieved once conversion is underway following a national policy decision. If these long-term economic benefits are also included, then the total economic impact by 2050 could create and sustain thousands of jobs across Yorkshire and the Humber, surrounding regions and across the UK for decades to come.

There is economic growth potential for other hydrogen suppliers linked to the network in the future. The project relies on carbon capture and storage for which economic uses for waste carbon could be found in the future. There would be new market opportunities for a new generation of household and industrial gas appliances and all of the associated supply chain benefits in manufacturing, retail and installation. Hydrogen fuelled vehicles are another potential growth area with significant environmental benefits in terms of air quality and for which there is a global market.

The Energy Research Partnership's October 2016 report, "Potential Role of Hydrogen in the UK Energy System" concluded that:-

- Hydrogen appears to be a convincing pathway to decarbonisation that could be rolled out to the majority of customers by 2050.
- A strategic long-term plan is needed for hydrogen to make it zero-carbon. Carbon capture and storage will need to be in place for early production in 2030. Energy security implications of import dependency will need assessing and appropriate measures developed.
- Hydrogen is already entering the energy system in stand-alone applications. It has the potential to play a valuable, integrated role, helping to manage the electricity grid, fuel vehicle fleets and industry.

The National Committee on Climate Change's October 2016 report, "Next Steps for UK Heat Policy" concludes that "Government must set out the role of hydrogen for buildings on the gas grid in the next Parliament. The Government will need to make a set of decisions in the next Parliament and beyond on the best strategy for decarbonising buildings on the gas grid. Specifically, it will have to decide on whether there is a role for hydrogen supplied through existing gas networks (extending the useful life of the gas grid infrastructure) alongside other technologies such as heat pumps."

KPMG's January 2017 report," Energising The North" emphasises the potential value of the clean energy sector to the future of the northern economy and finds that:-

- From 1997 to 2014, the Northern energy sector (comprising the North West, the North East and Yorkshire and the Humber) accounted for c23% of total UK economic value for the energy sector.
- In 2014 the Northern energy sector contributed some £3.5bn in GVA to the regional and the UK economy.
- The North plays an important role in areas including smart grids, decarbonised gas (e.g. hydrogen), offshore wind and transport.
- Key projects include development of electric vehicles by Nissan in Sunderland. H21 City Gate Project in Leeds ,the Smart Grids Centre based in Newcastle, the National Centre for Energy System Integration, the National Institute for Smart Data Innovation and the Siemens offshore wind turbine factory in Hull. Many other developments are also underway across the region
- We identify the potential for energy to increase GVA growth by up to £2.3bn by 2050 by building on existing capabilities and exploiting opportunities in smart power, decarbonised gas and transport.

Conclusion

We remain committed to exploring this exciting project in the Leeds City Region and Tees Valley. There is wide spread political backing for this project and we are excited about its potential to not only contribute significantly to ensuring long term energy affordability, but to our local, and indeed the national carbon emission reduction targets and also the potential transformational impacts on the economy in terms of job creation, growth and innovation. By establishing the first commercial hydrogen economy in the world it would place our region on the map, making it the first port of call globally for hydrogen technologies /region of excellence. We call on the Government to join with and support us in our efforts to develop the H21 project as a flagship project for the Northern Powerhouse and the UK as a whole.

Section 11. Appendix K – Signatures

Appendix K: NIC BID ACKNOWLEDGMENT

Background

A. The parties listed below ("**the Parties**") are parties to the H21 NIC BID

Acknowledgement and Agreement

The Parties have submitted this bid on the basis that they agree to provide their 25% share of the mandatory 10% network licencees' contribution towards the NIC bid costs. If the bid is successful, the parties will sign contracting terms based on the arrangements typically adopted for collaborative Network Innovation Allowance projects.

All parties can confirm their full support and financial commitment to the H21 NIC bid.

The Parties have signed this Acknowledgement on the date set out below.

Signed by .... Authorised Signatory

for and on behalf of CADENT LIMITED

....

Name and position of Authorised Signatory

DAVID PARKIN, DIRECTOR SAFETY AND NETWORK STRATEGY

Date 20/07/17

Signed by .... Authorised Signatory

for and on behalf of SCOTLAND AND SOUTHERN GAS NETWORKS PLC

....

Name and position of Authorised Signatory

PAUL DENNIFF Network Director

Date 17th July 2017

Signed by .... Authorised Signatory

for and on behalf of NORTHERN GAS NETWORKS LIMITED

....

Name and position of Authorised Signatory

MARTIN ALDERSON

ASSET RISK MANAGEMENT & SAFETY DIRECTOR

Date 19th July 2017.

Signed by .... Authorised Signatory

for and on behalf of WALES AND WEST UTILITIES LIMITED

....

Name and position of Authorised Signatory

C. CLARKE

DIRECTOR OF ASSET MANAGEMENT

Date 20TH JULY 2017