ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Project Code/Version Number:
CADENT06/02

1. Project Summary

1.1. Project Title	HyDeploy2		
1.2. Project Explanation	The project builds on the foundational work at Keele University to demonstrate on public distribution networks that natural gas containing levels of hydrogen beyond those in GS(M)R can be distributed and utilised safely. Successful demonstration has the potential to facilitate 29TWh pa of decarbonised heat nationally, and more by unlocking extensive hydrogen use.		
1.3. Funding licensee:	Cadent Gas Limited		
1.4. Project description:	**1.4.1. The Problem(s) it is exploring** The UK has committed to substantial carbon savings; heat contributes to a third of its current emissions. Reducing heating carbon intensity via hydrogen over the gas grid provides a customer-focused solution, but is limited by the current tight GS(M)R UK limits. **1.4.2. The Method(s) that it will use to solve the Problem(s)** Building on the foundational work undertaken at Keele, this will be the first GB deployment of hydrogen into the public gas network. It will move from the requirement to survey, test and trial all parts of a network prior to injection, to the ability to inject into an untested network, as necessary for roll out. This will be achieved through development of a representative and resilient evidence base though further trials & a roadmap for hydrogen deployment through blending in a 48 month project, running from Apr-19 to Mar-23 **1.4.3. The Solution(s) it is looking to reach by applying the Method(s)** The project objective is that a supplier of hydrogen is able to apply to inject hydrogen into a GDNs network, just as biomethane producers can today. This enables hydrogen to deliver cost-effective and non-disruptive carbon savings to the customer. **1.4.4. The Benefit(s) of the project** Successful demonstration has the potential to facilitate 29TWh pa of decarbonised heat in the GB, substantially more than the existing RHI scheme is projected to deliver, with the potential to unlock wider savings through more extensive use of hydrogen. It addresses the energy trilemma, saving £8billion to consumers, and avoiding 119 million tonnes of carbon by 2050, whilst providing a greater level of diversity in supply.		
1.5. Funding			
1.5.1 NIC Funding Request (£k)	£13,282	1.5.2 Network Licensee Compulsory Contribution (£k)	£1,497
1.5.3 Network Licensee Extra Contribution (£k)	0	1.5.4 External Funding – excluding from NICs (£k):	0
1.5.5. Total Project Costs (£k)	£14,969		

1.6. List of Project Partners, External Funders and Project Supporters (and value of contribution)	Project Partners:	Cadent Gas Limited Northern Gas Networks Limited Health and Safety Laboratory, Progressive Energy, ITM Power Keele University	
	Project Supporters:	WWU SGN	
1.7 Timescale			
1.7.1. Project Start Date	April 2019	1.7.2. Project End Date	March 2023
1.8. Project Manager Contact Details			
1.8.1. Contact Name & Job Title	Andy Lewis Network Innovation (Future Role of Gas)	1.8.2. Email & Telephone Number	andy.lewis@cadentgas.com 01455892524 07970831058
1.8.3. Contact Address	Cadent Gas Limited Brick Kiln St, Hinckley, LE10 0NA		
1.9: Cross Sector Projects (only complete this section if your project is a Cross Sector Project, ie 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	7	1.10.2. TRL at Project End Date	9

Section 2: Project Description

2.0. Executive Summary

The UK is legally bound to make ambitious carbon reductions. Reducing the carbon intensity of heat continues to present a major challenge and an obstacle to meeting its commitments, as recently highlighted by the Committee on Climate Change in its 2018 Progress Report to Parliament. 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. Heat demand is highly variable and, compared with alternatives such as heat pumps, gas is readily capable of meeting peak heat. Delivering low carbon heat via gas capitalises on existing network assets cost effectively and means that customers do not require disruptive and expensive changes in their homes. Blending hydrogen into the gas network enables the potential to deliver 29TWh of decarbonised heat in Great Britain, saving £8 billion of cost and 119 million tonnes of carbon by 2050. It also unlocks a pathway to establishing hydrogen more widely across the energy system.

The UK currently only permits $0.1\%_{vol}$ hydrogen in the network. The HyDeploy project at Keele is establishing the first proof of principle that up to $20\%_{vol}$ hydrogen can be injected, and the requirement for subsequent public trials to achieve national deployment was made clear at the start of that project. There is a need to move from the requirement to survey, test & trial all parts of a network prior to injection, to injecting into an untested network, as necessary for roll out. A project overview is provided in Appendix C. The ultimate project objective is that a supplier of hydrogen will be able to apply to inject hydrogen into a GDNs network, just as biomethane producers can today.

This project is necessary. Like other international first-of-a-kind hydrogen blending programmes, the project at Keele was deliberately structured to manage and control the operational context. There is a necessary transition to establish safety on a public network where fewer specific control measures can be put in place.

It is timely. The Exemption case has been developed and has been submitted to the HSE for the project at Keele. No fundamental barriers to blending have been identified. By starting this programme next year, the evidence base relating to the public network can be developed in order to allow a seamless transfer from the end of the live trial at Keele to the first public trial, maintaining momentum. Importantly it expedites roll out of blending as a near term carbon reduction solution. NGN is engaged in power to gas opportunities based on this through its InTEGReL project, and Cadent's HyNet NW project is seeking to deliver a hydrogen blend to over 2 million homes in the Liverpool Manchester area by mid 2020s predicated on this programme.

2.1. Aims and objectives

2.1.1 The Problem(s) which needs to be resolved

The UK is committed to a pathway to carbon reductions through the Climate Change Act. In 2016 it adopted its ambitious and legally binding fifth carbon budget for the period 2027-2032 as part of this trajectory. Heat contributes a third of the UK's carbon emissions. The updated Carbon Plan[1] and more recently the Clean Growth Strategy[2] specifically identifies the need for low carbon heat in order to meet these targets. As recently as June 2018, the Committee on Climate Change in its Progress Report to Parliament[3] highlighted that contrary to the vital need for reduction in emissions in this sector, *'this year, emissions in the industry, buildings and waste sectors have increased'*, and issued a call to action; *'Act now, climate change will not pause while we consider our options. And act in the consumer interest: pursue the low-cost, low-risk options'.*

The Carbon Plan identifies that by 2030 there is a requirement for between 83-165TWh of low carbon heat per annum. In 2017[4] the RHI delivered around 8.5TWh of renewable heat. In its 2018 RHI impact assessment[5], BEIS revised *down* its projections indicating *'that by 2020/21, the RHI could deliver 21.4TWh of renewable heat'*. Therefore a step change in low carbon heat is required.

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. Delivering low carbon heat via gas capitalises on existing network assets cost effectively and means that customers do not require disruptive and expensive changes in their homes. The importance and reliance of the UK on the gas network was exemplified during recent adverse weather conditions experienced during the 'beast from the east'.

Alternatives such as electrification using heat pumps will make a contribution. However, as recognised in BEIS Heat Strategy[6], in its RHI consultation, in a 2018 report for the National Infrastructure Commission[7], this approach require substantial consumer capital outlay and disruption. Consumers are required to change the basis of their heating system in terms of heat source and low temperature heat distribution systems. Furthermore, electricity generation, transmission and distribution network will require additional capacity to handle the additional variable demand for heat. There is also a role for biomass boilers, noting the concerns with air quality in urban areas, and heat networks, subject to the installation of new infrastructure.

All of these approaches require that the consumer makes substantial changes to their own heating system. This represents a substantial barrier to adoption of such low carbon heat solutions, as demonstrated in the NIA Funded Bridgend[8] study undertaken by WWU in 2015, which drew the primary conclusion that *'the majority of domestic consumers (87%) will not change their existing heating provision unless significant financial benefits will be accrued, and only then if they have funding available... If their current system was operating well and providing heat for their homes they would not change their heating systems and spend*

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[1] The Carbon Plan: Delivering Our Low Carbon Future December 2011, updated 2013.
[2] The Clean Growth Strategy Leading the way to a low carbon future, BEIS October 2017
[3] Reducing UK emissions, 2018 Progress Report to Parliament, Committee on Climate Change, June 2018
[4] RHI_monthly_official_statistics_tables_31_December_2017_final
[5] https://www.legislation.gov.uk/ukia/2018/84/pdfs/ukia_20180084_en.pdf
[6] The Future of Heating, DECC 2016
[7] Cost analysis of future heat infrastructure options, Report for, National Infrastructure Commission, Element Energy Limited, E4Tech, March 2018
[8] http://www.smarternetworks.org/Files/Bridgend_Future_Modelling_%E2%80%93_Phase_2_150910144351.pdf

money unnecessarily.' Delivery of a low carbon gas which can operate in existing appliances requiring no modifications on the part of the consumer overcomes this substantial barrier.

The existing gas network has over 284,000km of pipelines, delivering over 720TWh pa to over 23 million customers with 99.99% security of supply[9]. It is able to meet peak demand for any 6 minute period over 20 years. The gas system not only sustains peak heat demand but also supports the very large swings in demand within the day through significant storage capacity. This asset has an important role to play in the cost effective delivery of heat into the future[10]. A key element of this is delivering low carbon gas.

Gas can be decarbonised by (a) using bio rather than fossil carbon, i.e biomethane, already increasingly & successfully deployed in the UK, and (b) removing the carbon by using hydrogen. The latter is identified as important[11] but recognises further development activity is required. Two potential hydrogen scenarios are considered; either as a blend in the network feeding existing appliances with no requirement for changes to equipment or infrastructure, or as a conversion to 100% hydrogen. The former has the potential for roll out in the near term offering decarbonisation and financial benefits across the distribution system with no disruption to consumers. It also provides a pathway to adoption and use of hydrogen more widely, not only for heat, but for other sectors such as flexible power generation and transport, as demonstrated by both NGN's InTEGReL project[12]. Cadent's HyNet project[13] is based on delivering a hydrogen blend to over 2 million homes in the North West, as well as unlocking these wider decarbonisation benefits.

The HyDeploy project at Keele University (henceforth 'Keele') is establishing the first proof of principle that up to $20\%_{vol}$ hydrogen can be injected, and the requirement for subsequent public trials to achieve national deployment was made clear at the start of that project. There is a need to move from the requirement to survey, test & trial all parts of a network prior to injection, to injecting into an untested network, as necessary for roll out. That is what this project sets out to achieve.

2.1.2. The Method(s) being trialled to solve the Problem

The Method proposed is to reduce the carbon intensity of heat, cost effectively, via hydrogen blending in the gas grid. Based on the foundational HyDeploy trial at Keele, the objective is to enable deployment and rollout across the UK. The outturn project objective is that a supplier of hydrogen will be able to apply to inject hydrogen into a GDNs network, just as biomethane producers can today, enabling delivery of cost-effective & non-disruptive carbon savings to the customer. It is important to commence this next year for a seamless transition of equipment & teams from Keele to the first public trial, maintaining momentum & delivering timely deployment.

The Method builds on the principles established in the HyDeploy project at Keele, which drew on the work by SGN in the "Opening up the gas network" project, as well as other work internationally. The purpose of the Keele project was to provide the core evidence base require to support in principle the injection of hydrogen in the UK. For a first project, a

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9 http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas/
10 'The Role of Gas in UK Energy Policy', Le Fevre C, Ox Inst. for Energy Studies (2015)
11 'The Future of Heating: Meeting the challenge' DECC (March 2013)
12 https://www.northerngasnetworks.co.uk/ngn-you/the-future/integrel/
13 www.hynet.co.uk

closed private network was deliberately chosen to enable the most complete dataset to be collected about the network, with as many variables controlled. This not only enabled sound risk management in this first project, but also provided a greater level of reassurance for those involved. HyDeploy2 will address the key elements necessary to translate from the seminal project at Keele to full deployment. It will move from the requirement to survey, test and trial all parts of a network prior to injection, to the ability to inject into an untested network, as necessary for roll out. It will also provide a comprehensive roadmap for deployment. The Method is delivered through a 4 year project, running from Apr-19 to Mar-23 as described below.

2.1.3 The Development or Demonstration being undertaken

The project has three main components (a) development of the evidence base, (b) execution of public network trials and (c) development of the roadmap for deployment.

Developing the evidence base is necessary to support both the specific public trials & address wider network requirements for roll out. This builds on the work at Keele, but extends it to address the significantly wider issues required on a public network, as described in more detail in Section 2.3.

In addition to the technical programme to support the Exemption application, there are a number of enabling activities necessary to undertake the trial phase. This includes development of the overall customer engagement plan, engagement with key supply-chain stakeholders (appliance manufacturers and suppliers, gas suppliers and shippers) as well as extending the regulatory solutions, relating to billing & equipment ownership.

Two trials will be undertaken to provide the breadth of demonstration necessary to underpin wider network applicability. Importantly the second trial must also support the principle of reduced data collection at the Exemption stage, based on the evidence from the first trial, to enable subsequent roll out. Each trial will require development of the evidence base into a Quantitative Risk Assessment to support Exemption applications to GS(M)R, and subject to granting by the HSE, the trial phase using the hydrogen production and grid injection equipment transferred from Keele.

The third element of the project is to ensure that there is a deliverable deployment plan for hydrogen blending on the network. This activity will be undertaken concurrently with the other project elements, as it will feed into these as well as draw on their outcomes. This will address issues relating to cost optimal network injection points and pressure tiers, the regulatory and commercial basis for deployment to support policy development and importantly the skills and training work necessary for wider roll out.

2.1.4 The Solution(s) which will be enabled by solving the Problem.

By establishing the level of hydrogen blend which can be accommodated safely in the gas distribution network, the project unlocks a solution to low carbon heat which cannot be adopted otherwise. This has the potential to deliver up to 29 TWh per annum of non-disruptive low carbon heat, substantially higher than the RHI scheme expect to deliver.

There is a suite of technologies available to deliver low carbon hydrogen, from biogenic sources - particularly wastes, from electrolysis, and as well as from fossil sources with Carbon Capture and Storage (CCS) as it becomes established. This latter is exemplified by the HyNet and H21 projects. Combined, these sources represent a diversification of heat supply, neither dependent on instantaneous electricity, nor solely on gas, with other indigenous feedstock such as waste contributing sustainably. These are discussed in more detail in Section 3 & 4. The carbon benefits are shown to have the potential of saving a cumulative 119 million tonnes CO_{2eq} by 2050 for the GB, and offering financial savings of £7,918 million on a cumulative discounted basis, with the assumptions provided in Appendix B. This route addresses the energy trilemma; substantial carbon savings compared with natural gas, whilst being 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

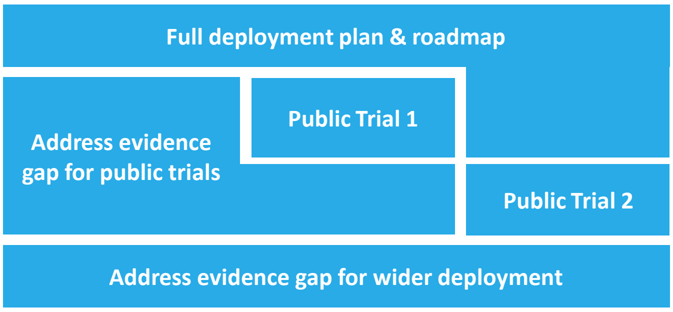
Injection of a hydrogen blend into the network has a potential range of impacts, including changes to the combustion characteristics of the gas, chemical effects on materials on the network and in appliances, impacts on leak detection and network operation and maintenance, as well as impacts on the billing and the commercial regime necessary for deployment. Whilst the UK network historically operated on a hydrogen-rich town gas, this was phased out in the 1970s. At that stage there was an extensive programme of burner adjustment and replacements to operation on natural gas. Since then appliance design has evolved, and there have been changes to materials used for pipeline design, network monitoring and management equipment and techniques.

The objective of the programme is to reach the point whereby a hydrogen supplier is able to apply to inject into a gas network, as biomethane producers can today. This requires the necessary evidence base that the change is safe across the UK gas distribution network.

The HyDeploy project at Keele provides the foundation. Keele University was specifically chosen for a first trial as it provided a well-controlled site and allowed a comprehensive dataset to be collected about that network, appliances and installations. Such an approach is consistent with projects in Europe such as Engie's GrHyD project, which is the French equivalent of the Keele project, noting that the GrHyD project is more confined than the Keele demonstration as it is a newly built gas network.

The evidence collated for Keele covers the characteristics of the hydrogen blend, the impact on the materials found at Keele under the network conditions and the impact on the specific installations and appliances at Keele. The operational procedures deployed on the network were all reviewed, and where necessary modifications identified to accommodate the blend. The Keele project has also delivered the detailed design of equipment suitable for blending and injecting hydrogen into a gas network. Together this evidence base has been drawn together in a newly developed Quantitative Risk Assessment for hydrogen blending. On the basis of this comprehensive assessment, an application has been made to the HSE for an Exemption to the regulations to permit injection of hydrogen at a level of 20%vol. Overall learning points from the Keele project are described in Appendix E, and Appendix D maps out the technical learning ones.

The fundamental principle of an Exemption for a change of Gas Quality Management Regulations is that the safety of the gas users is not prejudiced. In order to establish this, any potential impacts must be fully understood and assessed. On a closed private network such as Keele it is possible to fully characterise the network, appliances and installations and have confidence that they are well maintained and fundamentally sound. For widespread deployment, the gas network with 23 million users and 284,000 km of network, cannot be so comprehensively characterised.



This requires an integrated programme. The necessary evidence base to support the safety case to the HSE must be developed; this is described in detail in Appendix D, which lays out the 'gap analysis' between this work and that at Keele. Based on that, the Exemption is developed for the first trial site, followed by the trial phase which itself feeds into the process of Exemption for the second site. Underpinning this is the delivery of the roadmap for deployment. The details are described Section 2.3.

Undertaking such a programme is necessary to achieve deployment, it does require more than one trial and is timely, as laid out below.

It is necessary: Public trialling is a necessary step from the trial at Keele to full deployment. That project was deliberately structured to manage and control the operational context. There is a necessary transition to establish safety on a public network where fewer specific control measures can be put in place. This was an integral part of the first NIC project proposal & previously supported by Ofgem through the Expert Panel with full visibility of this requirement.

It requires more than one trial: At full deployment, applicants to inject hydrogen cannot be required to undertake safety checks in every home affected. Therefore it is critical that sufficient, representative evidence is collected in this project. Given the relative geographical homogeneity of housing stock, this is difficult to achieve in a single location, delivering a sufficient range of appliances and network materials and components. The second trial must support the principle of reduced data collection for Exemption, based on the evidence from the first trial, to enable subsequent roll out.

It is timely: The Exemption case has been developed and has been submitted to the HSE for the project at Keele. No fundamental barriers to blending have been identified. The live trial at Keele will be completed in March 2020; equipment should be directly transferred to the public trial (a) to avoid mothballing and (b) to expedite roll out of blending as rapidly as possible, maintaining momentum and enabling delivery of deployment at scale such as HyNet.

2.3. Description of design of trials

This section provides an overview of the trial being undertaken. A full description of the project can be found in Appendix C, along with the programme in Appendix G. The three core areas are (a) development of the evidence base, (b) execution of public network trials and (c) development of the roadmap for deployment.

The programme itself is designed to allow the development of the core evidence base commensurate with the needs of each public trial. The two exemption processes provide natural project milestones into each trial. By the end of the programme, the objective is that the evidence from both Exemptions, as well as the evidence collected from the trials and the wider road mapping work, provides the industry with the basis to adopt hydrogen blending as a solution to decarbonise heat, and inform the necessary government policy to support it.

2.3.1 Evidence Base Development

Required to support both the specific public trials & address wider network requirements during roll out.

<u>Public trial specific evidence</u>

This builds on the principles established at Keele, extended to cover the specifics of the public trials. The scientific programme is described in detail in Appendix D, which identifies in each area the knowledge gaps from the trial at Keele that must be addressed for wider roll out, the rationale and the activities to be undertaken. This is summarised below.

In many cases at Keele, it was possible to take a conservative position. The range of materials, appliances, installations is more limited than on the public network. Where there were uncertainties in the evidence base, conservative assessments of the risk were undertaken. This was because in that context it is possible to invoke a range of mitigation measures, and refinement of procedures to manage the overall risk. This was the rationale for undertaking the first trials on a close private network such as Keele. For a wider deployment it is necessary to refine the evidence.

There has been close collaboration between HyDeploy and the team delivering the GrHyD project in France. Many of the knowledge gaps below, have been identified by both teams, with limited evidence available internationally. This provides confidence that the work has not been undertaken before and is therefore necessary. This work is focused on hydrogen blends. Key partners in this project are also involved in 100% hydrogen work, and are able to ensure that there is no duplication with that work, and that any information which can support those programmes is appropriately shared.

Materials: The trial at Keele addressed materials found on that specific site following a comprehensive asset survey. For roll out it is important to address the range of materials found on the wider network, covering both metallic and polymeric components. As noted below, this will include operational pressures up to 39 bar to enable cost effective deployment. To enable understanding of the impact of long term operation on materials, the work must be expanded to evaluate the impact of hydrogen blends on materials under cyclical loading conditions and the impact on fatigue life addressing both crack initiation and growth. Hydrogen embrittlement is a long term degradation mechanism and it is important to understand the basis of materials failure to allow predicative capability. Cathodic charging is a technique to accelerate absorption compared with gaseous soaking. This will be assessed and through a carefully defined experimental programme be calibrated against uptake from partial pressures of hydrogen from gaseous soaking. This approach is designed to simulate decades of gaseous exposure, potentially in a few days, enabling development of an evidence base for long term operation, and potentially experimental cost savings.

The experimental output will progressively build confidence in the materials performance of any GDN network containing a hydrogen blend. The aim will be to provide short-term confidence to allow the trials to be undertaken, while also producing data applicable to long term exposures of a network over a wide range of pressures.

The work will be undertaken and managed by HSL supported by third party organisations with the skills and equipment necessary to undertake the specialist areas of work. Specific universities with the necessary capabilities have been identified, particularly Manchester and Sheffield.

Appliances & Installations. The laboratory testing and field testing at Keele established that appliances that are functioning correctly and well-maintained can safely burn hydrogen blended gas that meets the GS(M)R Wobbe Index specification in accordance with existing UK natural gas safety standards. A comprehensive site survey and programme of remedial work provided confidence that the appliances at Keele were properly installed and well maintained. An understanding of how poorly maintained, malfunctioning and maloperated appliances will respond to hydrogen blended gas is required to build the confidence that on a wider network these appliances will pose no greater risk operating on the blend. Additionally, an assessment of the performance of pre-GAD (pre 1996) appliance is required to ensure there is no anomalous operating characteristics in the aging UK appliance stock. During the work for the project at Keele, it was identified one particular class of sensor used in gas fires required further understanding of operational efficacy for a blend. This issue was addressed for Keele by ensuring that the specific types in the relatively few appliances were suitable, however further evidence is required to assess the situation for wider network application.

A testing programme will be established, managed by HSL and delivered by KIWA based on the understanding from Keele. The first public trial includes a full gas safety survey of the installations on the network. This will provide an extensive data set of appliances and modes of installation shortcomings, poor maintenance, malfunction and maloperation, in order to ensure that the testing envelopes the expected range of conditions encountered on an 'uncontrolled' network. This data will be fundamental to the evidence base to support the second trial where only a sample of installations will be surveyed.

Through a technical review and an industry consultation exercise information has gathered on potential longer-term effects of hydrogen blended gas on appliance integrity and accelerated testing is being undertaken on the network at Keele. This data will be assessed to establish long term integrity of components and impact on maintenance and warranties. This area of work well supported by appliance manufacturers.

It is important to establish the impact of hydrogen blends on installation leakage characteristics. Direct assessment of these approaches through measurement of leak rates with hydrogen blended gas was not possible during the onsite testing programme at Keele University due to issues with temperature equilibration of the installation gas volume during bottle testing. At Keele a conservative position was taken on the basis of analytical assessment and remedial works on installations. To underpin wider roll out it a robust leak measurement test will be developed, evaluated for test installations and through testing at Keele during the live trial phase.

In order to support the public trials, refinements procedures must be communicated to the wider gas operative community. Development of training packages to inform the gas network and fitter community is required so that the implications of hydrogen blending are communicated clearly and unambiguously.

Gas characteristics and Procedures. There are a number of important areas relating to gas characteristics and therefore associated procedure which need to be addressed for public deployment.

Through the HyDeploy programme at Keele around 200 existing gas procedures were assessed for suitability for hydrogen blends. It was determined that the majority of these remained suitable, with only a subset requiring refinement for Keele. In many of those cases, changes were identified to take a conservative position for that trial. A more detailed evidence base relating to specific aspects of gas characteristics allows a more refined assessment and minimise procedural changes for wider deployment.

The migration of gas from a subsurface leak source (e.g. a low to medium pressure pipe rupture) has a bearing on building proximity distances and gas leak sweep distances. Conservative positions were taken at Keele, but which add complexity to gas network operators. HSL will undertake experimental and theoretical modelling using existing facilities and approaches to assess the behaviour hydrogen blends allowing the GDNs to assess the implications for procedures.

It has always been recognised that hydrogen permeates faster through the walls of PE pipelines faster than natural gas. The absolute leakage rate is very low, and not an issue of itself, but this could affect the concentration of hydrogen in the permeate. This would only be an issue where there are specific public network pipe configurations such as 'inserted mains' or running of pipelines through ducts (not present at Keele). Experimental work be undertaken to replicate in-field conditions to assess this.

Hydrogen blended gas has a wider flammable range and the minimum ignition energy is lower than natural gas. This can be managed at Keele through the mitigation measures in place, but an understanding of the frequency of different ignition sources of different strengths is required to refine the implications more widely. This will be assessed through frictional ignition tests at HSL using the methods developed for the MechEx pre-normative European research programme.

A method to quantify the dispersion and migration of hydrogen blended gas around a domestic property is necessary. This is understood in industrial plants and the implications understood in the open, but not within buildings. At Keele this is mitigated through survey and remedial works to establish that installations are fundamentally sound, but requires further data to understand the risk under less controlled conditions. Existing dispersion models will be refined and validated from data obtained from a new scaled experimental rig which will replicate the layout of a two-story building.

Gas detection instruments were assessed for the operation at Keele and subsequent detailed enabling work is ongoing, including separate research at Keele. The initial work identified that there was a degree of cross-sensitivity in the detectors. This could be accommodated by appropriate operational procedures, but it would be strongly preferable to facilitate the detection industry to develop equipment to meet the requirements of routine and emergency gas detection procedures.

Together this work will be used to underpin review and refinement of the operational procedures to support not only the public trials, but will include engagement with all the GDNs to provide the basis for wider roll out.

<u>Wider deployment evidence base</u>

This evidence base is not necessary to undertake the specific public trials, but is critical to deliver roll out of blending and, as such, will receive input from all GDNs (WWU and SGN included).

Output from the roadmap work will be used to ensure that evidence is developed for appropriate pressure tiers for the future to ensure that blending can be delivered at least cost to consumers. Injection at higher volumes unlocks economies of scale on hydrogen production. Whilst such volumes could be distributed via an extensive hydrogen network to the medium and low pressure tiers (<2bar) it is more cost effective to inject into fewer injection points at higher pressure tiers in the network. For example the HyNet project has identified that over 2 million homes and business could be reached in the North West region from just 4 injection points into the Local Transmission System. This requires injection into natural gas pipelines at a high pressure , increasing the partial pressure of hydrogen and introducing a wider range of pipeline material types, both factors which must be properly understood. Whilst this understanding is not necessary for the specific trials, it is critical for roll out and this work is included within the scientific programme.

Deployment requires that all consumers can accept the blend. Whilst commercial installations have been extensively covered at Keele, with more expected alongside the public trials, the evidence base for industrial users must be developed. Almost all industrial users are connected to the distribution system, with very few connected to the NTS. Based on work by Cadent in its HyNet project, blend tests will be undertaken on industrial boilers as well as high temperature furnaces & kilns in the ceramic & glass sectors to ensure that they don't 'gate' the ability to blend into the network. Other work relating to CHP & CNG transport applications will also be reviewed.

2.3.2 Public trials

For the reasons outlined above, two trials will be undertaken. Both trial locations have been selected based on the requirement to provide a representative evidence base, each one with around 700 installations, matched to the scale of the existing equipment.

<u>Enabling activities</u>

In order to undertake the trials preparatory work is required. This includes development of the overall customer engagement plan, engagement with key supply-chain stakeholders (appliance manufacturers and suppliers, gas suppliers and shippers) as well as addressing regulatory issues, particularly relating to billing but also equipment ownership. The regulatory aspects are addressed in more detail in Section 7.0.

<u>Customer engagement</u>

Delivering a customer focused solution is the core rationale for the project. Cadent and NGN take pride in their commitment to their care for their customers. Therefore this project places the needs of the customer at its centre. A full and successful customer engagement plan was developed for the project at Keele which will be further developed for the two public trials. The experience at Keele, customer journey and outline plan is summarised in Section 8.0, supported by example material from Keele in Appendix K.

<u>First Public trial</u>

Following an extensive process of site review and selection, a trial location for the first public trial has been identified on Cadent's network. It requires only a single isolation from the network. It has 700 dwellings points and includes range of housing types and ages of mixed demographic as well as a diverse range of network. It also falls in a region deemed by Ofgem as an 'Energy Regulatory Pilot Area'. As part of risk managing project delivery, a reserve site has also been selected.

Customer engagement and Survey. The customer engagement plan will be rolled out in the local region. It is anticipated this will include the offer of a site visit to the project at Keele. This will enable the network and appliance survey process. During the first trial, the project will seek to engage with every customer on the relevant network in order to undertake safety checks on every appliances and installation. A qualified gas fitter and installation team will be developed to support this activity. This team will also provide the appropriate repair and replacement services as required. As part of this, training will be provided to Gas Safety engineers relating to hydrogen-blend operation to support the subsequent trial phase. Where required local testing on NG-H2 blends will be undertaken, this specialist work will be undertaken by KIWA in conjunction with the gas fitters. The network will be surveyed and modelled. The operational procedures will be assessed in light of the findings from the evidence base and refined where necessary.

Exemption development and submission. Based on the technical evidence base, site specific data and operational procedures review, a Quantitative Risk Assessment for the trial will be undertaken. This will underpin the Exemption application for submission to the HSE. Based on the positive experience with Keele, close engagement will be maintained with the HSE during the development of the application. The Exemption process is described in more detail in Section 7.0.

Installation. The necessary permissions and preparation of the site for the installation of the hydrogen production and equipment will be prepared in parallel to the survey and engagement work. Subject to the granting of an application, the hydrogen production, injection and monitoring equipment developed at Keele will be relocated, installed and commissioned on site.

Injection trial phase. A 10 month programme, covering winter peak and summer mininum will be undertaken to confirm and understand the operational behaviour of the network and appliances. During this phase, a sample of installations will be checked and servicing will be offered to all customers on the network. This provides an opportunity to confirm that appliance behaviour is consistent with the basis of the Exemption.

<u>Second Public trial</u>

The trial location for the second public trial has also been identified on NGN's network. It is located to provide access to a number of readily isolatable networks which can complement the characteristics of the first trial. It is a strategic location which already has good Local Authority support for this kind of trial, and is practically well suited to the installation and operation of the equipment. As part of risk managing project delivery, a reserve sites have also been identified.

The same process of customer engagement will be undertaken, building on the experience from the first public trial. The survey process will be significantly reduced, consistent with the philosophy of the programme. Gas Safe checks will be undertaken on a sample of properties, and no specific blend tests are expected to be required. However, this will still need development of an appropriate qualified gas fitter and installation team to do the checks and any repair and replacement (there still be an obligation to address any safety related issues identified in the properties sampled).

The Exemption submission will be prepared, based on the additional technical work, particularly relating to poorly installed and maintained appliances, as well as the more limited survey data. Similarly the necessary enabling site work will be undertaken in parallel to the survey and engagement work with the equipment relocated, installed and commissioned subject to the Exemption. During the 10 month injection trial phase, a sample of installations will be checked and servicing will be offered to all customers on the network.

2.3.3 Roadmap development

A deployment plan for hydrogen blending on the network will be developed with input from all the GDNs. It is necessary to ensure that the wider programme of work is properly focused on deployment issues, not just those in the trial. It is a considerably smaller work package than the others, and will be undertaken concurrently with the other project elements, as it will feed into these as well as draw on their outcomes. This work package comprises four components. **Network models.** System techno-economic assessment, including cost optimal network injection points and pressure tiers, linked to network capacity, scale of hydrogen sources and types, and existing/expected network control strategies. **Regulatory basis**. Based on the findings from the trials, engagement with shippers and suppliers and building on the outputs from the Future Billing Methodology project, practical recommendations will be made relating with regard to billing regimes for the future from a hydrogen perspective. Recommendations regarding the transition from case by case Exemptions to Regulation changes will be made. **Commercial basis.** Refinement of ownership models and provision of techno-economic data to enable development by HMG of appropriate support structures. **Skills and Training.** Establish the optimal approach for developing the skills required not only within the GDNs, but also amongst the wider gas fitter community. Together these four components will form a Comprehensive Roadmap for full deployment.

2.3.4 Dissemination

This programme is intended to unlock the process of hydrogen blending on the gas network as a means to deliver a practical means to reduce the carbon intensity of heat. Therefore, it is important that the findings of the project are properly disseminated to key stakeholders. This is addressed in detail in Section 5.

2.4. Changes since Initial Screening Process (ISP)

There have been no significant changes since the ISP, although the Programme and costs have been refined based on more detailed information arising from the work undertaken by the project team in developing this bid.

Section 3: Project business case

3.0 Summary

This project is a key enabling step to the decarbonisation of the gas grid for the delivery of low carbon heat. For the reasons outlined in Section 2.0, the GB's mature and extensive gas network delivers heat cost effectively to consumers using their existing appliances. The programme will establish the use of hydrogen as a blend to reduce the carbon content of the gas delivered via the network without requiring changes to either network or appliances. Fundamentally the case made the original HyDeploy application remains as strong, if not more compelling. There is a wider understanding of the opportunities afforded by hydrogen, the necessary steps required before it is possible to convert of the network to 100% hydrogen, and the wider system and consumer challenges associated with conversion of heat to electricity. The quantified benefits are laid out below.

3.1 Great Britain energy system benefits

Great Brtain has a world class gas distribution network delivering heat to consumers. This existing asset is well suited to the profile of heat demand compared with other approaches such as electrification. A key issue in supplying heat energy is the variable nature of heat demand. Peak and seasonal demand is extremely variable with peak capacity load on a daily basis being over 500% of the lowest day and the hourly variation being even more substantial. This presents a challenge for electrification using heat pumps, as the need to peak heat results in a substantial load on the electricity network. This requires substantial additional generation[14], with recent work for the Committee on Climate Change[15] indicating that electrification of heat would require between 385 and 460GWe of installed capacity compared with around 100GWe today (and scenarios with reduced nuclear construction requiring even further renewable capacity). Importantly it also requires extensive reinforcement to both the electricity transmission and distribution networks to deliver this power. When combined with the expectation of an increased role of electrification in transport that pressure becomes significant.

Without this increase in electricity generation, transmission and distribution capacity, in an electric heat scenario, consumers would not receive the heat they require on the coldest days. In contrast, the existing gas grid is well proven in providing peak demand, being scaled to deliver the maximum 6 minute demand in 20 years.

The approach of this Solution is to exploit this existing network by reducing the carbon intensity of heat delivered through blending of hydrogen delivering up to 29TWh per annum of low carbon heat. This approach requires no changes to appliances and network providing a non-disruptive to customers. It can operate seamlessly with a range of future heat scenarios, and provides a deliverable pathway. Cadent's HyNet NW project demonstrates how blending into the local distribution zone to decarbonise domestic heat can work in combination with higher blends and full hydrogen in industry to deliver deeper decarbonisation. It also provides a platform for flexible hydrogen fuelled power generation to balance intermittent renewables, as well as facilitating complementary zero carbon

[14] KPMG 2050 Energy Scenarios , July 2016
[15] 'Analysis of Alternative UK Heat Decarbonisation Pathways' Goran et al, June 2018

solutions for transport. Critically blending enables customers to understand and become accustomed to hydrogen as fuel, develops large scale hydrogen production (including CCS), as well the supply chain and skills base. This could therefore provide a pathway to conversion of elements of the gas network to full hydrogen as exemplified by the H21 project. However, that approach is focused on large conurbations, and so anticipates that there will remain a considerable element of the network still operating on conventional gas. Therefore, a natural gas-hydrogen blend will also have an enduring role.

The majority of the benefits of this solution will be realised by gas customers by avoidance of installation of heat pump solutions, as well as avoided the costs associated incremental reinforcement of electricity networks, as summarised in Section 3.3.

3.2 Network licensee benefits

3.2.1 Aligned with Strategic direction

Both Cadent and NGN are seeking to make best use of the gas network in a low carbon economy. For example Cadent's stakeholders have said they want Cadent to remove barriers for the development of renewable gas and educate stakeholders on the role for gas in a low carbon economy[16]. This has been an ongoing activity for both parties, including specifically the use of hydrogen. Cadent undertook a series of documents engaging with stakeholders on the role of the Future of Gas[17], of which one dedicated to renewable gas specifically recognises the role of Hydrogen[18]. In May 2018, it launched the HyNet NW project[19] which is founded upon the use of hydrogen blending in its network, this element saving around 0.5 million tonnes of carbon per annum from its network from this initial project alone. NGN have been instrumental in initiating the H21 project, which is now a NIC funded project involving all the GDNs[20], seeking to address the barriers to full hydrogen deployment. All the GDNs as well as the Transmission Operator are pursing low carbon gas solution with a strong emphasis on hydrogen. They supported the formation of an All Party Parliament Group on Hydrogen[21] in July 2018, and there is close engagement on BEIS projects such as Hy4Heat[22]. Policy Connect is currently undertaking an enquiry entitled 'Next Steps for the Gas Grid' supported by National Grid providing evidence to support evidence to underpin energy policy, which has cross party support[23]. This work strongly advocates the role for hydrogen, and specifically sees the role for blending as central to energy policy for heat going forward. The IMechE recommends that Government works with industry to promote the use of hydrogen blends in the gas network[24]. WWU, SGN and National Grid are supportive of the project, sit on the current Advisory Panel and will do so for HyDeploy$_2$.

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16 http://www.talkingnetworksngd.com/assets/downloads/2013_Committing.pdf
17 http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas/
18 http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=45609
19 https://hynet.co.uk/
20 https://www.ofgem.gov.uk/publications-and-updates/network-innovation-competition-project-direction-h21
21 https://connectpa.co.uk/appg-hydrogen/
22 https://www.arup.com/en/news-and-events/news/Arup-and-Kiwa-Gastec-appointed-to-explore-potential-for-using-hydrogen-to-heat-UK-homes
23 https://www.policyconnect.org.uk/cc/
24 https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/imeche-energy-from-gas-report-final-may-2018.pdf?sfvrsn=2

3.2.2 Individual network benefits

The connection of hydrogen production facilities into the distribution system will result in lower NTS exit capacity costs for the individual GDNs. This benefit would start as hydrogen is connected. If exit capacity charges continued at their current levels, 29 TWh of hydrogen into the distribution system would represent savings of £5 million per annum in addition to the more substantial wider benefits discussed below.

3.2.3 New opportunities

The transition to the use of hydrogen provides a platform for wider developments of the gas system in the transition to a low carbon economy. Recent policy changes mean that conventional liquid fuelled transport is being phased out over the next 25 years. Renewable gas and hydrogen offer alternative vectors alongside electrification, with an increasing recognition that constraints to electricity transmission and distribution capacity, as well as charging times, mean that both gas and electricity vectors are likely to operate in tandem. This provides an opportunity for gas transporters to enter the transport fuel distribution market, with the benefits afforded to existing customers of underpinning and potentially increasing the overall customer base over which costs are distributed. Cadent is currently undertaking a study[25] into work related to the use of hydrogen for this market, addressing the implications and opportunities for the gas distribution network.

Enabling adoption of hydrogen brings forward opportunities for use of hydrogen for flexible power generation to balance intermittent generation, as well as considerations as to how the electricity and gas networks integrate to the benefit of customers and to decarbonise transport, most notably HGVs. NGN's InTEGReL project addresses these opportunities in terms of integration of gas, electricity and transport[26].

3.2.4 Underpinning the life of the network

The use of hydrogen capitalises the existing asset base and extends the life of the gas system. This exploits the sunk costs associated with an existing asset and avoids its costly decommissioning. Work by National Grid suggests that this is of the order of £8 billion.

3.3 Customer benefits

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

3.3.1 Financial benefits

Gas customers receive their heat at present via the gas grid using gas boilers. If the gas grid carbon intensity can be reduced, such as through hydrogen blending, then customers can continue to use their existing appliances and consume gas. If this is not possible, then an equivalent quantity of low carbon heat must be delivered via another means. As discussed below, the widely recognised alternative is heat pumps. Therefore such customers would need to invest in new heating systems and associated electricity costs. The financial benefits to customers has been analysed as summarised below, and explained in more

[25] http://www.smarternetworks.org/project/nia_cad0022
[26] https://www.northerngasnetworks.co.uk/ngn-you/the-future/integrel/

detail in Appendix B. The fundamental case remains consistent with the assessment undertaken for the original HyDeploy, updated primarily to reflect indexation and demand projections. The premise that heat pumps represent the appropriate alternative heat solution remains the case, and there have been no material changes in future projections in costs going forward over the timeframes considered.

As required, the modelling considers 3 horizons of assessment: deployment across the whole network; deployment across the participating GDN's networks; and the 'post trial' case, which is continued operation of the equipment post trial.

National Grid maintains a number of scenarios for the development of the energy system into the future (Future Energy Scenarios). These produce forward curves of adoption of different technologies and energy vectors to deliver electricity, heat and transport in the GB energy system, based on a complex combination of constraints.

In all its scenarios, heat pumps play an important role in the decarbonisation of heat. Whilst the timings of the introduction of such solutions varies between scenarios, in all cases heat pumps are the 'marginal' low carbon solution adopted in order to meet the carbon targets required. The introduction of hydrogen into the network allows the avoidance of an equivalent proportion of the heat pump installations, providing that heat delivered by hydrogen is more cost effective.

The approach taken has been to calculate the levelised cost of heat delivered by air source heat pumps (the lowest cost heat pumps) accounting for projections of cost and performance developments expected over the period, based on referenced sources, along with the expected cost of power. Absolute values are shown in Appendix B. This is compared to "business as usual" which is the supply of heat from a natural gas fired boiler accounting for its efficiency, and purchase cost and retail cost of gas. This excludes the cost of the electricity network reinforcement required for this decarbonisation route, which is considered separately below.

Together, this provides the base case against which the costs of a hydrogen route can be assessed. The purpose of this project is to ascertain the level of hydrogen blend feasible without making appliance or network changes, therefore the key determinant is the cost of the decarbonised hydrogen.

The three sources of hydrogen are considered: bio-hydrogen, electrolysis and from steam methane reformation. The cost base of each of these has been calculated based on referenced data sources for capital cost and performance of the production methods, as well as underlying 2018 energy pricing from the wider Future Energy Scenario Modelling over the period. Against the mix of production technologies over time shown in Appendix B, the hydrogen cost has been converted to a retail price for the hydrogen, as for natural gas. The cost of a unit of useful heat has been calculated by dividing the cost of hydrogen by the efficiency of the boiler as well as the costs of owning and operating a gas boiler. The net additional cost of decarbonised heat from hydrogen compared with gas is calculated and compared with heat delivered by heat pumps.

The cost of the decarbonised heat relative to natural gas for heat pumps and from hydrogen is similar in 2020 at £89/MWhr. Whilst both are seen to fall over time, the cost of heat via hydrogen does so rapidly, so that by 2030 the heat pump route is £71/MWhr compared with hydrogen at £55/MWhr. At 2050, this is £55/MWhr and £45/MWhr respectively. This excludes the cost of electricity network reinforcement for the heat pump solution.

Gas consumption on the distribution network is based on National Grid's Slow Progression scenario over the period. The reference scenario is a blend rate of $20\%_{vol}$. This is consistent of the findings from the HyDeploy project at Keele, and is consistent with the work undertaken by Engie in its GrHyD project at Dunkirk which commenced injection at $20\%_{vol}$ on 11 June 2018, injecting hydrogen into a new gas network. A further $10\%_{vol}$ case is also shown, as it is recognised that the transition from a closed private network to a public network may identify issues that could constrain the level of blending. Given that $10\%_{vol}$ is already permitted in parts of Europe, this was selected as an appropriate lower bounding case, although the expectation is that the blend rate will be considerably higher. The trajectory to attaining these volumes of hydrogen over the period is assumed to be governed by the availability of hydrogen from the mix of production technologies. The assumptions for which are laid out in Appendix B.

In addition the savings associated with avoidance of network reinforcement otherwise required to deliver the equivalent level of low carbon heat delivered by heat pumps has been estimated. This cost has been calculated on a per annum basis over time in Appendix B.

The savings are calculated based on the level of decarbonised heat supplied for each year over the period. These are expressed cumulatively on a Net Present Value basis (Discount of 3.5% for first 30 years and 3.0% thereafter) and are shown in the table below, consistent with Appendix A.

Cumulative NPV	Blend rate (Method)	To 2020 £million	To 2030 £million	To 2040 £million	To 2050 £million
GB Values	20% Blend (M1)	0	2,090	6,352	7,918
	10% Blend (M2)	0	942	2,666	3,161
Licensees (63% of GB)	20% Blend (M1)	0	1,317	4,002	4,988
	10% Blend (M2)	0	593	1,679	1,991
Post Trial	Either blend	0	0.5	0.8	0.8

The savings are shown for the GB case, just the Cadent and NGN networks and a post trial case, which is the continued operation of the grid entry and electrolyser units post trial, avoiding the equivalent of 164 Air Source Heat pumps.

At its peak this equates to a GB saving of over £800 million per annum for the 20% case.

The costs associated with the requirement for increased generation capacity, estimated to be around 8.8GWe, to service the peak demand of 3 million avoided heat pumps, has *not* been included in this analysis. In reality these would need to be introduced via the capacity market. Assuming £49 per kWe of installed capacity, this would equate to a further £4,100 million saving over the period on an NPV basis, which would ultimately be paid by consumers who would have had to move from gas to electricity for their heating.

The potential role that Electrolysis units could offer as balancing services to the electricity grid have also not been included, although this is widely recognise to be a valuable element of the technology, and hydrogen storage has been included in the assumptions.

The costs associated with the decommissioning of the gas grid have not been accounted for. These are estimated by National Grid to be around £8,000 million, which are avoided or deferred by utilising the grid to deliver low carbon heat.

3.3.2 Non-financial benefits

The non-financial benefits are one of the key attractions of this approach inasmuch as they enable households to participate in delivering carbon reductions without substantial barrier (as discussed in Section 6). Both the WWU Bridgend study, as well as KPMG's 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 solutions want a gas solution which requires no change on their part. Even new build infrastructure tends to be based on gas heating; it is a low cost and low risk solution for developers and is trusted by potential purchasers.

3.4 Environmental benefits

This is the key rationale for the project; to enable customers across the network to reduce the carbon content of the heat they consume without disruption or capital outlay.

Alongside the financial benefit assessment, the carbon savings achieved by blending hydrogen into the distribution system have been assessed. This considers both 10% and 20% hydrogen blend cases. Based on a wide range of references, the carbon intensity the three hydrogen production techniques are established, and assumptions are made about the mix of these hydrogen sources over the period to 2050. This also shows that both hydrogen and heat pumps deliver similar levels of carbon savings, but the hydrogen route is substantially lower cost compared with heat pumps, as well as being less disruptive. This is explained in more detail in Appendix B. The table below summarises the results on a cumulative basis as required for Appendix A.

Cumulative Carbon Saving	Blend rate (Method)	To 2020 Te CO_2 eq	To 2030 Te CO_2 eq	To 2040 Te CO_2 eq	To 2050 Te CO_2 eq
GB Values	20% Blend (M1)	0 mill	9.6 mill	63.8 mill	118.5 mill
	10% Blend (M2)	0 mill	4.8 mill	31.9 mill	59.2 mill
Licensees (63% of GB)	20% Blend (M1)	0 mill	6.0 mill	40.2 mill	74.6 mill
	10% Blend (M2)	0 mill	3.0 mill	20.1 mill	37.3 mill
Post Trial	Either blend	0	3,019	6,521	6,521

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 makes contribution to the Government's current strategy for reducing greenhouse gas emissions, as set out in the document entitled "the Carbon Plan" published by DECC (now known as BEIS)

What aspects of the Carbon Plan the Solution facilitates

The Carbon Plan identifies that by 2030 there is a requirement *to 'deliver between 83-165TWh of low carbon heat'*. In 2017[27] the domestic RHI delivered an estimated 0.8TWh[28] and the non-domestic RHI delivered 7.7TWh. Over the life of both schemes, the renewable delivered heat is dominated by non-domestic biomass boilers and biomethane (85%), with only 5% delivered though heat pumps, with heat pump accreditations flat at around 6,500 per annum, compared with a peak of over 15,000 accreditations in 2015. This emphasises that challenges associated with customers having to make expensive and disruptive changes to their homes. In its 2018 RHI impact assessment[29], BEIS revised down its projections indicating *'that by 2020/21, the RHI could deliver 21.4TWh of renewable heat'*. Hydrogen blending has the potential to deliver substantially more decarbonised heat than the entire RHI has delivered, and without disruption to the domestic customer.

In order to meet UK carbon commitments, a substantial step change is required. Consistently the Committee on Climate Change (CCC) has challenged government on the lack of progress in this sector, most recently in its July 2018 Report on Progress to Parliament[30], it has stated that *"In the last five years, emissions outside of power and waste have plateaued. My Committee has chosen this moment to give a strong message to Government: Act now, climate change will not pause while we consider our options. And act in the consumer interest: pursue the low-cost, low-risk options".*

The Carbon Plan Executive Summary states that *'the oil and gas used to drive cars, heat buildings and power industry will, in large part, need to be replaced by electricity, sustainable bioenergy, or hydrogen'*. The Plan identifies the consumer and network challenges associated with adoption of non-gas, low carbon solutions such as biomass combustion or heat pumps. These are explicitly outlined as: high upfront capital costs for consumers; Disruption and time taken to install such systems; most heating system replacements are a 'distress purchase' where the requirement is rapid reinstatement; added strain on the electricity grid associated with heat pump solutions.

The Carbon Plan provides BEIS's overall framework, which is embodied in a number of further documents focused specifically on the low carbon heat sector. In its low carbon heat

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27 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/674579/RHI_monthly_official_statistics_tables_31_December_2017_final.xlsx

28 Note that only the total energy between April 2014 and December 2017 are reported, so the 2017 heat delivered is estimated using this figure and accreditations over time.

29 https://www.legislation.gov.uk/ukia/2018/84/pdfs/ukia_20180084_en.pdf

30 https://www.theccc.org.uk/comingup/ccc-report-2018-progress-report-parliament/

strategy document[31], BEIS identifies the role for hydrogen and observes that *'In the near term, relatively small quantities of hydrogen could also be injected into the gas grid to enrich natural gas and reduce carbon emissions from conventional gas-fired boilers'* and that *'it may also be possible to repurpose the existing low-pressure gas distribution grid to transport hydrogen at low pressures, which could be used in modified gas boilers and hobs, and in building-level fuel cells.'* It identifies that *'More evidence is needed on whether hydrogen-based approaches hold practical promise for the UK'*. This was reiterated in its follow on document[32] focused on implementation steps. Most recently in its Clean Growth Strategy[33] it stated that '*Clean fuels such as hydrogen and bioenergy could be used for transport, industry, and to heat our homes and businesses. We need to test how they work in the existing gas network, whether they can fire industrial processes, and how they could be used in domestic appliances."* Hydrogen is one of the three scenarios it proposes for 2050. A key conclusion from the work by Imperial for the CCC[34] is that "..*the focus of any action should be to address uncertainties…Hence consideration should be given to a programme of technology deployment on a pilot trial basis. These initiatives should be designed to encompass all aspects of deployment from production through to the end-users, while including all types of representative buildings."* This is exactly the purpose of this project; to trial the blending of hydrogen at scale, enabling deployment of a low carbon solution for domestic heat customers.

<u>The contribution the roll-out of the Method across GB can play in facilitating these aspects of the Carbon plan</u>

Establishing practical injection of hydrogen at between 20%$_{vol}$ fraction into the gas distribution network would deliver 29TWh of decarbonised fuel. This is considerably greater than BEIS' projected delivery of renewable heat from the RHI by 2021. BEIS have substantially reduced the expectation of the role that heat pumps play towards this, but still rely on a 3 fold increase from deployment today. Solutions which address requirement for considerable customer investment and avoidance of disruption will be important.

The carbon savings are quantified in detail in (Section 3 & 4.1.3ii, supported by Appendix B) which shows that by 2050 decarbonisation of the gas network by using a hydrogen blend has the potential to save 119 million tonnes CO_{2eq} by 2050 on a cumulative basis.

The project facilitates wider adoption of hydrogen. It addresses customer perceptions of hydrogen through experience, as well as development of the supply chain and skills base. This could therefore provide a pathway to conversion of elements of the gas network to full hydrogen as exemplified by the H21 project. However, that approach is focused on large conurbations, and so anticipates that there will remain a considerable element of the network still operating on conventional gas. Therefore, a natural gas-hydrogen blend will also have an enduring role.

<u>How the roll-out of the proposed Method across GB will deliver the Solution more quickly than the current most efficient method in use in GB.</u>

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[31] "The Future of Heating: A strategic framework for low carbon heat in the UK", DECC (2012)
[32] "The Future of Heating: Meeting the Challenge", DECC (March 2013)
[33] "The Clean Growth Strategy Leading the way to a low carbon future" BEIS (Nov 2017)
[34] "Analysis of Alternative UK Heat Decarbonisation Pathways" Goran et al (June 2018)

Delivery of low carbon heat via heat pumps face substantial barriers to entry as outlined in the Carbon plan, and evidenced in the work undertaken by WWU in their Bridgend project. The requirement for high levels of capital outlay and substantial disruption, means that consumers are not adopting these technologies as widely as anticipated. This is evidenced by the low rates of uptake experienced by BEIS in the RHI, despite the them receiving very high tariffs of £105/MWhr for air source heat pumps and at the maximum 'Value for Money' cap for ground source heat pumps at £205/MWhr. It recognises that non-financial barriers remain significant.

The overarching benefit of the proposed Solution is that consumers are not required to make any changes and, as shown in the financial assessment, the overall costs are substantially lower.

By focusing on the blending of hydrogen at a level which requires neither modification to appliances nor to the network, there are no infrastructural barriers to deployment. This means that on successful delivery of this project, roll out is not hindered by the requirement to undertake asset changes on the network, nor importantly disruptive changes to consumer appliances. Furthermore, because no changes are required, should blending levels revert at any point in the network in the future, the system remains resilient. Therefore no additional provisions are required to be put in place for that outcome. Therefore, compared with conversion to zones of the network to 100% hydrogen, this approach is able to be adopted significantly more quickly.

Roll out is therefore governed by the provision of hydrogen generation. As outlined below, three potential sources of hydrogen are considered, from electrolysis, from bio-hydrogen and reformation of gas with Carbon Capture and Storage (CCS). This suite of technologies can provide a pipeline of hydrogen over the next 3 decades. Electrolysis is an established technology with no technical barriers to deployment, as demonstrated by this project and currently being used for injection in Europe. Bio-Hydrogen is a simplification of BioSNG which has operated at scale in Sweden, and being demonstrated in France, with a demonstration plant in construction in the UK. Production of hydrogen by reformation is established technology, but this route does depend on establishment of CCS infrastructure. The HyNet NW project is designed to follow seamlessly from the public trials in this project to roll out hydrogen blending across 2 million homes in the North West, establishing the first large scale hydrogen production and CCS infrastructure in the UK by 2025. Therefore this suite of technologies is able to provide hydrogen in the short, medium and long term with a change in the mix over time, as discussed in more detail in Appendix B.

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

This is the key rationale for the project; to enable customers across the network to reduce the carbon content of the heat they consume without disruption or capital outlay.

The Carbon benefits to customers have been analysed in detail, as described in Section 3 and in more detail in Appendix B. The table below summarises the result from this analysis, based on the natural gas which is displaced through the use of hydrogen, fully accounting for the carbon emissions associated with its production.

Cumulative Carbon Saving	Blend rate (Method)	To 2020 Te CO_2 eq	To 2030 Te CO_2 eq	To 2040 Te CO_2 eq	To 2050 Te CO_2 eq
GB Values	20% Blend (M1)	0 mill	9.6 mill	63.8 mill	118.5 mill
	10% Blend (M2)	0 mill	4.8 mill	31.9 mill	59.2 mill

On a per annum basis, the 20% carbon saving equates to around 6 million tonnes saving per annum, or around 200kg CO_{2eq} per householder per annum. In carbon terms, it is equivalent of removing 2.5 million vehicles from the road.

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

The financial benefits to customers have been analysed in detail, as described in Section 3 and in more detail in Appendix B. In all future looking scenarios heat pumps are the 'marginal' low carbon solution adopted in order to meet the carbon targets required. The introduction of hydrogen into the network allows the avoidance of an equivalent proportion of the heat pump installations, providing that heat delivered by hydrogen is more cost effective. In this analysis the cost of heat delivered by hydrogen is compared to the cost of heat delivered via air source heat pumps. This analysis includes the savings associated with avoidance of network reinforcement otherwise required. The savings are calculated based on the level of decarbonised heat supplied for each year over the period. In this analysis, the costs associated with the requirement for increased generation capacity, estimated to be around 10GWe of capacity to service the peak demand of 3 million avoided heat pumps, has *not* been included in this analysis. Neither have the costs associated with the decommissioning of the gas grid, estimated to be around £8,000m, which are avoided by utilising the grid to deliver low carbon heat.

The figures are expressed cumulatively on a Net Present Value basis and are shown in the table below, consistent with Appendix A. At its peak this equates to a saving of around £800 million per annum.

Cumulative NPV	Blend rate (Method)	To 2020 £million	To 2030 £million	To 2040 £million	To 2050 £million
GB Values	20% Blend (M1)	0	2,090	6,352	7,918
	10% Blend (M2)	0	942	2,666	3,161

The cost per tonne of carbon abatement is just 65% of that expected for the Wylfa Nuclear plant (on the basis of Strike price of £77.50/MWh, which itself is considerably lower than Hinkley Point C). Further, it is tackling an area of energy economy which is particularly challenging to address.

4.2 Provides value for money to gas/electricity distribution/transmission 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 beneficial impact on all GB gas distribution Licensees; if it is successful, the hydrogen could be injected across the network. This project is a collaboration between two gas distribution network operators, Northern Gas Networks and Cadent. In addition, both SGN and WWU support the programme and have agreed to sit on the Project's Advisory Panel.

The programme unlocks blending of hydrogen on the wider public network delivering a practical and safe means to deliver low carbon, flexible heat. In particular it establishes the practical and operational requirements on a public network. The specific learning from the project is therefore directly attributable to the gas transportation system.

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 in Section 4.1.4, the £13.3 million of NIC funding, building on the initial funding for HyDeploy at Keele, enables a low carbon solution which delivers discounted savings of £7,920 million. A breakeven on the project support would be achieved by the mid 2020s, more than delivered by the HyNet NW project alone.

More widely, based on KPMG's assessment[35], enabling adoption of hydrogen as part of a wider low carbon gas-based energy system could increase the £8 billion saving associated with blending, by a multiple of more than twenty times to between £170 to £196 billion, compared with an all-electric future.

This project delivers value for money by reusing the equipment developed for the initial HyDeploy trial at Keele (Electrolyser, Hydrogen grid entry unit and analytical equipment) on two separate trial sites. This equates to nearly £2 million of design, development and fabrication. Seamless moving of this equipment to the new sites maximises utilisation.

Overall this project is expected to trial a hydrogen blend in around 1500 homes, in two distinct locations, providing the necessary data to support roll out covering a wide range of network configurations and appliance types. This equates to fifteen times more installations than at Keele, for less than double the cost, including clearing the necessary wider barriers to deployment.

This programme builds on an established core consortium, with established working practices and efficiencies. The project will be managed such that costs are controlled and value delivered. Cadent and NGN have executed many IFI/NIA/NIC projects and have well established contractual and governance arrangements for delivery, with an experienced management team structured to deliver the project cost-effectively. Based on the significant potential savings highlighted above, combined with the reuse of existing investments, the request for £13.3m from NIC to enable UK deployment offers good value.

The proposed project will address the key elements necessary to translate from the seminal project at Keele to full deployment. It will move from the requirement to survey, test and trial all parts of a network prior to injection, to the ability to inject into an untested network, as necessary for roll out. The outcome sought is that a hydrogen producer can apply to any GDN to inject into the network in the same way that a biomethane producer can today. The process that was undertaken for biomethane has now enabled over 85 plants to connect to the network, and established biomethane as the lowest cost and dominant means by which domestic consumers are able to decarbonise heat today. This project seeks to enable that position to be achieved for hydrogen use as a blend.

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[35] "2050 Energy Scenarios", KPMG, July 2016

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

As outlined in Section 6.0, building on the existing delivery consortium for HyDeploy delivers the project cost effectively. It allows seamless transfer of skills and knowledge from the project at Keele, minimises administrative and governance costs and maximises benefits through established relationship within and beyond the project team.

- There is a significant level of know-how and experience developed through the project team. Whilst the core knowledge has been distilled into the Exemption submission and is being shared widely, there are skills and abilities, along with intangible knowhow which has been developed by the team. Retaining the core team means that the project benefits in terms of time saving associated with detailed understanding at the outset and decisive focus on key issues. This translates into value for money for the project.
- The project will benefit from the learning developed from the HyDeploy programme at Keele. A number of project areas were found to cost more than originally budgeted, particularly costs relating to the first of a kind hydrogen grid injection unit. The collaborative project strategy has enabled cost savings to be realised across the project to mitigate cost overruns. The established project teams enable the same collaborative processes to be deployed to manage cost and budgets effectively. This is managed through the project management team, supported by the governance of the steering committee.
- Through the existing HyDeploy project, relationships have been developed across the supply chain which have delivered value for money. Appliance manufacturers have contributed: significant time to workshops; provided instrumented equipment to the project; and the four largest boiler suppliers are not only providing eight boilers to the trial programme, but supporting accelerated testing and forensic analysis post trial. Similarly, analytical equipment suppliers are providing measurement equipment free of charge. The project team is building on this trust and these relationships to deliver value for money under $HyDeploy_2$, saving costs on the experimental programme, but also ensuring that the benefits are maximised, ensuring that the market is ready for wider roll out.
- Through the InTEGReL project, NGN have developed close working relationships with Newcastle University, Northern Power Grid as well as key local authorities. Elements of the programme are being leveraged through these relationships to deliver enhanced value for money. Important work relating to public perceptions of hydrogen will be undertaken in conjunction with and integration with other programmes achieved during the North East trial, delivering project cost benefits.
- Through the HyNet project, relationships have been developed with a wide range of industrial users and equipment suppliers, such as burner manufacturers who are keen to support the project and enable the necessary trial work to take place. This is allowing a cost effective experimental programme.

In the event that further savings can be achieved during the course of the project, then unspent funds will be returned to gas customers via the mechanism provided for in the NIC governance process.

The programme has been designed to allow phasing of spend corresponding to confidence in each project stage. The Exemption for the first trial will not be submitted until the trial phase at Keele is complete; the equipment will not be relocated until the Exemption is granted; the follow-on phase of technical evidence for the second trial is scheduled to take place only once the Exemption for the first trial has been secured; and the second trial will only take place once the first trial is completed. This manages risks and cost exposure.

Cadent and NGN 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 I, and is summarised in the Table below:

	Total Labour across Project					Other costs	Total
	No of staff	Man-days	Rates Range	Rates Ave	Labour Cost		
	FTEs	Days	£/day	£/day	£000	£000	£000
Evidence	6.3	3,468	230-1549	£834	£2,901	£2,898	£5,799
1st Trial	6.6	2,532	230-1549	£487	£1,233	£3,281	£4,514
2nd Trial	6.7	2,572	230-1549	£469	£1,200	£2,565	£3,765
Dis'm+Rdmp	2.0	1,737	230-1549	£412	£714	£178	£891
Total	11.7	10,309	230-1549	£587	£6,048	£8,921	£14,969
NIC Funding request	Not accounting for bank interest				£5,443	£8,029	£13,472
	After OFGEM Bank interest provision						£13,282

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 revenues associated with the use of the gas network account for around 18-20% of the total gas price to consumers and this proportion is likely to remain approximately the same into the future. The overarching benefits of using hydrogen as a blend to decarbonise the gas grid are seen in the reduced need to develop alternative, more expensive low carbon heating technologies. However, the main benefit to the gas network from use of hydrogen is that it underpins its continued utilisation. By delivering low carbon energy over the existing network, the gas network itself, with an asset value of around £25bn, retains its importance in the wider mix of low carbon heat solutions. The wider development of hydrogen as a vector may also offer new opportunities for gas network operators in the future, such as a transport fuel.

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

As outlined in Section 4.4, Cadent and NGN will continue to use the existing team that has delivered HyDeploy at Keele University. Both parties considered carefully the role that each partner has played in the project. For the reasons outlined in Section 4.2.3 this delivers value for money, reduces project risk, and maximises the project benefit. The original team selection was predicated on their established processes to identify participants in their innovation projects.

4.2.6 (vi). The costs associated with protection from reliability or availability incentives and the proportion of these costs compared to the proposed benefits of the Project.

This project does not impact reliability or availability incentives

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 the Project is innovative & evidence it has not been tried before;

The HyDeploy programme is enabling physical injection of hydrogen blended with natural gas into the GB network for the first time. In the transition from town gas, Dutton established the impact on networks and appliances of a range of gas compositions through 'interchangeability' diagrams, but due to the lack of naturally occurring hydrogen in North Sea Gas, these were simplified to exclude its effects, setting the regulatory limit to just 0.1%. This level has been embodied in the GS(M)R and therefore neither the gas grid nor GB appliances have transported or utilised hydrogen blends.

The HyDeploy project at Keele is providing the first foundational stage. This project has allowed development of much of the core science associated with blending. However, the case for Exemption on that closed private network is predicated on detailed knowledge of all components & appliances, the benefits associated with a small and tightly controlled network and a range of mitigation measures which can be put in placed in this context. Together this allows an Exemption application where some of the very conservative assumptions can be offset by specific measures to ensure that the risk is managed.

Delivering a hydrogen blend on a public network is a significant further innovative step, yet the HSE must be convinced that it does not prejudice the safety of gas users and consumers. The public network inevitably entails a wider range of network materials and in-service duty conditions, will have significantly more appliance types, and crucially a mix of installation qualities, including poorly maintained equipment, and networks managed by a wider range of operators and procedures, with less scope for 'special measures'. It is clear from the engagement with the HSE on the Exemption at Keele, this greater level of unknowns will require a considerably greater evidence base and scrutiny. Furthermore, the objective is that after HyDeploy$_2$, a hydrogen provider can apply to a GDN to inject into the network much as a biomethane producer can today. This means that the evidence base developed must be sufficiently robust that this does not require further assessment of appliances each time that such an application is made. It is also imperative that all users are able to accommodate the blend. Given that the majority of industrial users are also connected to the Local distribution system, it is also imperative that the robust evidence base is developed that they are also able to accept the blend.

HyDeploy$_2$ builds on the substantial evidence base developed at Keele, but also the wider activities being undertaken internationally on hydrogen blending. The GrHyD project in France commenced injection at 20% for the first time on 11 June 2018, and the HyDeploy team has developed a good working relationship with the Engie team delivering that project. This is a new gas network with 100 new homes and appliances and one hospital; in that regard it is a more conservative project then even the HyDeploy Project at Keele. Delivering a blend on an old public network is a considerably more innovative project than this. The work in HyDeploy$_2$ will deliver that evidence base to enable roll out.

Not only does this novel project enable blending hydrogen onto the gas network, it unlocks wider development of hydrogen as a vector. More widely, establishing a market for hydrogen via the network, enables the market growth for other applications from larger scale industrial users to transport.

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 barriers this project will address relate entirely to the ability of a GB gas network to secure an appropriate Exemption from the hydrogen limit from HSE, and to undertake operational trials of Hydrogen-Natural Gas blends. There is no direct financial benefit to the network to undertake such a programme, and no reason it should do that under business as usual operation. The Project Risk Register can be found in Appendix H, with an overview in Section 6.1.4 below. In summary, the key risks this programme seeks to address are The risks this programme seeks to address are: **Technical & Operational** - operation of appliances safely on a blend, safe operation of the network including network flows, pipeline integrity, network maintenance and leak detection; **Commercial** - metering of hydrogen and appropriate billing regimes; and **Regulatory** – securing Exemptions to the GS(M)R and establishing the basis for future roll out. None of these risks would need to be addressed if the GDNs were to continue to operate the network using natural gas. The rationale for the project is to enable an alternative, low cost & non-disruptive decarbonisation solution for the customer and for the UK to meet its carbon commitments.

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

4.4.1 Processes undertaken to select the project

As outlined in the original HyDeploy proposal, public network trials were an integral part of taking the work on the closed private network at Keele to wider roll out. In that regard this project has been in the development pipeline since that first proposals.

For both GDNs has been important to establish (a) that the fundamental rationale for delivering low carbon heat via gas and specifically hydrogen blending remains an imperative strategic requirement, (b) that it is supported by the other GDNs and doesn’t conflict or duplicate other work being undertaken and (c) that the evidence base from the project Keele supports this next step. Cadent and NGN are confident that these requirements are compellingly met to take this next stage. The recognition of the importance of customer focused low carbon heat solutions has increased since the decision to undertake the original HyDeploy project. The benefits of gas in providing peak heat and the challenges associated with heat pumps has been increasingly understood, and therefore the expectation is that low carbon heat will be delivered though a mixture of vectors. The project has the support of the other GDNs, and no fundamental barriers to delivery have been identified at Keele.

Through the GIGG process innovation managers share openly their ideas and roadmaps for innovation to ensure that duplication is avoided, and that coherent developments are undertaken. Through this WWU and SGN continued support for this next project has been established. In evaluating and developing their innovation project pipeline Cadent and NGN ensure that projects: (a) are aligned to the vision of the GDN, specifically in this case the role of gas in the future, (b) meet OFGEM’s criteria; accelerating the low carbon economy, benefiting the gas customer and innovative, (c) are deliverable - the level of risk attached to achieving the outcome and clarity of scope outputs, and (d) are collaborative with credible partners. $HyDeploy_2$ has been positively assessed on these criteria by the GDNs.

4.4.2 Collaboration and Partners

To deliver this project safely and effectively and ensure that its delivery is risk managed requires collaboration between the right partners. This project will building on the existing delivery consortium for the HyDeploy at Keele. This allows seamless transfer of skills and knowledge from the project at Keele, minimises administrative and governance costs and maximises benefits through established relationship within and beyond the project team.

The core partners are all signatories to an existing Project Collaboration Agreement. $HyDeploy_2$ will be able to adopt this agreement with minor project-specific modifications, avoiding repetition of the lengthy process required to put this in place under the original HyDeploy project

This project is a true collaboration between two GDNs. **Cadent Gas** is the Funding Licensee & project sponsor and will undertake the first trial on its network and **Northern Gas Networks** is the collaborating GDN and will undertake the second public trial on its network. They both bring their expertise and experience to the project. As explained in more detail in Section 6 and Appendix K, the partners are: **Health and Safety Laboratory (HSL):** is of the UK's foremost health and safety experimental research establishments whose experience significantly de-risks the project. They will plan and oversee the scientific & experimental programme, building on the extensive work from the project at Keele. **Progressive Energy** is responsible for Project management, planning and overall programme co-ordination as it has done for HyDeploy. It also has a track record of providing in depth technical challenge and review. **ITM Power** is uniquely experienced in hydrogen grid injection projects and will continue to maintain the hydrogen production plant. **Keele University** will remain a project partner, albeit in a much reduced capacity compared with the original project on its site. Their continued involvement facilitates any additional technical testing on the network at Keele required for the public trials as well as supporting the public trial customer engagement programme, such as hosting site visits. Separate from this project, Keele are undertaking sociological work on energy and hydrogen, informing communications.

In addition to the core partners, the project is supported by key identified industry experts: **KIWA Gastec** will undertake further laboratory work on appliances and support the practical survey, test and trial work, building on their extensive experience at Keele and SGN's Oban project. **Dave Lander** is a well-respected specialist in the field, and will continue to develop the safety case and manage the QRA and Exemption for submission to the HSE. **Otto Simon (OSL)** has a track record of delivery in NIC projects and will provide construction management for the hydrogen production and injection equipment on both trial sites.

4.5 Relevance and timing (Criteria f)

Not only has the UK signed up to international agreements relating to carbon reductions by 2050, it has enacted legislation through the Climate Change Act to bind future governments to interim carbon targets, with the substantial delivery gap highlighted subsequently by the Committee for Climate Change which it needs to address[36].

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[36] Reducing UK emissions 2018 Progress Report to Parliament, CCC (June 2018)

Addressing the carbon emissions associated with heat is a key element in delivering on these commitments. Given that gas provides over 80% of GB heat demand today through the most extensive gas network in the world, it is important to reduce its carbon intensity. Deployment will also require appropriate support regimes which values the externalities of carbon reduction. At present low carbon heat is supported through the Renewable Heat incentive. Under the last comprehensive Spending review, this scheme has been funded until March 2021. Therefore there is likely to be a unique opportunity to restructure this regime at that point in time to enable support of new low carbon solutions such as hydrogen from various sources, augmenting existing support for biomethane. The timing of this project is apposite, and can provide the evidence base that BEIS requires in order to evaluate new technologies for introduction into such schemes. BEIS has a large strategic Heat Options programme currently underway, and this project feeds into that process, with key BEIS representatives on the existing Advisory Board who wish to continue in that role.

In relation to the wider energy debate, there are discussions with Government and the wider industry around the long term role of gas networks. Decisions will need to be made about the future approach to gas networks in the RIIO-2 process. This project will continue to inform those discussions through demonstrating the potential for carbon reductions via hydrogen.

Section 5: Knowledge dissemination

This Project will conform to the default IPR arrangements set out in Section 9 of the Gas NIC Governance Document.

The consortium is committed to a knowledge sharing programme, and sees this as a major component of the value of the project. The learning generated and its relevance, the audience and means of dissemination is laid out below.

5.1. Learning generated & and the applicability to other network Licensees

The Licensee and partners are committed to sharing the knowledge generated by this project. It will provide unique & referenceable data for all GDNs and other stakeholders looking to produce, deliver or utilise hydrogen using the gas grid. It will inform policymakers and consumers about the opportunity Hydrogen as a blend offers as a non-disruptive low carbon heat solution. The overarching learning generated is to establish and demonstrate the safe level of hydrogen blend which can be accommodated on the public network and used in operational appliances, whilst maintaining performance. This is built up of a number of key learning elements outlined below. This information is necessary for any Network Licensee looking to accept blended hydrogen in their network SGN & WWU have both agreed to participate in the project's Advisory Panel.

Materials	This will address the range of materials found on the wider network, covering both metallic and polymeric components, including LTS operational pressures. This will evaluate the long term impact of long term operation on materials, including the impact on materials under cyclical loading and on fatigue life.
Appliances	Focused on understanding how poorly maintained, malfunctioning and mal-operated appliances will respond to hydrogen blended gas to build confidence in their operation of such appliance in the field.
Gas Leakage measurement	To underpin wider roll out a robust leak measurement test will be developed, evaluated for test installations.
Gas Operative	In order to support the public trials, refinements to procedures

training	requires development of training packages to inform the gas operative & fitter community, which will be made available.
Gas characteristics	New evidence will be collected to support wider roll out and refinement of operational procedures, including: subsurface gas migration characteristics and impact of proximity and gas leak sweep distances; impact of preferential permeation on inserted mains and ducted pipelines; assessment of low energy ignition sources, and a more refined understanding of dispersion and migration of hydrogen blended gas within buildings.
Gas Detection	Facilitating development of gas detection instruments with reduced cross-sensitivity, in to enable more straightforward operational procedures for use with blends.
Operational Procedures	Based on the evidence built up through the programme, operational procedures will be further refined for use on the wider network. Whilst the Exemptions will be specifically for Cadent and NGN's networks, WWU and SGN will be engaged in the process to ensure that the proposals are workable on their networks.
Field Survey Data	This will deliver a body of data relating to appliance types and installation integrity, focused on blending.
Trial data	The trials themselves will provide wider confidence in the operation of a network and appliances on a hydrogen blend on a network with a range of material types and demographically representative installations and appliances. This will be reported as part of the programme.
Quantitative Risk Assessment	A sophisticated QRA was developed for Keele; this work will revise and update this based on the evidence secured relating to characteristics of a public network.
Exemption principles	Through these public trials, combined with those undertaken at Keele, a series of three Exemptions will be developed. These will address the key issues required for blending more widely.
Evidence to support all users	Deployment requires that all consumers can accept the blend. This will provide evidence relating to operation on large boilers as well as high temperature furnaces & kilns in the ceramic & glass sectors.
Establish billing principles	In order to undertake the public trials, the billing regime developed for Keele will be adapted to be suitable for trials on a public network, though engagement with both OFGEM as well as shippers and suppliers. Combined with the findings from the FBM project, this will establish underlying principles for billing more widely.
Roadmap for deployment	Assessment of cost optimal network injection, establishment of regulatory principles, evidence to enable policy support, and training to provide a roadmap for deployment
Basis to inform policy	Refinement of ownership models and provision of operational techno-economic data to enable development by HMG of appropriate enabling policies.

5.1.1 Knowledge capture

Much of the learning arises from rigorously designed experimental activities. HSL provides internationally recognised experience in structuring and delivering such work. This is combined with the depth of experience of KIWA on gas networks and systems. These parties, along with the rest of the project team have significant experience in capturing knowledge and learning. This ensures that it is scientifically rigorous and unambiguous. All information will be captured by work programme and recorded using a regular reporting structure to provide the basis for dissemination. The Network Licensees are confident that the quality of the captured learning will be not only able to support the Exemption for this project, but will provide an international acclaimed referenceable body of evidence to support hydrogen deployment across the distribution network.

5.2. Learning dissemination

5.2.1 The Audience

The audience for dissemination is summarised below.

Gas consumers	Gas consumers are the primary stakeholders for the project. Its purpose is to enable a 'democratic' means by which consumers can reduce their carbon emission from heat without disruption or capital outlay. They need to understand the opportunities and a chance to have any concerns they may have addressed. This includes industrial consumers on the LDZ. The consumers on the local networks where the trials are being undertaken are the primary focus. The project priority is to inform and share knowledge with them, which is integral to the customer care programme, discussed in Section 8.
Gas network owners & operators	The purpose of this project is to provide the body of evidence and a track record of Exemptions from the HSE that allows gas network companies accept applications to inject hydrogen onto their public gas networks. As the project is being delivered, it also supports decisions relating to their wider decarbonisation strategies. Letters of support from WWU and SGN are in Appendix L.
Gas Shippers & Suppliers	Changes to the gases being transported in the network has important impacts on commercial arrangements for gas shippers and suppliers. The Keele project was on a private network where the university was the gas supplier for all customers. This project will address billing issues with the wider gas shipper and supplier community for the trials, and seek to lay the foundations for roll out, supported by work such as the "Future of Billing" project. British Gas is on the Advisory Panel.
Regulatory and Standards Bodies	As described in Section 7, deployment of hydrogen as a blend on the network requires regulatory agreement from the HSE as well as OFGEM. Wider changes relating to the GS(M)R are also being considered, where the requirements are translated into a separate standard, under the management of IGEM. These parties are stakeholders in the execution of this project, and in deployment.
Policymakers	This project opens up the role for the gas network in delivering a solution for non-disruptive low carbon heat. BEIS's Strategic Heat Options team is an active participant in the HyDeploy project, on its Advisory Panel which will continue into $HyDeploy_2$. The project informs the role of blending and provides a valuable template for public trialling of full hydrogen, being the first of this type of trial in the UK
Energy and Network trade bodies	Energy Utilities Alliance seeks to shape the future policy direction within the energy sector with the Energy Networks Association focusing on issues relating to 'pipes and wires'. Both organisations are supportive of the project with letters of support in Appendix L.
Appliance Manufacturers & Trade bodies	Changes to the gas composition needs co-operation with appliance manufacturers. During the HyDeploy project at Keele, there has been excellent engagement with manufacturers & the Heating and Hot Water Industry Council (HHIC, part of the EUA), with the provision of expert advice and equipment. $HyDeploy_2$ will build on this, demonstrated by the EUA letter of support and one from Worcester Bosch in Appendix L.
Academic institutions	Delivery of this work requires collaboration from the foremost academic experts in the UK, particularly in relation to materials interaction with hydrogen, work which will be managed by the HSL. Keele University

	remains a participant in the project as the host for the original project, maximising knowledge transfer & supporting customer engagement.
International Bodies	The work will provide valuable data for bodies such as the European gas Research Group (GERG) which has been championing the role of hydrogen for many years. Importantly, this will be two way engagement as this project builds on their knowledge and experience. They will sit on the Advisory Panel; a letter of support is in Appendix L. The project has developed bilateral links with Engie and Eon in relation to their blending projects in France and Germany respectively.

5.2.2 Means of dissemination

The project team is committed to disseminating the learning from this project to the audience identified above. This will build on the successful approach to dissemination developed during the first HyDeploy project at Keele, tailored to the specifics of this project and the needs of its stakeholders, many of whom have already engaged with the project. A carefully structured communications strategy will be developed collaboratively by Cadent and NGN building on the experience at Keele. This will use a variety of channels dissemination as shown below.

Knowledge sharing Events	The HyDeploy project at Keele provides the template for such events. Prior to the house to house testing customer engagement events were held to listen, educate and explain. The project launch in London engaged with wider stakeholders. More detailed workshops are being developed to share the findings associated with the evidence base for the exemption targeted at industry experts from the UK and abroad. This project will build on the learning from these. Local events will be held in the trial areas, with good support already developed with the Local Enterprise Partnerships and authorities, as well as educational establishments. Keele will continue to participate in the project, which will enable site visits for the first public trial customers to witness the trials and engage with Keele customers. The same principle will then roll forward with the second public trial customers visiting the first.
Project Website	An extensive website has been developed for the first project www.hydeploy.co.uk, which will be expanded for HyDeploy2. The website is accessible and informative for the general public and contains information relating to the environmental benefits and addresses gas safety. It will be expanded to provide the portal for specific trial information and other key stakeholders.
Social media, general and industry trade media	The website will be supported by a wider social media presence. Excellent engagement with wider media outlets has been achieved during HyDeploy, with strong coverage achieved for the HyDeploy launch.
Literature Development	Building on success, and learning points from the project at Keele, further project specific literature including factsheets, flyers & brochures will be developed to communicate the Project to the various audiences. This includes specific information for consumers, Section 8.
Journal Articles	This will include industry and trade journals such as IGEMs 'Gas International' as well as academic journals.
Conferences	Information will be presented at the annual gas networks innovation conference, as well as other gas and low carbon conferences.
Industry networks	Learning from the project will be shared with the industry networks, such as IGEM, the ENA R&D working group and the EUA. Hydrogen focused bodies, such as the GERG HIPS forum has provided an

	opportunity for sharing with experts.
Progress & Close out reports	The annual progress reports and the close out reports will be hosted on the dedicated website with links from other sites as required by OFGEM.

The partners in this project are all active in the field and participate in a wide range of innovation projects. This informal network of communication will further enhance the knowledge sharing outwards from this project, as well as ensuring new learning and best practice flows back into the $HyDeploy_2$ programme.

5.3. IPR

The project team will comply with the default IPR Provisions. The purpose of this project is to generate a body of knowledge which can be shared, in particular by all the Gas Distribution Network Companies, all of whom are either partners in the project, or who sit on the Advisory Panel. All parties have an interest in seeing hydrogen deployed on the network and therefore have the freedom to share the work, and there is no intention or opportunity to exploit arising IPR commercially. Copyright will exist on the reports produced as part of this work, but they will be published in the public domain. Background IPR, such as that supplied equipment for the purposes of executing the project will remain owned by the suppliers as Commercial Projects. However, for example, detailed functional specifications developed for the gas mixing unit will be shared in the public domain to allow other suppliers to supply into the market in the future. The consortium agreement will ensure that the NIC provisions are adhered to by the project partners.

Section 6: Project Readiness

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

This project is particularly well placed to start in a timely manner. The project team has been working together for over 2 years developing and delivering the project at Keele, and there is a clear and focused understanding of the activities required to deliver the outcome.

Most importantly the team is well established with a strong track record of collaborative working. The project has addressed challenging issues both technically and commercially, through which the team bonds have grown strong to deliver successful outcomes. Strong governance processes have been put in place, including an effective collaboration agreement, which provides a good template to deliver this second project. Day to day operation of the project has worked well, with tightly managed processes, including robust monthly reporting processes and decision making including an effective steering committee. To date, all SDRCs have been delivered effectively and the project being held in high regard by stakeholders in the UK and internationally. The Advisory Board have been complementary about the quality of work undertaken, and the foundational role this project plays in informing future heat policy.

Lessons have also been learned through undertaking the project, which have been incorporated in the plans for this subsequent programme. These key learning points are summarised in Appendix E. A substantial technical and scientific knowledge basis and understanding has been developed through the first project at Keele. This has been distilled into the Exemption application. The detailed cross linkages and underlying knowhow underpinning this should not be underestimated. The scientific rigour provided by HSL, combined with the practical experience from the GDNs and KIWA has provided a valuable project tension, delivering the high quality outputs necessary to present the case for Exemption.

Detailed customer engagement has been successfully delivered, covering the most intrusive element of the programme. This has been well received at Keele, with strong support for the project principles and as a consequence the project teams have been welcomed into homes to undertake the necessary survey work. The principles from this provide the foundation for an effective communications plan for the public trials, in terms of understanding, developed material and skilled personnel.

Practical experience associated with undertaking installation surveys is invaluable in developing working methods for the future. This will expedite mobilisation and improve the efficiency and quality of data collection.

The Quantitative Risk Assessment was considerably more sophisticated than originally anticipated, with over 200 basic events and gates, compared with that originally developed for HyStart, which was fewer. It was found that the quality of data available from across the industry is not always as detailed as would be ideal, but the most challenging aspect is translating the core science experimental findings into quantitative data to input into events and gates. This understanding will inform the way in which initial data is gathered in this experimental and survey programme.

An Operational Procedures Forum has been instrumental in reviewing and assessing over 200 operational procedures. This has involved scientists, procedural experts and operators from both Keele and the GDNs. The extent of the activities required were greater than originally anticipated. Now, the team is mobilised and informed to further refine the requirements for the wider network, and also to understand better the scope of work.

Supply chain stakeholder engagement. Through the programme at Keele, an excellent working relationship has been developed with the supply chain. Appliance manufacturers have provided experts and equipment, including instrumented equipment for lab testing and eight boilers for accelerated testing at Keele. They have also provided direct support an reassurance to customers in the field about the trials. In terms of analytical equipment, gas measurement and detection equipment providers have also engaged through another working group, providing practical equipment and technical insights and support. These organisations are eager to continue supporting the next phase of the project.

Practical work relating to the public trials themselves has already been expedited. Site selection processes have already been undertaken, assessing locations against the project requirements in terms of diversity of evidence base, but also the practical criteria necessary to ensure that the project is deliverable. The equipment necessary to deliver the trials can be relocated from the project at Keele. It will be fully commissioned and field tested and able to be transferred to the trial sites. Permitting principles are established from Keele and the services and utility requirements are well understood.

The HyDeploy project has engaged internationally, with close co-operation with European hydrogen blending projects. In particular there has been valuable information exchange with the GrHyD project in France which commenced injection in June 2018. This work has found that different experimental methodologies have provided complementary and confirmatory results, and duplication has been avoided. This track record of close co-operation will deliver higher quality outputs more cost effectively.

This strong foundation will provide the basis to undertake a carefully structured and deliverable project, which the partners are confident can be delivered effectively, on time and within budget. Key aspects of that 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 G. This is divided into three key areas: the development of the evidence base to support both trials as well as wider roll out, the delivery of the two network trials and a smaller task to develop the roadmap to widespread deployment. Within these areas are the extensive individual work packages necessary to deliver the programme. The activities and their detailed planning has been developed by the experienced team and undergone a careful review process.

The project plan is assumed to commence on 1st April 2019 and is a 4 year programme. This will be reviewed prior to commencement of the project and progress will be monitored through a regular review process by project partners throughout the delivery of the project as employed at Keele. There are some areas of the project programme which are strictly outside of the control of the project partners, such as the Exemption process. An excellent working relationship has been developed with the HSE to assist in managing this process and the programme is based on the experience gained through the Keele project. Risks will be mitigated by engagement and sharing of information ahead of formal submission. Such risk factors are discussed in detail below.

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. The Project organisation is summarised in the management diagram in Appendix F.

The core partners are all signatories to an existing Project Collaboration Agreement. HyDeploy$_2$ will adopt this agreement with minor project-specific modifications, avoiding repetition of the lengthy process required to put this in place under the original HyDeploy project. This tried and tested 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 made up of representatives nominated by each of the project partners. The Chair of the Steering Committee shall be the Project Director for Cadent, should the Chair not be available the Chair is delegated to the Project Director for Northern Gas Networks. The Steering Committee will meet on a quarterly basis to review Project progress reports, performance against budget, key Project risks and material issues. The Project Collaboration agreement lays out the governance requirements of the Steering Committee.

The Project Director for Cadent is accountable for the successful allocation of Milestones and allocation of stage funding under the NIC allowance. The Project Directors for both NGN and Cadent shall report progress to their Executive Committees.

Project Management is provided by Progressive Energy, responsible for co-ordinating the day to day operations of the project, coordinating and reporting to the Steering Committee, and acting upon decisions, in particular with relation to budget management, and submitting requests for Milestone completion and sanctions to progress to subsequent project stages. Working project meetings of the participants will be held on a monthly basis.

HSL is responsible for oversight the technical programme throughout the project and its delivery. Much of this work is undertaken by HSL, but there are elements which will be undertaken by third parties with appropriate facilities and expertise, under the management of HSL.

Cadent and NGN are responsible for customer engagement and delivery of the trial programmes in each of their networks respectively.

Otto Simon Limited is the construction manager for relocation and installation of the hydrogen production and grid entry units for the trial sites. This provides a seamless continuation from the project at Keele, but is a less extensive activity given there is no requirement to fabricate the equipment. It undertake CDM requirements until the plant has completed recommissioning and handed over.

The rights and responsibilities of each of the Project participants will be clearly established, based on the successful collaboration for the project at Keele. These will clearly identify the responsible person or persons for delivery of the project in each organisation and the method of communication to be used.

The project structure also includes an Advisory board. The purpose of this board is twofold. Primarily it is to ensure that the views of the other two GDNS (SGN and WWU), as well as those of key stakeholders including the HHIC and IGEM, are communicated to the Steering Committee. It also has an important role in facilitating knowledge dissemination and to underpin subsequent roll out of hydrogen blending onto the gas networks more widely. This has been particularly effective during the first HyDeploy project, the participants have reviewed the approach being proposed for $HyDeploy_2$ and are supportive, and wish to continue their involvement in this next phase. During the 12 month overlap between the projects, meetings will be structured to address the issues of both projects efficiently to minimise time and costs for all parties.

6.1.3 Project Partners, contractors and team

Building on HyDeploy, Cadent and NGN have secured a team comprising experienced and expert companies and individuals. The project partners and their roles are summarised below, detailed company summaries and CVs of key individuals can be found in Appendix J.

This project is a true collaboration between two GDNs. **Cadent** is the Funding Licensee & project sponsor and **Northern Gas Networks** is the collaborating GDN. They bring both bring their expertise and experience relating to the gas network to the project, will host the individual trials in their respective network areas, and between them have undertaken NIA and NIC projects in the past.

Health and Safety Laboratory (HSL): One of the UK's foremost health and safety experimental research establishments. They have particular understanding of the issues that HSE need to see addressed in this field. This experience significantly de-risks the project by ensuring that the relevant evidence base is understood from the outset, and also ensures close and effective engagement with the HSE throughout the process. They have put in place appropriate governance processes to manage HSE's requirements during the Exemption evaluation process which has proven particularly effective during the first HyDeploy project. They will plan and oversee the technical programme in their own laboratories, at KIWA and at other third parties. Their work includes analysis and synthesis of the results from the testing and trial programme. **Progressive Energy:** Project management, planning and overall programme co-ordination. It is managing the HyDeploy project and has a track record of providing in depth technical challenge and review in the first project. **ITM Power:** Uniquely experienced in hydrogen grid injection projects and will continue to maintain the hydrogen production plant and role as a partner facilitates project engagement with the wider hydrogen sector and international activities. **Keele University** will remain a project partner, albeit in a reduced capacity compared with the original project on its site. Their continued involvement facilitates any additional technical testing on the network at Keele required for the public trials as well as supporting the public trial customer engagement programme, such as hosting site visits. In addition to the core partners, the project is supported by key identified industry experts:

KIWA Gastec will undertake further laboratory work on appliances and support the practical survey, test and trial work, building on their extensive experience at Keele and SGN's Oban project. **Dave Lander** is a well-respected specialist in the field, and will continue to develop the safety case and manage the QRA and Exemption for submission to the HSE. **Otto Simon (OSL)** has a track record of delivery in NIC projects and will provide construction management for the reinstallation of hydrogen production and grid entry equipment on both trial sites.

6.1.4 Project Delivery Risk Assessment and Mitigation

The project will be managed using a structured approach to Project delivery risk. A project delivery risk register has been drawn up as shown in Appendix H which identifies risks, risk management and mitigation plans. This builds on the detailed project management risk register used to deliver the current HyDeploy project. It is based on a standardised approach where risks are categorised and assessed in terms of Likelihood and Impact. Likelihood is assessed on a scale from 1 to 5, from Remote to Almost Certain, and Impact assessed between 1 and 5 from Insignificant to Showstopper. In both cases standard industry guidance is used against each category. Mitigation measures against each risk are identified and actions allocated. The risk, on the basis of the mitigation measures being put in place, is reassessed. As is currently undertaken for the HyDeploy project at Keele, this tool will be used proactively to manage the project throughout the delivery phase, with clear responsibility for each item and ownership of mitigation measures. As a management tool, the risk register will be developed to a high level of detail (at its peak the first HyDeploy register had nearly 400 individual items identified, assessed and monitored), will be updated regularly throughout the project and will provide the basis for internal project reporting and management.

This is a project delivery risk assessment tool. Its primary purpose is to manage the overall delivery of the project safely to time and to budget. The detailed assessment of the safety risk associated with injection of hydrogen as a blend *per se* is the inherent purpose of the project. This is fully addressed by the Quantitative Risk Assessments being undertaken for the Exemption applications, at a much greater level of detail than is appropriate to address in this project delivery tool. The role of this risk register is to ensure that this work stream is effectively delivered. It identifies areas of safety risk associated with delivery of the experimental programme and mitigation steps to be taken.

Delivery risks cover those risks that undermine the project objectives, particularly in terms of overall Outcome, Environmental issues, Budget, Schedule and Reputational risks. This risk register benefits from the experience in the first HyDeploy project, understanding the issues which have presented delivery risks to that project and which require specific mitigation. The overall programme for $HyDeploy_2$ has been developed cognisant of these risks and therefore generally these risks are expected to have a relatively low probability of crystallising. However, each of the areas of technical risk will undergo detailed design and planning as part of the first stage of the programme, to ensure they are properly understood and managed.

Other project risks relate to the wider context, for example the wider political and policy agenda with regard to decarbonisation in general and of heat in particular. These risks require that the project must maintain contact with stakeholders outside of the project. For instance the potential changes to the GS(M)R regulations which would see Schedule 3 taken out of the GS(M)R Regulations and managed as a standard by IGEM may come into force during this project. This is unlikely to effect the applications for Exemption for the trials, however the project team should continue engagement with IGEM to ensure that the evidence base for hydrogen blending is understood should this move to a standard take place.

6.1.4 Interface with other Innovation Projects

This Project forms part of a wider roadmap towards deployment of Hydrogen on the GB gas network, and interfaces with a range of other Innovation programmes. Over the last two years the recognition of the role hydrogen could play in decarbonising heat has grown substantially, with a range of projects being undertaken. HyDeploy is the most advanced of these in undertaking trial activities on live gas networks.

Upstream it directly builds on the Cadent/NGN HyDeploy programme at Keele (2016)[37]. It also integrates with a number of directly related projects in particular a parallel programme "Hydrogen in natural gas – impact on gas engine CHP"[38] (2017). It is a key element in the HyNet project[39], which would be the first large scale commercial deployment of hydrogen blending. This project establishes large scale production of low carbon hydrogen production to deliver over a 1 million tonnes of carbon dioxide abatement. Half of this is proposed to be through blending on the network to deliver to over 2 million households and businesses. This can be achieved through injection at just four nodes on the Local distribution system to enable cost effective deployment of hydrogen blending. Cadent is ensuring that the interface between these projects is carefully managed to ensure that the outcome from the HyDeploy programme meets the requirement of this first project. By undertaking the first trial in this region HyDeploy facilitates early customer engagement.

Both NGN and ITM are actively pursuing integrated projects across the electricity, gas and transport sectors with NGN's InTEGRel project. Work with ITM and BEIS identified the benefits and opportunities associated with large scale electrolysis in network balancing at its Lower Thornley site, again anticipating large scale hydrogen blending into the network, enabled by HyDeploy. Cadent's "Hydrogen Grid to Vehicle (HG2V); Network purity for

[37] http://www.smarternetworks.org/project/nggdgn03
[38] http://www.smarternetworks.org/project/nia_cad0009
[39] www.hynet.co.uk

Transport" programme[40] (2018) is also investigating the interface between hydrogen blending and the use of hydrogen as a transport fuel. National Grid Transmission is also exploring the opportunities for hydrogen blending in the transmission network.

Both Cadent and NGN are undertaking a variety of smaller innovation projects relating to gas network management and repairs (such as the "Assessment and Creation of Novel PE Pipe Repair Systems[41] NIA, 2018). Close integration of the operational teams in the HyDeploy project (through the 'Operational Procedures Forum'), any implications from changes to network management techniques can be fed into the programme.

Downstream this project interfaces with the Cadent NIC (2016) "Future Billing Methodology" [42], project considering the changes to billing methodology necessary to facilitate adoption of new gases and blends more widely.

NGN have been instrumental in initiating the H21 project, which is now a NIC funded project involving all the GDNs[43], seeking to address the barriers to full hydrogen deployment. All the GDNs as well as the Transmission Operator are pursing low carbon gas solution with a strong emphasis on hydrogen. There is also close engagement on BEIS projects such as Hy4Heat[44], which is seeking to provide the downstream evidence base for conversion to full hydrogen.

Cadent and NGN are committed to ensuring that the interfaces between these projects are managed to secure best value for money, ensuring collaborative sharing of knowledge between projects, and avoiding duplication. The Advisory board which includes all stakeholders is instrumental in achieving this, but is also supported by the GIGG process, and the recently formed GDN hydrogen working group.

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, building on the detailed knowledge derived from experience in the HyDeploy project at Keele. This ensures that not only are the technical activities accounted for, but importantly that communications and consumer engagement are properly considered and costed.

HSL have undertaken a review of the underlying evidence base secured through the HyDeploy project at Keele and developed a detailed gap analysis to identify the scope of work required (Appendix D). This has enabled them to developed a detailed budget for this element of the programme, including identification of third party work. They have engaged with specific academic institutes who have the skills and equipment capable of delivering

[40] http://www.smarternetworks.org/project/nia_cad0022
[41] http://www.smarternetworks.org/project/nia_cad0018
[42] http://www.smarternetworks.org/project/nggdlgn04
[43] https://www.ofgem.gov.uk/publications-and-updates/network-innovation-competition-project-direction-h21
[44] https://www.arup.com/en/news-and-events/news/Arup-and-Kiwa-Gastec-appointed-to-explore-potential-for-using-hydrogen-to-heat-UK-homes

the required materials testing programme and established the associated costs. Experience from the first HyDeploy programme has enabled costing of the laboratory testing of appliances. Costs of testing the blend for industrial users has been developed from engagement with host sites, facilitated by the HyNet project.

Customer engagement plans and associated costs have been developed based on experience at Keele, informed by both Cadent and NGN's experience of customer engagement programmes on the wider networks. This also accounts for the wider demographic, such as the anticipated need for translation services.

The delivery of the trial phases also draws on the experience at Keele. This provides high quality information on the level of resourcing required and associated costs of the house surveying programmes (100% for the first public trial and a sample for the second). A consequence of surveying properties and appliances is that some equipment and appliances will be identified that must be repaired or replaced. The obligation to do this rests with the project. The project has asked to undertake the survey, not the consumer. If the work is not done, the network operator would be obliged to cut off the consumer which is unacceptable. Given that this is a public network trial, the best evidence for this requirement comes from the Oban trials where the outturn appliance failure rate was 56 units following a survey of 2650 with around half requiring replacement. Combined with up to date costs of such repair work from the project at Keele, provisions have been made for this, including temporary heating. The costs of primary equipment are avoided since this is being repurposed, however the costs of installation have been developed based on the known requirements and costs at Keele. This has also informed site identification to minimise costs where possible.

The more limited work programme associated with the roadmap for deployment has been informed by the issues identified during HyDeploy, as well as other projects, such as HyNet. Training and skills has been identified as a particular requirement, and development of an appropriate strategy for this is one of the more significant elements of this workstream, along with the necessary engagement with suppliers and shippers

The consolidated costs have been reviewed by the project partners. In particular, the risk register for the Project has been reviewed to identify areas which require allowances to be made against specific activities. Given that there are contingent provisions such as for replacement of appliances, there is potential for underspend. NIC Governance defines an approach for this, and the project will ensure it complies with these requirements.

By these means, and through an internal review process, there is confidence, not only that the scope is well defined and comprehensive to deliver the project, the associated costs are considered to be robust.

6.2.1 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 Project Directors at Cadent and NGN for sign off. Cadent 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)

The data presented in this proposal has been verified. In general, third party evidence has been used to support assertions and the entire proposal has been reviewed by the Project Partners. The following table summarises the areas of the project and the verification process followed.

Programme Strategy & Scope	This was developed by Progressive Energy, Cadent and NGN and underwent a review process by the project partners, including the overall budget provision.
Technical Evidence Programme & Budget	The overall experimental programme was developed by the HSL, based on a detailed gap analysis between the requirements of the Keele project and that required on the wider network. The combined programme was reviewed by all the project partners.
Communications Budget	This was developed based on the outturn communications scope and costs from HyDeploy at Keele, updated to reflect the key changes. This was developed Cadent's communications team and reviewed by Progressive Energy and NGN.
Exemption Process	Costs to develop the safety case and QRA were determined based on the project at Keele, providing good confidence in veracity.
Equipment Re-installation programme & budget	The core equipment is being repurposed. The costs of the new installations have been developed based on the costs for Keele established through the physical works team. This has informed by local knowledge of the trial sites.
Trial plan & budget	The combined programme was developed by Progressive Energy in conjunction with the HSL and reviewed by Cadent and NGN
Dissemination	Figures were developed by the partners and reviewed by Cadent against the costs under other NIC projects.
Carbon & Financial Benefits	This is based on the assessment developed by National Grid for HyDeploy and reviewed by the Expert Panel in the previous submission. There have been minor updates reflecting changes to underlying energy curves and cost indexation.

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

In the carbon and financial benefits assessment, two cases of hydrogen blending are considered. The expectation from the work at Keele is that a blend of 20% $_{vol}$ can be achieved, which is supported by the work being undertaken by Engie in France in its GrHyD[45] project also trialling 20%$_{vol}$. A level of 10% $_{vol}$ is already permitted in parts of Europe and has successful been trialled at this level into an existing network by Eon. Therefore there is a high level of confidence that this represents a lower bound case, which still offers significant benefits and lower costs compared with alternative solutions for heat decarbonisation. This would also unlock the opportunities for the gas grid to play a role in

[45] http://grhyd.fr/

energy diversion from electricity via electrolysis. It would allow new forms of gas such as Bio-SNG to simplify the process by removing the constraint of 0.1% and it would open up the possibility of the use of hydrogen as ballast for high Wobbe gas rather than deliberately adding nitrogen. More widely, establishing the level of hydrogen which is feasible as a blend provides clarity on its decarbonising role or otherwise for the future of the gas grid. This clarity is strategically important as the UK seeks to establish the best, least disruptive and most cost effective route to decarbonisation of heat.

6.4 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. Ahead of commencement of each public trial phase the Steering Committee must sanction progress. This requires that (a) an Exemption is secured from the HSE for hydrogen injection (b) the local network Owner (Cadent and NGN respectively) sanctions the trial and (c) that the Steering committee has agreed that the project delivery risk relating to the next phase of the project has been assessed by the project partners and is agreed to be acceptable. These gateway criteria must be met for the Steering Committee to sanction the next network trial element of the project.

More generally, the Steering Committee will have the power to suspend the Project in the event that: 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

There are three regulatory issues which need to be addressed in order to undertake the project

GS(M)R Exemption. Core to the project is the securing of an Exemption for each of the Public trials being undertaken, and is addressed through the project programme.

Billing. During the trials gas customers will be supplied with gas which has a calorific value which is lower than the flow weighted average. The principles to handle this have been established for the trial at Keele, but will require embodiment with a wide range of suppliers during the public trials.

Ownership of gas production equipment by a gas transporter. Despite the fact that this is a small scale demonstration project, accruing no commercial benefit to the gas transporter, the Regulator is currently taking the view that Cadent Gas limited as a regulated gas transporter is unable to own this equipment. Cadent is seeking a derogation to this as this reduces commercial complexity and risk, although has a number of contingent provisions should a derogation not be possible.

7.1 Health and Safety Executive

The purpose of this project is to establish the level of a blend of hydrogen in the gas distribution network which can be safely delivered and used in existing appliances whilst maintaining performance. The outcome is a route to reducing consumer’s carbon emissions from heat without disruption or requirement for capital outlay.

The Gas Safety (Management) Regulations (GS(M)R) sets out the requirements of gas conveyed in the network. Specifically in Part 1 of Schedule 3 this stipulates a hydrogen limit of 0.1%vol. Therefore any blend of hydrogen will require a derogation to this limit, in the form of seeking a formal Exemption to the requirements of GS(M)R.

Exemption from any requirement imposed by the GS(M)R are provided for by Regulation 11 of the GS(M)R. Essentially the HSE shall not grant an Exemption "unless it is satisfied that the health and safety of persons likely to be affected by the Exemption will not be prejudiced in consequence of it". Exemptions may be granted subject to conditions and a limit in time and may be revoked at any time by a certificate in writing. The HSE decision, will be based on no additional risk or/and as low as reasonably practicable.

The evidence base has been developed for the HyDeploy project at Keele, including assessment of the impact of a hydrogen blend on gas characteristics, materials on the network, operation of appliances, operation of the network, including gas detection as well as assessment of the equipment being used to produce the hydrogen and deliver the blend. Together this has been used to develop a detailed Quantitative Risk Assessment.

For the public network trials, this process must be developed for the much wider network characteristics, range of appliances and installations. HSL have developed a comprehensive gap analysis relating to the additional evidence required for a public network trial (Appendix D). The first trial will seek to undertake gas safe checks on all installations and appliances on the network, the second will use the evidence from the first. Combined with laboratory assessment of non-compliant installations, to build the evidence base with much reduced survey data. This provides the pathway to full deployment where such survey work would be unfeasible for wider roll out. These subsequent Exemptions must also provide evidence that the network procedures on the wider network are suitable. Each Exemption will require Quantitative Risk Assessments for the specific trial.

Subject to a successful outcome from these trials, and satisfaction that the gas blend can be conveyed safely, the objective would be to secure a more enduring regulatory position. This would range from revision to the requirement in Schedule 3 of GS(M)R or a class Exemption similar to that offered by the HSE for the requirements regarding oxygen content for biomethane injected onto the network.

Wider industry changes relating to the GS(M)R are also being considered, where its requirements may be translated into a separate standard, under the management of IGEM. Therefore the Project has already engaged with IGEM with a view to including the evidence base for hydrogen safety alongside the evidence base they are already collating for widening the Wobbe Index. Subject to the speed with which such structural changes take place, this may modify the specific process by which permission would be secured to undertake the trial. However, it is certain that the quality of scientific and technical evidence base would remain just as important, and therefore there would be no impact on the wider programme of activities.

Finally, it is recognised that the wider activities of the trial must be carried out safely with all due care, covering issues beyond the narrow remit of the GS(M)R. HSL is highly experienced in the execution of such trial and experimental projects, and the installation will be properly managed under CDM regulations by Otto Simon.

7.2 Billing

Billing arrangements for domestic customers during the trials will need to be addressed to ensure that at no point are they disadvantaged. Currently consumers are billed on the basis of the volume of gas consumed during their charging period, determined at their meter, and the billing calorific value (CV) for their charging period, determined from the average of applicable daily Local Distribution Zone Flow Weighted Average CVs (LDZ FWACVs). During the trial, hydrogen will be added to the natural gas, therefore the Calorific Value of delivered gas will be reduced. If the existing regime were to continue then the domestic customers would be disadvantaged as they would receive less energy than they would be billed for.

The proposal is that customers will be billed on a declared Calorific Value basis. This is already used for parts of the GB gas network, where the billing Calorific Value is a declared in advance. This would be set as a conservative value in favour of the consumer for the duration of the trial accounting for both the underlying gas composition of natural gas and the level of hydrogen blended. The Calorific Value would also be measured during the trial to demonstrate that this is the case, but the measurement would process could then be less onerous as it would simply have to demonstrate that the Calorific Value of gas conveyed is greater than the declared billing Calorific Value.

This is the billing strategy that has been agreed in principle for the trial at Keele. The detailed methodology and specific Calorific Value determination regime will be developed in detail with OFGEM for the public trials to ensure that the evidence base and detailed approach provides absolute confidence that the interests of the customer are protected. It will also need to be agreed with Gas Suppliers for delivery during the trial. This will build on the engagement achieved through Cadent's Future Billing Methodology Project. Early engagement with suppliers has been planned into the programme.

Declared CV is currently permitted by the Gas (Calculation of Thermal Energy) Regulations (part III) and is currently in operation within the Scottish Independent Undertakings.

7.3 Ownership of hydrogen production equipment

The primary purpose of this trial is to demonstrate that hydrogen can be blended into the local distribution network for safe transportation and use. Hydrogen is required in order to undertake the trials. As established in the first HyDeploy trial at Keele, the hydrogen will be produced on demand using an electrolyser. This avoids the requirement for storage of large volumes of hydrogen, and was established as being the best value for money option for the trial at Keele. Through redeployment of this equipment for the two further public trials, the cost of hydrogen is significantly reduced.

Cadent as funding licensor owns the grid entry unit and commercially is best placed to own the hydrogen production equipment, as being ultimately responsible for the trial and Keele, and the trial on its network.

However, currently, the Gas Act 1986 prohibits gas transporters from owning gas production equipment. The regulators current view is that a Secretary of State exemption against section 7(3A) of the Gas Act 1986 would be required as well as a derogation against Standard Special Condition A36 (which could only be issued after an exemption had been made).

This is a small scale demonstration project, accruing no commercial benefit to the gas transporter. As such Cadent Gas limited is seeking a derogation to this as this reduces commercial complexity and project risk. However, Cadent is putting in place a number of contingent provisions should a derogation not be possible, specifically identifying routes where this asset is not owned by a regulated gas transportation company.

Section 8: Customer Impact

8.1 A Customer focused Solution

Cadent and NGN take pride in their commitment to their care for their customers. Therefore this project places the needs of the customer at its centre.

The rationale for undertaking the project is to develop a method for reducing customers' carbon emissions arising from heating their homes which avoids significant disruption and capital outlay. 83% of UK households are connected to the gas grid with their homes heated and hot water provided by gas via gas boilers. The work by WWU[46] developed through structured and extensive engagement with customers has drawn critical conclusions which must inform strategies for addressing the carbon emissions associated with our built environment. The purpose of this work was to *"understand consumer willingness to change and to pay….in relation to changing energy sources"*.

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[46] http://www.smarternetworks.org/Files/Bridgend_Future_Modelling_%E2%80%93_Phase_2_150910144351.pdf

This further substantiated the conclusions drawn by others that financial payback is a necessary, but insufficient criteria for customers to change their heating systems; unavailability of capital as well as their desire to change are also barriers to change. Specifically it identified that "T*he majority of domestic consumers (87%) will not change their existing heating provision unless significant financial benefits will be accrued, and only then if they have funding available, i.e. readily available cash to replace a heating system or low cost loans, and only if the system is coming close to the end of its cost effective life cycle and/or actually fails. Without these potential failure signs, then consumers would simply opt to do nothing. If their current system was operating well and providing heat for their homes they would not change their heating systems and spend money unnecessarily."*

Therefore reducing the carbon intensity of the gas grid requiring no change on their part, provides a customer focused solution. It is also a 'democratic' solution which allows all customers to participate in reducing carbon emissions, not just 'middle classes who can use the RHI to heat their swimming pools'. Alternative solutions for domestic customers such as heat pumps or biomass systems require substantial upfront capital investments in excess of £7,000 and often substantially more, which is contrary to addressing issues of fuel poverty. The carbon benefits of incremental reductions in carbon intensity of the gas network are significant and cost effective, described in Sections 3 & 4.

8.1 Customer interactions

In order to undertake these trials it is essential that customer's gas supply and appliances operate safely, reliably and deliver the performance they expect. This necessarily involves undertaking surveys of installations and appliance on the effected networks. This has been successfully undertaken for the HyDeploy Project at Keele. The process was designed to minimise the impact on individual customers. This was well supported by appliances and gas suppliers, providing necessary assurances.

It is also important that the customers are properly informed about the project through provision of clear and accessible information. This also provides an opportunity for them to understand the valuable role they will be playing in revolutionising how the UK could decarbonise its heating sector. The strategy for this customer engagement is described in Section 8.2 below.

8.1.1 Pre-trial interactions

The specific impact on the domestic customers will be the installation and appliance survey ahead of the individual trial phases. This process will be managed by a customer liaison team whose role is to ensure that customers are fully informed, are able to ask any questions they may have, and will assist with scheduling of the tests. They will interface with the operational team both in terms of the survey and any necessary remedial works and keep the customer informed. This was very successfully delivered during the trial at Keele.

For the first trial permission will be sought from all customers to undertake a standard Gas Safe check. This is the type of test which landlords are required by law to undertake on an annual basis for their properties. For customers who are long term tenants, this will be familiar. For others it should provide welcome confidence in the safety and integrity of their installation.

This survey will identify and test all gas appliances. This will require access to each appliance in each property, wherever they are installed. This checking will consist of visual checks and monitoring of flue gases, but will not require movement of any appliances.

To undertake these tests access will be required for less than 1 hour with appointments arranged by mutual agreement, with customers able to choose slots and have the opportunity to ask any questions they may have.

It is recognised that many property owners will not be available during the working day. Provision in the programme has been made for evening and weekend work to accommodate this. Because this trial will involve a significantly greater number of properties, a larger team will be deployed, offering a greater level of flexibility.

Should any appliance be identified which is unsafe, the householder will be offered repairs, or if necessary a new appliance. This was successfully undertaken at Keele, and was well received by customers who had their appliances repaired or replaced free of charge. They also benefited from the confidence that their gas appliances and installations were safe.

Based on learning from Keele, a local gas safe contractor will be contracted to provide the gas safe engineers for testing, repair and installation work. Importantly this will also provide an established contractual basis to secure spare parts and equipment, as well as access to the other trades necessary to undertake the work. Changes to building control and gas standards can also mean that replacement requires that the installation is brought up to current standards, entailing potentially relocation of flues and changes to ventilation requirements. One of the key learning points from Keele was that scheduling this work (scaffolding, minor building works, asbestos management and localised re-decorating) requires careful planning to minimise customer disruption.

In addition to the standard gas safe checks, permission will be sought from a subset of properties to undertake tests using bottled hydrogen blends. Test gases will then be connected downstream of the gas meter, which will be non-invasive when the meter is outside, but may entail some minor disruption if inside. This will provide further validation of the laboratory findings relating to appliance operation on hydrogen blends, and where there are unusual appliances provide the opportunity to undertake tests in the field. For the Keele project, this was undertaken for all properties that were accessed. The reduced requirement provides for more flexibility and means that permission is not required from all customers.

For the second public trial, the requirement to survey is further reduced. Only a sample of properties will be gas safe checked, and there is no intention to bottle test appliances on any installations.

8.1.1 Main trial Phase interactions

There will be some minor impacts on the local community, when the hydrogen production and installation equipment is relocated to the trial site. The system is based on prefabricated units, minimising onsite works. Changes to the physical connections on the gas network will be managed under the existing GDN procedures, using best practice to minimise any customer impact.

During the operating trial period, there will be a requirement for some spot checks on installations and appliances. Each of these checks will be considerably shorter than the initial surveys. The selection of these will be developed based on both the technical requirements, but also the customer engagement process, accounting where possible for the interest in participation of individual customers. As part of the project, gas customers will be offered free servicing of equipment during the trial.

It is extremely unlikely that there will be any unplanned interruptions during the network test phase of the trial, with the hydrogen injection unit designed to ensure continuity of natural gas supply. However if there were a fault or failure in the system, standard emergency procedures would be followed, which could result in a partial system shut down.

8.2 Customer Engagement Plan

This project requires interactions with customers and customer's premises. This project will comply with the conditions relating to customer engagement and data protection as set out in the NIC Governance Document. Both GDNs also have stringent internal processes to ensure that customers interests are fully protected.

The project will build on best practice developed in the HyDeploy project at Keele, which itself benefited from learning in the SGN Oban "Opening up the gas network" project. The Keele engagement process was well received, as shown by the feedback from one of the customers:

"I am proud of Keele's involvement in HyDeploy and the UK's initiative to reduce carbon emissions. I particularly appreciated the wealth of information that was provided about the project."

The Keele project has provided insights into customer perceptions of low carbon solutions and hydrogen from a very specific demographic. To undertake the public trials will require an understanding of perceptions from a much wider section of society. NGN have an established relationship with Newcastle University who have undertaken early work in this area and will undertake further work to support the programme.

A full customer engagement plan was developed for the project at Keele, which was also reviewed during delivery in order to maximise the opportunity for learning in a culture of continual improvement. The customer engagement plan for the public trials will be developed from this basis and the objectives and key elements are summarised below:

- The objective of the engagement strategy is to achieve active participation and a positive experience for the customers, specifically:
    - To provide customers with the right information about HyDeploy to enable them to make informed decisions.
    - To respond to customers' feedback and concerns in a prompt and efficient manner.
    - To provide key stakeholders and community groups with the right information so they are fully informed about the project.
- The plan makes a number of commitment to customers, specifically:

  - To keep them warm and secure by delivering gas safely, reliably and efficiently,
  - To deliver the Project for the benefit of all of gas customers in the UK.
  - To engage with customers and stakeholders at all relevant points in the decision making process to ensure that their views are taken account of, and ensure they have all the relevant information.
- The Plan sets out
  - How the ongoing communications with our customers will be sustained and sets out the arrangements put in place for responding to queries or complaints relating to the project.
  - How the needs of Priority Services Customers will be addressed and how they will be appropriately treated, including the ways information will be provided to any person acting on behalf of a Priority Services Customer in accordance with condition 37 of the Gas Supply Licence.
  - How consents required as part of the project will be obtained are also set out in this plan.
  - How safety related information is communicated to customers
  - How customer queries and complaints will be handle
  - How customers data will be protected under the requirements of GDPR

Importantly, the plan describes the customer journey through the project. An example of this journey is shown for the Keele project in Appendix L, which will be specifically developed for each individual public trial

The Project will be prepared to use a variety of communication channels to reach the impacted customers and wider stakeholders as required. These will be two-way wherever possible and will include: Direct correspondence (by letter and email), Information leaflets, the Project website, Personal conversations by telephone or at customers' properties, Social media channels including Facebook, local meetings to present and discuss project plans with customers and key stakeholder groups (Through its InTEGRel programme, NGN have also developed working relationships with local educational establishments and expects to work closely with them to run events), Targeted on-boarding information provided to new tenants/householders, Posters, Film / animation, On site champions and Surveys. Examples of the website and literature produced for Keele is shown in Appendix L.

Section 9: Project Deliverables

Ref	Project Deliverable	Deadline	Evidence	NIC fund request
1	Customer Engagement Plan	31/10/19	Confidential Project Report including: • Demographic assessment of trial location • Results from UK customer market research workshops relating to future energy changes • Results from hydrogen perception assessment to inform engagement • Customer Engagement strategy • Data protection strategy • Example engagement material	5%
2	Evidence base for first trial	30/06/20	Confidential Project Summary Report addressing: • Overview of key issues • Core materials findings • Key Appliance Laboratory testing findings • Key Appliance in-field testing findings • Gas Characteristics • Gas Detection • Summary of Procedures findings • Evidence gap for second trial	29%
3	First Exemption submission	31/09/20	Evidence of Exemption submission: • Receipt of application by HSE	3%
4	First trial commencement	31/01/21	Short form report demonstrating • Completion of installation including photographic evidence of the facility • Evidence of first injection into grid	9%
5	Evidence base for second trial	30/07/21	Confidential Project Summary Report addressing: • Overview of key issues • Core materials findings • Key Appliance Laboratory testing findings • Key Appliance in-field testing findings • Gas Characteristics update • Gas Detection update • Procedures update	12%

Ref	Project Deliverable	Deadline	Evidence	NIC fund request
6	First trial completion	31/12/21	Confidential Project Summary Report addressing: • Technical summary of trial phase • Customer engagement findings including assessment of hydrogen perceptions and experience during trial • Key learning for second trial	8%
7	Second Exemption submission	31/10/21	Evidence of Exemption submission: • Receipt of application by HSE	3%
8	Second trial commencement	30/04/22	Short form report demonstrating • Completion of installation including photographic evidence of the facility • Evidence of first injection into grid	7%
9	Second Trial completion	28/02/23	Confidential Project Summary Report addressing: • Technical summary of trial phase • Customer engagement findings including assessment of hydrogen perceptions and experience during trial • Key learning for roll out	8%
10	Completion of wider network evidence base, roadmap & dissemination	31/03/23	Project Report including: • Evidence base relating to the use of blended hydrogen for industrial users, encompassing burner laboratory testing and field-testing results for boiler and direct fire applications • Roadmap findings including Network model assessment, Regulatory basis for deployment, commercial requirements and summary of engagement with BEIS, and summary of skills/training experience during trials and strategy for roll out. • Summary of dissemination activities undertaken	16%

Ref	Project Deliverable	Deadline	Evidence	NIC fund request
N/A	*Comply with knowledge transfer requirements of the Governance Document.*	*End of Project*	*1.Annual Project Progress Reports which comply with requirements of the Governance Document.* *2.Completed Close Down Report which complies with 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: Appendices

Appendix A: Benefits Tables

Method	Method name
Method 1	20%vol blending rate
Method 2	10%vol blending rate

Gas NIC – financial benefits: **Cumulative net financial benefit (NPV terms; £m)**

Scale	Method	Method Cost	Base Case Cost	Benefit 2020	Benefit 2030	Benefit 2040	Benefit 2050	Notes	Cross-references
Post-trial solution *(individual deployment)*	Method 1	App B	App B	0	0.5	0.8	0.8	Case for first public trial, blend rate only changes project extent not savings.	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0	0.5	0.8	0.8		
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	App B	App B	0	1,317	4,002	4,988	Both GDNs NGN/NG = 63%GB Displacing 2.9 mill ASHP	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0	593	1,679	1,991	Displacing 1.5 mill ASHP	
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	Method 1	App B	App B	0	2,090	6,352	7,918	Displacing 2.9 mill ASHP	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0	942	2,666	3,161	Displacing 1.5 mill ASHP	

Gas NIC – carbon and/or environmental benefits: **Cumulative carbon benefit (tCO2e)**

Scale	Method	Method Cost	Base Case Cost	Benefit 2020	Benefit 2030	Benefit 2040	Benefit 2050	Notes	Cross-references
Post-trial solution *(individual deployment)*	Method 1	App B	App B	0	3,019	6,521	6,521	Case for first public trial. Blend rate only changes project extent not benefit.	All assumptions in Appendix B, summarised in Bid Section 3.6
	Method 2	App B	App B	0	3,019	6,521	6,521		
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	App B	App B	0 mill	6.0 mill	40.2 mill	74.6 mill	Both GDNs NGN/NG = 63%GB Displacing 2.9 mill ASHPs	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0 mill	3.0 mill	20.1 mill	37.3 mill	Displacing 1.5 mill ASHPs	
GB rollout scale *If applicable, indicate the number of relevant sites on GB network.*	Method 1	App B	App B	0 mill	9.6 mill	63.8 mill	118.5 mill	Displacing 2.9 mill ASHPs	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0 mill	4.8 mill	31.9 mill	59.2 mill	Displacing 1.5 mill ASHPs	
If applicable, any environ benefits cannot be expressed tCO2e.	Method 1	**Post-trial solution:** N/A **Licensee scale:** N/A, **GB rollout scale:** N/A						Primary purpose is tCO2e. All quantified	Appendix B
	Method 2								

Appendix B: Justification of Financial and Carbon benefits

B1. Strategic approach

The fundamental merits of using hydrogen as a blend has not changed significantly since the HyDeploy applications. The need for a low carbon solution for heat has gone up, the challenges associated with alternative solutions has become better understood, and there have been no material changes to the underlying costs over the period to 2050 relative the level of uncertainty over such a projection, although the figures are updated to a 2018/19 money basis and more recent underlying energy demand projections.

The approach taken uses the methodology agreed in the previous application, incorporating the clarifications made during the review process. In all National Grid's Future Energy Scenarios, heat pumps play an important role in the decarbonisation of heat. Whilst the timings of the introduction of such solutions varies between scenarios, in all cases heat pumps are the 'marginal' low carbon solution adopted in order to meet the carbon targets required. Therefore, the introduction of hydrogen into the network allows the avoidance of a proportion of the heat pump installations, providing that heat delivered by hydrogen is more cost effective. Ascertaining that this is the case, and demonstrating the quantum of that saving is the purposes of this analysis.

Levelised costs of heat pump solutions over the period are developed, based on referenced sources, and the levelised cost of low carbon hydrogen produced by various production routes are also calculated. In both cases these are compared with heat delivered by natural gas. The quantum of hydrogen penetration is projected, based on the underlying natural gas consumption, blend rate, and ramp up of production rate over the period. This, combined with the per unit savings from the levelised cost assessment is used to provide the net saving on a per annum basis from which the cumulative Net Present Value is calculated. Data for the carbon emissions from heat pumps and for the different methods of producing hydrogen are evaluated in order to ascertain the savings made by displacing natural gas in the network. This is summarised in Figure B.1 below.

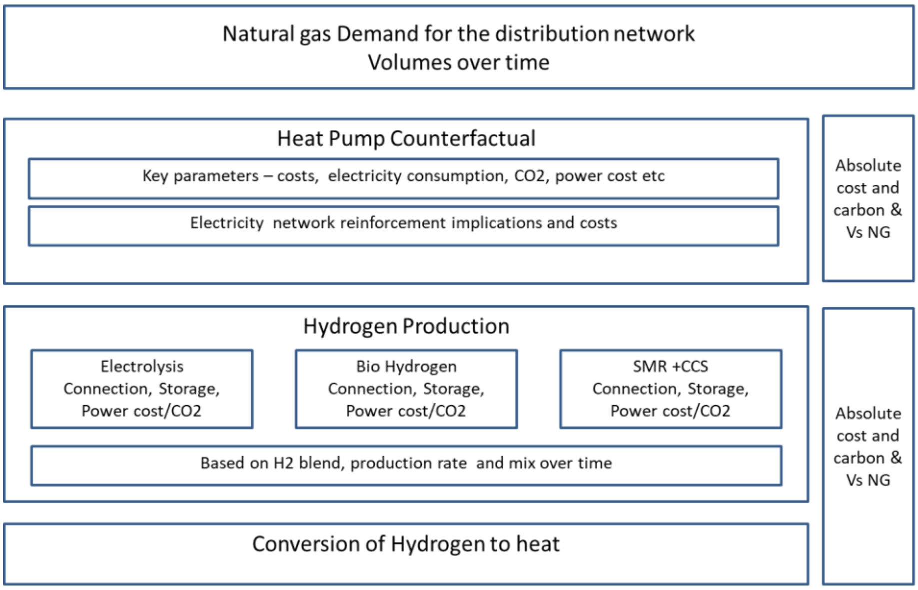


Figure B1. Overview of modelling approach

B.2 Assumptions

B.2.1 Baseline Scenario

Slow Progression was used as the reference scenario in this case, with gas consumption on the distribution network going from 505TWh down to 353TWh over the period. The purpose of this project is to establish the level of hydrogen blend Hydrogen blending in the UK. This is undertaken for two levels; the 20%vol reference, and a low bounding case of 10%vol, already permitted in parts of Europe. The trajectory to attaining these volumes of hydrogen over the period is assumed to be governed by the availability of hydrogen as discussed below.

B.2.2 Hydrogen Production

The purpose of this project is to establish a blend level which requires no changes to appliances or network. Therefore the only additional cost of heat delivered by this route is the production cost of the hydrogen itself, then assumed to be burned in a typical gas boiler to provide heat. Three routes for hydrogen production were considered: Bio-Hydrogen, Electrolysis and reformation of gas with carbon capture and storage. For the purposes of this analysis a blend of these production routes was considered. Each of the routes is considered below in terms of expected cost base, carbon intensity and hydrogen volumes. The detailed assumptions are listed at the back of Appendix B.

<u>Bio-Hydrogen production</u>

The feedstock is gasified and the syngas processed and polished to provide a catalytic quality gas. This is converted using the water gas shift, a robust catalyst which fully shifts the syngas to hydrogen and CO_2 for straightforward separation.

Costs: The costs of Bio-hydrogen production were established in a biohydrogen study, based on waste fuelled plants at scales between 300-600GWhr. For the purpose of this assessment, it has been assumed that only the smaller plant is feasible, along with a requirement for storage and distribution of the hydrogen to points on the distribution network.

Carbon Intensity: The Bio-hydrogen study showed the carbon intensity to be 61 -19 kgCO2e/MWhr as grid electricity carbon intensity falls. This is conservative; using the same approach that BEIS used in its RHI impact assessment, BioSNG has a *negative* carbon footprint as this route displaces landfill as a means of disposing of the waste, giving a figure of -90 to -132kgCO2e/MWhr depending on grid average electricity. Storage of the CO_2 could be further credited to the plant under the assessment regimes; reducing the emissions further to -351 & -415kgCO2e/MWhr, but this hasn't been assumed None of these benefits have been credited in the assessment, but show that the values are conservative.

Volumes: A study by Anthesis demonstrated the potential to produce up to 100TWh of BioSNG from indigenous feedstocks, which equates to around 120TWh of biohydrogen due to the higher conversion efficiency. This is substantially higher than the levels of hydrogen considered in the scenarios considered here (14TWh).

<u>Electrolysis</u>

Hydrogen is currently produced internationally and in the UK by electrolysis.

Costs & performance: The cost base of electrolysis is dominated by the capital cost of the equipment and the electricity required for conversion. Capital costs and performance have been taken from the Horizon 2020 European work on Fuel Cells[47], and work by Element Energy projecting developments into the future[48]. The performance is given as reaching 50KWh/Kg of hydrogen in 2023 which equates to around 76% on an energy basis. In reality, the electrolyser proposed for this project can already attain this level of efficiency, so this is a conservative figure, by 2030 it is projected to reach 47KWh/Kg. For the purposes of this analysis, 4 hours of hydrogen storage was assumed such that it needn't generate during peak power demand. Overall uptime was assumed to be 50%, accounting for both fluctuations in demand, as well as the potential ability to use the equipment to provide grid balancing services, although the benefits were not credited.

Carbon intensity: The carbon intensity of the hydrogen produced by this route depends on the electricity. This is based on the expected blend of marginal low carbon generation and grid average intensity over the period, referencing the slow progression scenario.

Production Volumes: Electrolysers are modular units. The cost assumptions shown above are for units with a hydrogen production rating of 2.5MWth. Based on an uptime of 50% this equates to around 100 modules per TWh of gas production with an expectation that at some sites there would be multiple modules. This kind of capacity would be within the capability of production. ITM are currently evaluating the potential for 100MW units.

Gas Reformation & CCS

Currently, bulk volumes of hydrogen are produced by Steam Methane Reformation of natural gas. This is an established process used internationally and in the UK, for example at BOC's Teesside plant. However, unless the CO_2 is removed then the carbon intensity of hydrogen produced by this route is worse, on an energy basis than natural gas due to the process efficiency. Therefore it requires Carbon Capture and Storage in order to deliver low carbon hydrogen. The hydrogen production process lends itself to capture, as it already has to separate CO_2 from the product hydrogen, although this requires optimisation for this application. The Port Arthur plant in the US already has carbon capture fitted. The key dependency is the existence of CO_2 transportation and offshore geological storage infrastructure.

Costs: The H21 Project has provided a suite of reference data[49], based on engineering assessments by Amec Foster wheeler, building on the previous work by the Teesside Collective[50]. This includes assessment of the efficiency & costs of hydrogen production, storage & distribution, as well as costs for CO_2 transport & storage. The HyNet project assessed the cost of hydrogen to be substantially lower, driven in part by lower cost transport and storage. For this assessment, the higher figures have been retained.

[47] Fuel Cell & H2 joint undertaking (FCH JU), Multi - Annual Work Plan (2014 – 2020)
[48] http://www.fch.europa.eu/sites/default/files/study%20electrolyser_0-Logos_0.pdf
[49]http://www.kiwa.co.uk/uploadedFiles/Our_Services/Energy_and_Carbon_Advice/H21%20Report%20Interactive%20PDF%20July%202016.pdf
[50] http://www.teessidecollective.co.uk/wp-content/uploads/2015/06/Teesside-Collective-Business-Case1.pdf

Carbon intensity: The capture rate from that work was 90%, although alternative technologies could provide higher rates. Conservatively, when combined with the conversion penalty, the carbon intensity is 13% of Natural gas, or 31kgCO_2/MWhr.

Volumes: The assumed unit size of each plant is 190MWth rating or 1.5TWh per annum.

This source of hydrogen is likely to grow over the period, and is likely to be combined with other demands for decarbonised hydrogen; such as transport, power generation and chemicals, or conversion of specific areas to 100% hydrogen operation. The HyNet project is based on delivering a blend to over 2 million users in the NW region by the mid- 2020s

Combined Hydrogen blend

For the purposes of this assessment, it has been assumed that there is a blend of hydrogen from the sources outlined above. Initial projects are expected to be dominated by electrolysis, but during the mid 2020s, other sources such as reformed gas with CCS and bio-Hydrogen come on-stream.

Overall Hydrogen cost

In all hydrogen cases, the costs, and the carbon intensity factors in the conversion efficiency of the boiler to reach a like for like measure against heat pumps, as well as the retail price for distribution of hydrogen and the capital and operational costs of gas boilers

B.2.3 Heat Pump Counterfactual

The counterfactual low carbon heat source is Air Source Heat Pumps. This is the lowest cost heat pump solution, with least disruption. It is considered that this is the low carbon heat solution which the proposed method of hydrogen injection avoids.

Capital cost and performance projections were taken from BEIS' RHI consultation[51] and its work on cost savings attributed to mass market deployment[52] which accounted for expected performance improvements and cost reductions over the period. Other work does not materially change these assumptions. Datapoints were taken at 2020, 2030, 2040 & 2050, with levelised costs interpolated on a straight-line basis.

Retail Electricity costs over the period were taken from the September 2017 version of the DECC/HM Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas.

In reviewing the quantity of heat pumps displaced this was cross checked against the determined heat pump penetration in the 2 degree compliant scenarios, and this

[51]https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505972/The_Renewable_Heat_Incentive_-_A_reformed_and_refocussed_scheme.pdf
[52]https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf

confirmed that substantially more than 3 million heat pump units were assumed in that scenario, so it is reasonable to assume they are the counterfactual low carbon solution.

Network reinforcement costs associated with Heat pumps

In addition to the direct cost benefit to the consumer, there are other wider network benefits of the strategy of injecting hydrogen into the grid.

The level of heat pump penetration which would otherwise be required will require substantial reinforcement of the electricity distribution network, particularly at a residential level, in order to accommodate high levels of demand at peak heat. Conversely the existing gas grid already has the capacity to handle such peak loads. Based on the FES modelling, transmission reinforcement requirements equate to around 3.5GWe of reinforcement per million heat pump units; in this case a peak capacity of 8.8GWe in the 20% blend, with a cost of around £225m per GWe, based on ETAM investment case for RIIO March 2012. Based on an NIA study[53] the electricity distribution costs equate to around £790 per heat pump.

The costs associated with the requirement for increased generation capacity to service the peak demand of 3 million avoided heat pumps has *not* been included in this analysis. In reality these would need to be introduced via the capacity market. At the £49 per kWe of installed capacity considered to be required to ensure additional capacity, this would equate to a further £4,100 million saving over the period on an NPV basis, which would ultimately be paid by consumers who would have had to move from gas to electricity for their heating.

The potential role that Electrolysis units could offer as balancing services to the electricity grid have also not been included, although this is widely recognise to be a valuable element of the technology, and hydrogen storage has been included in the assumptions. The costs associated with the decommissioning of the gas grid have not been accounted for. These are estimated by National Grid to be around £8,000 million, which are avoided or deferred by utilising the grid to deliver low carbon heat.

B.3 Results

The results have been assessed for the cases required in Appendix A. The main results are for the GB. In addition, they have been scaled by the volumes of gas through NGN and Cadent's networks compared with the overall usage, which equates to 63%. A 'post trial' solution was also considered. Here it is assumed that the grid entry unit and electrolyser continue to operate after the trial period. The cost and carbon savings are calculated as above, displacing 164 Air Source Heat pumps.

B.3.1 Financial Benefits

The savings are calculated based on the level of decarbonised heat supplied for each year over the period. These are expressed cumulatively on a Net Present Value basis and are shown in the table below, consistent with Appendix A.

[53] Managing the future network impact of electrification of heat, ENWL, June 2016

Cumulative NPV	Blend rate (Method)	To 2020 £million	To 2030 £million	To 2040 £million	To 2050 £million
GB Values	20% Blend (M1)	0	2,090	6,352	7,918
	10% Blend (M2)	0	942	2,666	3,161
Licensees (63% of GB)	20% Blend (M1)	0	1,317	4,002	4,988
	10% Blend (M2)	0	593	1,679	1,991
Post Trial	Either blend	0	0.5	0.8	0.8

At its peak this equates to GB savings of over £800 million per annum. The cost per tonne of carbon abatement is just 65% of that expected for the Wylfa Nuclear plant (on the basis of Strike price of £77.50/MWh, which itself is considerably lower than Hinkley Point C). Further, it is tackling an area of energy economy which is particularly challenging to address.

B.3.2 Environmental Benefits

Cumulative Carbon Saving	Blend rate (Method)	To 2020 Te CO_2 eq	To 2030 Te CO_2 eq	To 2040 Te CO_2 eq	To 2050 Te CO_2 eq
GB Values	20% Blend (M1)	0 mill	9.6 mill	63.8 mill	118.5 mill
	10% Blend (M2)	0 mill	4.8 mill	31.9 mill	59.2 mill
Licensees (63% of GB)	20% Blend (M1)	0 mill	6.0 mill	40.2 mill	74.6 mill
	10% Blend (M2)	0 mill	3.0 mill	20.1 mill	37.3 mill
Post Trial	Either blend	0	3,019	6,521	6,521

On a per annum basis at a GB level, the 20% carbon saving equates to around 6 million tonnes saving per annum, or around 200kg CO_{2eq} per householder per annum. In carbon terms, it is equivalent of removing 2.5 million vehicles from the road.

B.4.Assumptions

Prices		Unit	2020	2030	2040	2050
Electricity	Wholesale	£/MWhr	£41.95	£55.47	£60.56	£65.70
	Retail	£/MWhr	£192.15	£196.26	£196.26	£196.26
Gas	Wholesale	£/MWhr	£13.57	£17.04	£19.05	£20.55
	Additional price for retail	£/MWhr	£21.40	£21.40	£21.40	£21.40
	Retail	£/MWhr	£35.91	£39.39	£41.39	£42.89
ASHP	Capex	£/KWth inst	£982	£827	£775	£723
	Inst Capacity	kWth	6.7	6.7	6.7	6.7
	Load Factor	%	17%	17%	17%	17%
	In situ Eff	%	250.5%	274.5%	284.7%	295.3%
	Disc Rate	%	7.5%	7.5%	7.5%	7.5%
	Life	years	20	20	20	20
	Opex	£/kWth/annum	£10.00	£10.00	£10.00	£10.00
	Electricity price	Retail £/MWhr	£192.15	£196.26	£196.26	£196.26
	Levelised Cost	£/MWhr (heat)	£147.04	£132.81	£126.64	£120.90

Gas Boiler	Capex	£/KWth inst	£84	£84	£84	£84
	Inst Capacity	kW	12.0	12.0	12.0	12.0
	Load Factor	%	10%	10%	10%	10%
	In situ Eff	%	91%	92%	92%	92%
	Disc Rate	%	7.5%	7.5%	7.5%	7.5%
	Life	years	12	12	12	12
	Opex	£/kWth/annum	£5.22	£5.22	£5.22	£5.22
	Gas price	Retail £/MWhr	£35.91	£39.39	£41.39	£42.89
	Levelised Cost, excl gas	£/MWhr	£19.30	£19.30	£19.30	£19.30
	Levelised cost delivered heat	kg/MWhr (heat)	£58.97	£62.11	£64.29	£65.91
	Carbon intensity delivered heat	kg/MWhr (heat)	232	228	228	228
Electrolysis	Capex	£/KWth inst	£1,031	£767	£692	£692
	Inst Capacity	kW	2500	2500	2500	2500
	H2 Storage Capital Cost	£000	£157	£157	£157	£157
	Grid Injection Capital Cost	£000	£626	£626	£626	£626
	Load Factor	%	50%	50%	50%	50%
	Efficiency	%	81%	83%	85%	85%
	Electricity Price	(£/MWh)	42.0	55.5	60.6	65.7
	Disc Rate	%	7.5%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£88.94	£96.49	£98.87	£104.95
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£121.93	£128.14	£130.73	£137.34
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£141.22	£147.43	£150.03	£156.63
	Carbon intensity delivered heat	kg/MWhr (heat)	65	26	6	1
Bio hydrogen	Capex Bio-SNG	£/KWth inst	£2,433	£2,302	£2,187	£2,078
	H2 Storage Capital Cost	£M	£14.8	£14.8	£14.8	£14.8
	Grid Injection Capital Cost	£M	£1.7	£1.7	£1.7	£1.7
	Hydrogen Transmission System Cost	£M	£16.7	£16.7	£16.7	£16.7
	Inst Capacity	MW H2	42.31	42.31	42.31	42.31
	Load Factor	%	85.0%	85.0%	85.0%	85.0%
	Gate Fee	£/te	-£39.15	-£39.15	-£39.15	-£39.15
	Disc Rate	%	12.0%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£73.62	£52.94	£49.95	£47.11
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£104.99	£80.81	£77.56	£74.47
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£124.29	£100.11	£96.85	£93.76
	Carbon intensity delivered heat	kg/MWhr (heat)	53	33	27	21
Reform + CCS	Capex Reform	£/KWth inst	£514	£487	£460	£433
	H2 Storage Capital Cost	£M	£76	£76	£76	£76
	Grid Injection Capital Cost	£M	£8	£8	£8	£8
	Hydrogen Transmission System Cost	£M	£60	£60	£60	£60
	Inst Capacity	MW H2	190.6	190.6	190.6	190.6
	Load Factor	%	90%	90%	90%	90%
	Efficiency	%	68.4%	68.4%	68.4%	68.4%
	CO2 T&S Cost	£/te	£41.76	£31.32	£20.88	£10.44
	Disc Rate	%	12.0%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£56.09	£52.42	£52.36	£51.54
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£85.63	£80.24	£80.17	£79.28
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£104.92	£99.54	£99.47	£98.58
	Carbon intensity delivered heat	kg/MWhr (heat)	34	33	33	33

Post Trial	Capex	£/KWth inst	0
Keele Hydrogen production & injection unit redeployment. Addition of 4 hours of storage	Inst Capacity	kW	374
	H2 Storage Capital Cost	£	£93,692
	Grid Injection Capital Cost	£	0
	Load Factor	%	50%
	Efficiency	%	75%
	Electricity Price	(£/MWh)	42.0
	Disc Rate	%	7.5%
	Life	Years	20
	Levelised Cost Hydrogen	£/MWhr	£80.78
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£112.90
	Carbon intensity delivered heat	kg/MWhr (heat)	65

Absolute Values for GB at 20% (Method 1)			To 2020	To 2030	To 2040	To 2050
Heat	Heat displaced	TWh pa	0.0	15.4	29.2	24.7
Absolute Values						
Fossil gas	Levelised cost of heat	£/MWh	59.0	62.1	64.3	65.9
	Annual Cost	£M pa	0	957	1,880	1,628
	Cumulative Net Present Value by decade	£M (NPV)	0	2,059	11,092	17,707
	Carbon intensity (delivered heat)	kg/MWth	232	228	228	228
	Annual emissions	000 te pa	0	3,518	6,674	5,638
	Cumulative emissions by decade	000 te	0	11,296	73,298	134,513
Absolute Values						
Heat pumps	Number of Units	000s	0	1,390	2,780	2,482
	Levelised cost of Heat (excl reinforcement)	£/MWh	147.0	132.8	126.6	120.9
	Annual Cost (inc reinforcement)	£M pa	0	2,477	3,656	2,928
	Cumulative Net Present Value by decade	£M (NPV)	0	5,978	25,623	38,004
	Carbon intensity	kg/MWth	71	34	11	3
	Annual emissions	000 te pa	0	531	319	80
	Cumulative emissions by decade	000 te	0	272	7,619	9,444
Absolute Values						
Hydrogen	Volume of hydrogen from electrolysis	TWh pa	0.0	3.2	4.4	3.7
	Volume of bio-hydrogen	TWh pa	0.0	8.6	13.4	11.6
	Volume of hydrogen from gas reformation + CCS	TWh pa	0.0	3.5	11.4	9.4
	Levelised cost of heat	£/MWh	142.3	110.9	106.9	106.0
	Annual Cost	£M pa	0	1,710	3,125	2,620
	Cumulative Net Present Value by decade	£M (NPV)	0	3,888	19,271	30,086
	Carbon intensity	kg/MWth	65	31	26	23
	Annual emissions	000 te pa	0	484	773	558
	Cumulative emissions by decade	000 te	0	1,725	9,487	16,027
Comparisons						
Carbon	Cumulative savings by heat pump relative to fossil gas	000 te	0	11,024	65,679	125,069
	Cumulative savings by hydrogen relative to fossil gas	000 te	0	9,571	63,811	118,486
Costs	Cumulative decarbonisation by heat pump relative to fossil gas	£M (NPV)	0	3,920	14,531	20,297
	Cumulative decarbonisation by hydrogen relative to fossil gas	£M (NPV)	0	1,829	8,179	12,379
Savings	Cumulative decarbonisation by hydrogen compared with heat pump	£M (NPV)	0	2,090	6,352	7,918

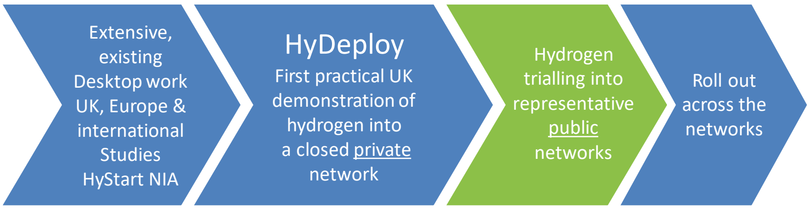
Absolute Values for GB at 10% (Method 2)			To 2020	To 2030	To 2040	To 2050
Heat	Heat displaced	TWh pa	0.0	7.7	14.6	12.4
Absolute Values						
Fossil gas	Levelised cost of heat	£/MWh	59.0	62.1	64.3	65.9
	Annual Cost	£M pa	0	479	940	814
	Cumulative Net Present Value by decade	£M (NPV)	0	1,029	5,546	8,853
	Carbon intensity (delivered heat)	kg/MWth	232	228	228	228
	Annual emissions	000 te pa	0	1,759	3,337	2,819
	Cumulative emissions by decade	000 te	0	5,648	36,649	67,256
Absolute Values						
Heat pumps	Number of Units	000s	0	695	1,390	1,241
	Levelised cost of Heat (excl reinforcement)	£/MWh	147.0	132.8	126.6	120.9
	Annual Cost (inc reinforcement)	£M pa	0	1,238	1,828	1,464
	Cumulative Net Present Value by decade	£M (NPV)	0	2,989	12,812	19,002
	Carbon intensity	kg/MWth	71	34	11	3
	Annual emissions	000 te pa	0	266	160	40
	Cumulative emissions by decade	000 te	0	136	3,809	4,722
Absolute Values						
Hydrogen	Volume of hydrogen from electrolysis	TWh pa	0.0	1.6	2.2	1.9
	Volume of bio-hydrogen	TWh pa	0.0	4.3	6.7	5.8
	Volume of hydrogen from gas reformation + CCS	TWh pa	0.0	1.8	5.7	4.7
	Levelised cost of heat	£/MWh	148.5	116.8	112.5	111.7
	Annual Cost	£M pa	0	900	1,645	1,380
	Cumulative Net Present Value by decade	£M (NPV)	0	2,048	10,146	15,841
	Carbon intensity	kg/MWth	65	31	26	23
	Annual emissions	000 te pa	0	242	387	279
	Cumulative emissions by decade	000 te	0	863	4,743	8,013
Comparisons						
Carbon	Cumulative savings by heat pump relative to fossil gas	000 te	0	5,512	32,840	62,534
	Cumulative savings by hydrogen relative to fossil gas	000 te	0	4,785	31,906	59,243
Costs	Cumulative decarbonisation by heat pump relative to fossil gas	£M (NPV)	0	1,960	7,265	10,148
	Cumulative decarbonisation by hydrogen relative to fossil gas	£M (NPV)	0	1,018	4,600	6,987
Savings	Cumulative decarbonisation by hydrogen compared with heat pump	£M (NPV)	0	942	2,666	3,161

Appendix C: Project Technical Definition

C.1 Background and Purpose

The UK has committed to substantial carbon savings; heat contributes to a third of its current emissions. Reducing heating carbon intensity via hydrogen over the gas grid provides a customer-focused solution, but is limited by the current tight GS(M)R UK limits. Building on the foundational work undertaken at Keele University, this will be the first UK deployment of hydrogen into the public gas network. It will move from the requirement to survey, test and trial all parts of a network prior to injection, to the ability to inject into an untested network, as necessary for roll out. This will be achieved through development of a representative and resilient evidence base though further trials & a roadmap for hydrogen deployment through blending in a 48 month project, running from April 2019 to April 2023. The requirement for public trialling following the first project at Keele University was established in the project definition and successful proposal to OFGEM for the original HyDeploy project in 2016.

The project objective is that a supplier of hydrogen is able to apply to inject hydrogen into a GDNs network, just as biomethane producers can today. This enables hydrogen to deliver cost-effective and non-disruptive carbon savings to the customer.



Successful demonstration has the potential to facilitate 29TWh pa of decarbonised heat in the GB, substantially more than the existing RHI scheme is projected to deliver, with the potential to unlock wider savings through more extensive use of hydrogen. It addresses the energy trilemma, saving £8billion to consumers, and avoiding 120 million tonnes of carbon by 2050, whilst providing a greater level of diversity in supply.

C.2 Project Approach

The objective of the programme is to reach the point whereby a hydrogen supplier is able to apply to inject into a gas network, as biomethane producers can today. Currently such biomethane producers still require an Exemption to GS(M)R if they plan to exceed the oxygen limit. However in that case, the principles of the exemption the evidence base are now established, and neither the individual producer nor GDN do not need to undertake specific, onerous activities in order to inject. In the future gas quality specifications may be moved from legislation (GS(M)R) to a separate Standard, which would allow the specifications themselves to be updated rather than project or class Exemptions being required. However, in all cases, the Regulator and body responsible for the Standard would need the necessary evidence base that the change is safe.

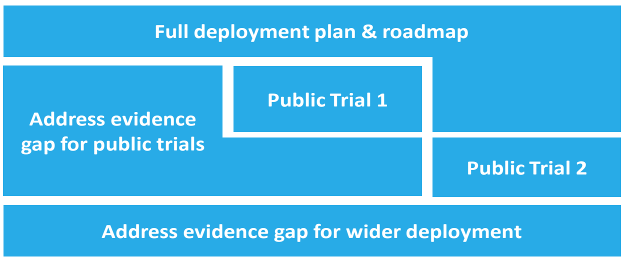
C.2.1 The HyDeploy Project at Keele University

The HyDeploy project at Keele has provided the foundational first elements of that evidence base. Keele University was specifically chosen for a first trial as it provided a well-controlled site and allowed the most comprehensive dataset to be collected about that network, appliances and installations. Therefore, the impact of a hydrogen blend can be established with a much greater degree of certainty, as is appropriate for a first-of-a-kind situation. Such an approach is consistent with projects in Europe such as Engie's GrHyD project, which is the French equivalent of the Keele project. However, the GrHyd project was more confined than the Keele demonstration as it is a newly built gas network.

The evidence collated for Keele covers the fundamental characteristics of the hydrogen blend, the impact on the materials found at Keele under the network conditions and the impact on the specific installations and appliances at Keele. The operational procedures deployed on the network were all reviewed, and where necessary modifications identified to accommodate the blend. The Keele project has also delivered the detailed design of equipment suitable for blending and injecting hydrogen into a gas network. Together this evidence base has been drawn together in a newly developed Quantitative Risk Assessment for hydrogen blending. On the basis of this comprehensive assessment, an application has been made to the HSE for an Exemption to the regulations to permit injection of hydrogen at a level of 20%vol.

C.2.2 The Requirement and Principles of HyDeploy2

The fundamental principle of an Exemption or a change of Gas Quality Management Regulations is that the safety of the gas users is not prejudiced. In order to establish this, any potential impacts must be fully understood and assessed. From a technical and scientific evidence perspective, this effectively requires 'proving a negative.' On a closed private network such as Keele it is possible to fully characterise the network, appliances and installations and have confidence that they are well maintained and fundamentally sound. For widespread deployment, the gas network with 23 million users and 284,000 km of network, cannot be so comprehensively characterised. Therefore, a methodology is required to build on the foundation from Keele and provide the necessary evidence and confidence that there is no prejudicial effect when deployed on the wider public network. This approach is summarised in the following figure and discussed below.



It is primarily achieved through a sequence of trials; the first replicates the Keele work on a wider, more representative network. Safety check are still carried out on all properties to provide the confidence to the regulator that the appliances and installations are fundamentally sound, although only a sample are bottled tested on a hydrogen blend prior to the trial. This will need to draw on an increased evidence base from laboratory testing of broader material types as well as procedures and equipment used on the public network. The data from this trial is then used to support the application to the HSE for the second trial, where only a sample of the properties are safety checked and none are bottle tested on a blend prior to the trial. This requires necessary laboratory evidence that operation of a hydrogen blend into unsound installations or poorly maintained appliances does not unduly increase the risk compared with the risks inherently associated with operation of such installations on natural gas. The dataset from both trials together must provide sufficient evidence to support the premise that injection of a hydrogen blend into a wider network does not prejudice the gas users.

The trials themselves therefore require a corresponding laboratory and scientific programme to underpin the safety case. In addition to the trials themselves, to is important to address two further areas of the evidence base to underpin wider roll out. Firstly, whilst the trials themselves will necessarily be undertaken into the low or medium pressure network due to their scale, blending can be deployed at lower cost with fewer injection points. This requires the ability to inject into higher pressure tiers of the distribution network. Therefore, it is important to establish the evidence base for safe operation at higher pressures in the materials used in such parts of the network. Secondly, a blend can only be rolled out if all users on the network are able to accommodate the modified gas. The Keele trial provides good evidence of operation into a wide range of commercial applications, and the subsequent public trials will demonstrate operation into a wide range of domestic installations, but neither addresses operation of a blend for industrial users. A programme of parallel tests on industrial appliances and equipment will be undertaken to provide the necessary evidence.

A well-structured deployment plan is required in order to ensure that the benefits of hydrogen blending are realised. This will be undertaken in parallel with the technical and trial programme to ensure that any specific requirements identified are addressed during the test programme. This work importantly includes techno-economic assessment to understand optimal network injection points and pressures, practical deployment of metering and billing, based on the outputs from FBM, as well as refinement of ownership models to inform engagement with HMG on fiscal support structures. Deployment can only take place with appropriate skills and training across the networks and an appropriate programme will be developed.

C.2.3 Key rationale for the proposal, in relation to the current project at Keele

It is necessary: Public trialling is a necessary step from the trial at Keele to full deployment. This was an integral part of the first NIC project proposal & previously supported by Ofgem through the expert panel with full visibility of the requirement.

It requires more than one trial: At full deployment, applicants to inject hydrogen cannot be required to undertake safety checks in every home affected. Therefore, it is critical that sufficient, statistically representative evidence is collected in this project. Given the relative geographical homogeneity of housing stock, this is difficult to achieve in a single location, delivering a sufficient range of appliances and network materials and components. The second trial must also support the principle of reduced data collection at the Exemption stage, based on the evidence from the first trial, to enable subsequent roll out. Demonstration that this incremental reduction in data collection can be safely delivered requires two exemption applications and trials.

It is timely: The rigorous scientific and operational case has been developed for HyDeploy at Keele, and the Exemption application has been made to the HSE. No fundamental barriers to blending have been identified. The live trial at Keele will be completed in March 2020 and equipment should be directly transferred to the public trial. This direct transfer is critical in order (a) to maintain momentum, enabling a seamless transition of equipment & teams from Keele to the first public trial, and (b) to expedite roll out of blending as rapidly as possible to make a meaningful contribution to the fourth carbon budget. The evidence base required to support the first public trial will be developed during the first year of $HyDeploy_2$. Undertaking this in parallel with the demonstration phase of HyDeploy at Keele, importantly provides opportunity to identify and secure any further data best collected on a live network operating on a blend. For example, this could include trialling new detection equipment.

C.3 Development of the Evidence base

C.3.1 Evidence required to support trials

This builds on the principles established at Keele, extended to cover the specifics of the public trials. The scientific requirements is described in detail in Appendix D, which identifies in each area the knowledge gaps from the trial at Keele that must be addressed for wider roll out, the rationale and the activities to be undertaken. This is summarised below. In many cases at Keele, it was possible to take a conservative position. The range of materials, appliances, installations is more limited than on the public network. Where there were uncertainties in the evidence base, conservative assessments of the risk were undertaken. This was because in that context it is possible to invoke a range of mitigation measures, and refinement of procedures to ensure that the overall risk associated with gas distribution and is not prejudicial to safety. These issues were foreseen, and were the rationale for undertaking the first trials on a close private network such as Keele. For a wider deployment it is necessary to refine the evidence, building on this foundational work.

There has been close collaboration between HyDeploy and the team delivering the GrHyD project in France. Many of the knowledge gaps, have been identified by both teams, with limited evidence available internationally. This provides confidence that the work has not been undertaken before and is therefore necessary. This work is focused on hydrogen blends. Key partners in this project are also involved in 100% hydrogen work, have ensured that there is no duplication with that work. In undertaking the work, will ensure that any information which can support those programmes is appropriately shared.

Materials: The trial at Keele addressed materials found on that specific site following a comprehensive asset survey. For roll out it is important to address the range of materials found on the wider network, covering both metallic and polymeric components. As noted below, this must include operational pressures up to 39bar to enable cost effective deployment. To enable understanding of the impact of long term operation on materials, the work must be expanded to evaluate the impact of hydrogen blends on materials under cyclical loading conditions and the impact on fatigue life addressing both crack initiation and growth. Hydrogen embrittlement is a long term degradation mechanism and it is important to understand the basis of materials failure to allow predicative capability. Cathodic charging is a technique to accelerate absorption compared with gaseous soaking. This will be assessed and through a carefully defined experimental programme be calibrated against uptake from partial pressures of hydrogen from gaseous soaking. This is approach is designed to simulate decades of gaseous exposure, potentially in a few days, enabling development of an evidence base for long term operation, and potentially experimental cost savings.

The experimental output will progressively build confidence in the materials performance of any GDN network containing a hydrogen blend. The aim will be to provide short-term confidence to allow the trials to be undertaken, while also producing data applicable to long term exposures of a network over a wide range of pressures. The work will be undertaken and managed by HSL supported by third party organisations with the skills and equipment necessary to undertake the specialist areas of work. Specific universities with the necessary capabilities have been identified, particularly Manchester and Sheffield.

Appliances & Installations. The laboratory testing and field testing at Keele established that appliances that are functioning correctly and well-maintained can safely burn hydrogen blended gas that meets the GS(M)R Wobbe Index specification in accordance with existing UK natural gas safety standards. A comprehensive site survey and programme of remedial work provided confidence that the appliances at Keele were properly installed and well maintained. An understanding of how poorly maintained, malfunctioning and maloperated appliances will respond to hydrogen blended gas is required to build the confidence that on a wider network these appliances pose no greater risk. Additionally, an assessment of the performance of pre-GAD appliance is required to ensure there is no anomalous operating characteristics in the aging UK appliance stock. During the work for the project at Keele, it was identified one particular class of sensor used in gas fires required further understanding of operational efficacy for a blend. This issue was addressed for Keele by ensuring that the specific types in the relatively few appliances were suitable, however further evidence is required to assess the situation for wider network application.

A testing programme will be established, managed by HSL and delivered by KIWA based on the understanding from Keele, as well as wider work such as the Oban trials. The first public trial includes a full gas safety survey of the installations on the network. This will provide an extensive data set of appliances and modes of installation shortcomings, poor maintenance, malfunction and maloperation, in order to ensure that the testing envelopes the expected range of conditions encountered on an 'uncontrolled' network. This data will be fundamental to the evidence base to support the second trial where only a sample of installations will be surveyed.

Through a technical review and an industry consultation exercise information has gathered on potential longer-term effects of hydrogen blended gas on appliance integrity accelerated testing is being undertaken on the network at Keele. This data will be assessed to establish long term integrity of components and impact on maintenance and warranties. This area of work well supported by appliance manufacturers.

It is important to establish the impact of hydrogen blends on installation leakage characteristics. Direct assessment of these approaches through measurement of leak rates with hydrogen blended gas was not possible during the onsite testing programme at Keele University due to issues with temperature equilibration of the installation gas volume during. At Keele a conservative position was taken on the basis of analytical assessment and remedial works on installations. To underpin wider roll out it a robust leak measurement test will be developed, evaluated for test installations and through testing at Keele during the live trial phase. In order to support the public trials, refinements to Gas Safe procedures must be communicated to the wider community of fitters. Development of training packages to inform the gas fitter community is required so that the implications of hydrogen blending are communicated clearly and unambiguously

Gas characteristics and Procedures. There are a number of important areas relating to gas characteristics and therefore associated procedure which need to be addressed for public deployment.

Through the HyDeploy programme at Keele around 200 existing gas procedures were assessed for suitability for hydrogen blends. It was determined that the majority of these remained suitable, with only a subset requiring refinement for Keele. In many of those cases, changes were identified to take a conservative position for that trial. A more detailed evidence base relating to specific aspects of gas characteristics allows a more refined assessment and minimise procedural changes for wider deployment.

The migration of gas from a subsurface leak source (e.g. a low to medium pressure pipe rupture) has a bearing on building proximity distances and gas leak sweep distances. Conservative positions were taken at Keele, but which add complexity to gas network operators. HSL will undertake experimental and theoretical modelling using existing facilities and approaches to assess the behaviour hydrogen blends allowing the GDNs to assess the implications for procedures.

It has always been recognised that hydrogen permeates faster through the walls of PE pipelines faster than natural gas. The absolute leakage rate is very low, and not an issue of itself, but this could affect the concentration of hydrogen in the permeate. This could only be an issue where there are specific public network pipe configurations such as 'inserted mains' or running of pipelines through ducts. Experimental work be undertaken to replicate in-field conditions to assess this.

Hydrogen blended gas has a wider flammable range and the minimum ignition energy is lower than natural gas. This can be managed at Keele through the mitigation measures in place, but an understanding of the frequency of different ignition sources of different strengths is required to refine the implications more widely. This will be assessed through frictional ignition tests at HSL using the methods developed for the MechEx pre-normative European research programme.

A method to quantify the dispersion and migration of hydrogen blended gas around a realistic house is necessary. This is understood in industrial plants and the implications understood in the open, but not within buildings. At Keele this is mitigated through survey and remedial works to establish that installations are fundamentally sounds, but requires further data to understand the risk under less controlled conditions. Existing dispersion models will be refined and validated from data obtained from a new scaled experimental rig which will replicate the layout of a two-story building.

Gas detection instruments were extensively assessed for the project at Keele. This identified that there was a degree of cross-sensitivities in the detectors. This could be accommodated by appropriate operational procedures, but it would be strongly preferable to facilitate the detection industry to develop equipment to meet the requirements of routine and emergency gas detection procedures.

Together this work will be used to underpin review and refinement of the operational procedures to support not only the public trials, but will include engagement with all the GDNs to provide the basis for wider roll out.

C.3.2 Evidence Required to support wider roll out

Output from the roadmap work will be used to ensure that evidence is developed for appropriate pressure tiers & network control strategies for the future to ensure that blending can be delivered at least cost to consumers.

Deployment also requires that all consumers can accept the blend. Whilst commercial installations have been extensively covered at Keele, with more expected alongside the public trials, the evidence base for industrial users must be developed. Based on work by Cadent in its HyNet project, blend tests will be undertaken on industrial boilers as well as high temperature furnaces & kilns in the ceramic & glass sectors. Other work relating to CHP & CNG transport applications will also be reviewed.

C.3.2.1 Hydrogen injection to higher pressure network tiers

One of the merits of deployment of a hydrogen blend is that it can be undertaken at a wide range of scales as no changes are required for the users. One delivery route is electrolysis of low carbon electricity, including for example of otherwise constrained intermittent generation. In this case, electrolysis is typically at moderate scale measurable in a few MW of capacity, sufficient for a few thousand users, and therefore injected into medium or low-pressure tiers.

Injection at higher volumes unlocks economies of scale on hydrogen production – for example with larger electrolysers, or step changes in production techniques such as conversion of fossil resources with carbon capture and storage. This confers substantial cost reductions in hydrogen production involving production at capacities of 100s MW. Whilst this could be distributed via an extensive hydrogen network to the medium and low pressure tiers (<2bar) further savings can be achieved by injection into fewer injection points at higher pressure. For example the HyNet project[54] has identified that over 2 million homes and business could be reached in the Liverpool City, Greater Manchester, Warrington, Wigan and Northern Cheshire regions from just 4 injection points into the Local transmission system. Given that new pipelines can cost in the range of £1.0-1.5M/kilometre and each injection point between £0.5-£1.0M, this approach substantially reduces both hydrogen transmission and injection equipment costs.

However, this requires injection into natural gas pipelines at up to 33 bar. This both (a) increases the partial pressure of hydrogen, and (b) changes the range of existing pipeline material types, including various grades of steel. These are both important factors which must be properly understood, in order to establish that hydrogen interactions with pipelines can be safely accommodated. A specific scientific programme of work has been developed in order to verify the premise, and establish the necessary evidence base

C.3.2.2 Ability of Industrial users to accommodate a hydrogen blend

<u>Background</u>

The underlying principle of HyDeploy (1 and 2) is to establish and demonstrate that a blend of hydrogen with natural gas can be safely adopted which requires no changes to

[54] www.hynet.co.uk

the network or users. This confers a reduction in heat related carbon emissions without significant behavioural change, nor costs of conversion. It is a common misconception that industrial users operate mainly on the National or Local Transmission Systems. However, the vast majority of industrial users operate on the local distribution system at pressures of 7 bar or lower. For example, work undertaken by HyNet in the North West, has established that over 95% of industrial users in that region are connected to the 7 bar system or lower. Therefore, it is a pre-requisite to delivering the HyDeploy blend level that such users can also accommodate this level of blend.

As with domestic and commercial users, this requires both analytical work, but also physical demonstration of operation, both to establish the fundamental safety case, but also to provide users with the confidence in operation. To a degree, industrial users are better placed than residential consumers to understand and address any potential implications of blend operation. For example, there is a technical and operational skill base, necessary to operate any industrial equipment, which doesn't and shouldn't need to exist for domestic or commercial consumers. Also, the number of individual users per unit of energy delivered are orders of magnitude lower. However, there are productivity and commercial imperatives which industrial users must be satisfied are maintained. Therefore, whilst the environment should be well suited to accommodating blend operation, the requirement to demonstrate that it can be adopted safely without productivity implications is critical.

For most industrial users, direct combustion represents the largest emissions of CO_2 and therefore energy consumption, as evidenced by BEIS in its industrial roadmap work[55]. This work segmented users by sector. This can be further segmented by application type, which demonstrates considerable commonality in user types. Key applications are shown below.

Sector Equipment type	Chemicals	Glass	Manufact. (eg FMCG, Automotive)	Oil and Gas	Ceramics & Cement	Pulp & Paper	Iron & Steel
Raise steam / hot water (boiler)	✓		✓	✓		✓	✓
Direct firing high/low temp	✓	✓	✓	✓	✓	✓	✓
CHP	✓	✓	✓	✓		✓	✓
Chemical	✓			✓	✓		✓

In many cases there is historic and ongoing experience of using hydrogen as a fuel. Many of the UK's industrial facilities were originally developed to use towns gas, and in the iron/steel and oil/gas sectors, use of hydrogen-rich 'off-gases' and 'refinery-gases' is fundamental to their operation, with downstream equipment being designed to operate safely and effectively on a wide range of gas compositions. There are even recent examples of conversion of conversion of industrial natural gas boilers to operate on 'full hydrogen', such as Innovyn and Sabic. This provides wider confidence in the ability of industry to accept the use of hydrogen in principle, but it is imperative that operation of blend into existing equipment is established.

[55] BIS (2015) Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, March 2015

Application Summary
Some industrial uses are analogous to domestic and commercial applications, such as boilers, but other applications such as direct firing or chemical use rely on different attributes of the fuel or feedstock which need to be considered. These are briefly summarised below.

All combustion applications depend on a burner, which for industrial applications can be of a range of configurations; not just pre-mix (like most domestic boilers) but post-aeration, where the fuel is delivered to the nozzle unmixed and the oxidant is added subsequently, either directly, or from the wider combustion atmosphere. In many industrial cases, the burner is supplied separately from the downstream equipment (such as boiler or furnace), rather than as fully integrated packages. Close engagement with burner manufacturers is required to provide practical evidence of operation, which is applicable to a range of applications.

Boilers: Steam and hot water raising is achieved through combustion of fuel gas through heat exchangers of a variety of types. Unlike domestic applications, this is often undertaken to produce steam, and therefore must operate at higher temperatures. It is important that materials of construction interactions with hydrogen, heat transfer rates (and therefore boiler efficiency), changes to air-fuel ratios including combustion control systems, safety management systems and emissions control can all be accommodated with a blend. This will require a robust evidence base.

Direct Fire - Furnaces & Kilns. In these applications the flame interacts with the product being made, including high temperature applications such as glass and brick making or lower temperature applications such as ovens and toaster in the food sector. Here key parameters are the emissivity of the flame, combustion temperatures and how heat is transferred to the product as well as any interactions between the products of combustion and the product being manufactured. In general, operation of a blend at 20%vol is not expected to substantially alter these characteristics. However, is important to demonstrate this satisfactorily, as well understand material interactions, ensuring that operation under upset conditions remains safe, including safety management systems, and that emissions (particularly NOx) for high temperature applications remain within permitted levels. This will require a robust evidence base.

Chemicals. In general, the presence of hydrogen does not present a fundamental issue. Many chemical applications benefit from the presence of hydrogen because it is the element required such as in fertiliser production or because its reductive properties can be helpful such as in iron & steel production. These applications are those which do tend to operate at such a scale, they feedstock they source are from the NTS. Therefore, whilst these applications will be documented within the HyDeploy2 programme, it is not anticipated that any practical testing is required.

Test Programme
As identified above, it is important to provide a robust evidence base that industrial users are able to accommodate a hydrogen blend, to ensure that they do not present a fundamental barrier to its adoption. Building on the wider work undertaken under the HyNet programme, a test programme has been developed.

Burner manufacturers have been identified who supply equipment into the UK market, many of whom have in-house test facilities, suitable for providing initial demonstration of blend operation. As with the domestic appliance testing work undertaken under HyDeploy this will including testing presentative burner types on an envelope of gas types, providing confidence in safe and effective combustion of blends over the range of underlying gas qualities permitted for delivery in the UK, as well as impact of deviations in blend rates beyond the permitted level. Close engagement with the manufacturers will be used to assess and evidence any potential long-term impact of hydrogen on any sensitive components identified; where required this will be integrated in the wider materials work identified in Section C.3.1.

Through HyNet, over 30 industrial users have been engaged across the sectors and users group has been established. Subject to successful burner operation a number of sites are prepared to act as hosts for specific demonstration trials. Unlike the domestic trials these will be relatively short intensive campaigns, necessary in order to interface with existing production. Therefore, hydrogen will be delivered to the sites, rather than produced on demand. Any hydrogen wetting components outside of the burner will be assessed in terms of long term impacts and integrated in the materials programme as above.

The programme will address the key application types assessed in the previous section.

- Single and multiple burner testing in a representative boiler application, assessing quality of combustion including operation of control systems, plant efficiency and performance, impact on emissions and impacts on safety devices.
- Direct firing application testing. Industrial host sites have been identified in both the glass and ceramic sectors. Demonstration tests will be undertaken assessing quality of combustion including operation of control systems, plant efficiency and performance, impact on emissions and impacts on safety devices. Importantly any potential impacts on the quality of the products being manufactured will be assessed in conjunction with the host sites.

An important element of the programme is important to assess the implications of the presence of hydrogen on an industrial site, in terms of existing operational procedures, zoning and DSEAR assessments. The host sites will provide exemplars to undertake this assessment and provide reference case studies.

<u>CHP Units</u>

Gas fuelled CHP units are used on the network to deliver heat and power. Depending on scale, these can be reciprocating engines or gas turbines. Work is already underway both in the UK as well as internationally on operation of such units on hydrogen blends. In general, this work is most appropriately undertaken by manufacturers, as they are providers of performance guarantees. For example, Cadent is currently undertaking a project with DNV-GL, supported by MAN, which includes hydrogen blend testing of engines designed for natural gas use. Initial findings are encouraging, indicating that in principle such operation can be delivered in this case. Whilst it is important for role out that such applications can accommodate the blend, it is inappropriate to replicate such practical work. $HyDeploy_2$ will be limited to desktop assessment of the state of the art in this sector, in order to engage with industrial users effectively.

C.4 Main Trials

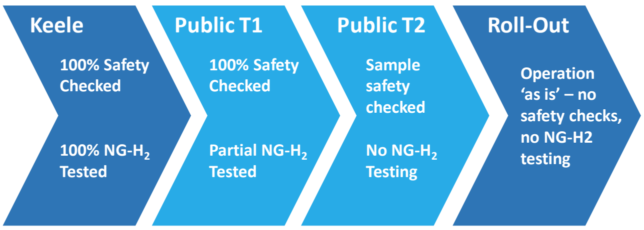
Two main trials will be undertaken; one in Cadent's North West region and the other in the North East by NGN. This ensures that the detailed operational procedures and network characteristics are assessed in detail, evaluated by the HSE and demonstrated Both trial locations will be selected in order to provide between them a representative GB evidence base. As agreed with OFGEM in the initial HyDeploy application, the hydrogen production and blending equipment will be used for both trials delivering value for money. Therefore, each trial will be around 600-900 domestic properties, matched to the scale of the existing equipment.

Engagement with customers is a key aspect of the programme, based on a comprehensive strategy which builds on the practical learning from the first project at Keele. This will include an extensive network and appliance survey for the first trial and a sampled assessment for the second. Both trials will require an Exemption for GS(M)R. This will be based on the development of a technical evidence base, site specific data and a Quantitative Risk Assessment. Subject to the granting of an application, the hydrogen production, injection and monitoring equipment developed at Keele will be relocated, installed and commissioned on site. For each site an injection trial of up to 12 months will be undertaken to confirm, understand and document the operational behaviour of the network and appliances.

Whilst the Installation and Injection phases take place on the first site, customers on the second trial site will be engaged, a reduced network and appliance survey undertaken, and the next Exemption developed based on this simplified data set as part of a trajectory towards roll out. Equipment will then be relocated and injection trials undertaken.

C.4.1 Trial strategy

The underlying objective and strategy for the trials is summarised below. The Keele trial is based seeking to safety check every appliance and installation on the network, including hydrogen blend testing using bottled gases prior to the Exemption.



The first public trial will still include seeking to undertake safety checks of every installation on the network. By virtue of being on a public network, it is expected that there will be a greater number of appliances that are poorly installed or maintained than at Keele. This will provide valuable evidence as to the prevalence and nature of such poorly maintained appliances. As at Keele, remedial work will be undertaken on such installations to ensure that they are compliant with gas installation requirements. During these safety checks a sample will be hydrogen blend tested using bottled gases. This is supporting the first phase of reduced evidence compared with Keele. During the trial, operational data will be collected.

The second public trial will safety check a subset of installation and appliances, and none will be bottle tested on the blend. Laboratory testing is required in order to achieve this. Specifically, data regarding non-compliant installations from the first public trial will be used to inform laboratory testing to establish confidence as to whether operation on a blend of poorly installed or maintained appliances is no more prejudicial to safety than operation on natural gas. This is a key part in establishing that a safety case can still be made on a reduced level of field data; as is required for future roll out. Similarly, during the trial itself it is expected that a lower level of data will be collected, focused on that required to enable future roll out.

C.4.2 Customer Engagement Plan

This is a customer focused project. Its purpose is to provide a way for customers to reduce the carbon intensity of the heat they consume without disruptive changes. However, in order to gather the necessary evidence during these trials, there is necessarily an impact, particularly relating to visiting homes to undertake the safety checks prior to the trials and in-trial data collection.

The project at Keele established a successful customer engagement programme, building on previous work in the industrial such as at Oban. The local support for the project was strong. Clear communication as provided by dedicate staff who got to know individual customers and spent time to understand any concerns. This included providing specifically focused information, including direct engagement with equipment and servicing suppliers. This was backed by carefully developed packages of information and a website designed around the needs of local domestic customers.

As a result, the project was able to gain the trust of customers. Notable feedback included one comment, *"I am proud of Keele's involvement in HyDeploy and the UK's initiative to reduce carbon emissions. I particularly appreciated the wealth of information that was provided about the project"*

The project team will build on the success of the engagement at Keele University for the public trials. Knowledge transfer will be delivered by direct involvement of many of the same personnel, and a detailed 'lessons learned' exercise has been undertaken to further improve the process. Much of the existing information provides the same foundation for communications, although this must be targeted to meet the needs of the specific local communities involved in the public trials. Keele University has an unusual demographic, and it is recognised that the needs and concerns of those in the public trial communities will be different. It will rightly include a wider social demographic. This will require that the wider range of customer needs is fully met, including those for whom English is not their first language.

This project will only be successful if the communications strategy is carefully and thoughtfully developed to meet the wide range of customer needs necessary.

C.4.3 Generic activities required to support the trials

In addition to the core scientific & operational procedural work outlined in Section C.4.2 and the development of the communications strategy, there are a range of additional activities necessary in order to undertake both trials.

C.4.3.1 Supply Chain Engagement

Engagement with the relevant supply chain is important to the success of the project, specifically: appliance manufacturers; appliance service providers & gas fitters; and gas shippers and suppliers.

Good engagement has already been established with appliance manufacturers, with an active working group supporting the HyDeploy project at Keele including provision of test boilers for that trial. They have also provided the necessary reassurance where required for local customers at Keele. It is important to build on this engagement for the public trials.

It is important to engage with the appliance servicing and gas fitter community. This is both at a national as well as a local level. For example, British Gas provide a Homecare service, which is a turnkey solution for customers which can include routine servicing as well as emergency call out. British gas are on the advisory board for the HyDeploy project at Keele, and as part of the customer engagement have provided support for that project. For HyDeploy2, the team will build on this engagement and extend it to other similar national organisations, as well as local gas fitters and service engineers in the trial regions. This early engagement will be used to roll out the necessary training ahead of the trial phase.

During HyDeploy2, customers will be provided with gas by a range of suppliers, unlike the original HyDeploy project, where the University was the sole supplier. British Gas is on the HyDeploy advisory board, but it is recognised that there is a need to extend this engagement significantly to support the trials. This will be undertaken, building on the relationships that Cadent has developed through the Future Billing Methodology project.

C.4.3.1 Billing strategy and regulatory approval

It will be necessary to develop a suitable billing strategy for the public trials. Blending of hydrogen with natural gas results in a reduction in volumetric calorific value. Domestic gas consumption is measured on a volumetric basis, and it is important to ensure that customers only pay for the energy that that is delivered.

During the Keele trial, there is a single gas supplier (the University) and it is feasible to use a conservative reference value for the calorific value to protect the consumer. Although some of the principles may be able to be applied to the public trial, the solution not only has to be accommodated by a variety of suppliers, but the regulatory requirements are likely to be different.

Therefore, a legally acceptable and workable solution must be developed, requiring engagement with suppliers as well as OFGEM. This is still expected to be a geographically and time bound solution for the purposes of the trial; it isn’t an enduring regime (the wider regime for billing gases of variable CV is being addressed by the Future Billing Methodology project, as discussed below)

C.4.3.1 Regulatory requirements relating to gas production

During the trial period hydrogen is being produced on demand. Over the period of the trial, using the equipment built for HyDeploy this is the lowest cost approach, and avoids the requirement for transport of hydrogen by road and storage in residential areas. However, this means that the project includes the production of gas. There are regulatory constraints applied to GDNs in this regard. Solutions to address this are being identified for the HyDeploy project at Keele, but it would be strongly preferable to establish a regulatory approach which would allow the GDNs to own this equipment for the period of the public trials. There is no question of the GDNs securing any commercial gain from the supply of gas; this is a demonstration programme where the GDNs are receiving no payment from customers for the hydrogen being delivered.

C.4.4 The Trials

An extensive site identification process has been undertaken in both regions, based on specific criteria.

Primary Criteria	Basis of Assessment
Ease of isolation from wider network	May be naturally isolated or require no more than two isolations
Downstream from biomethane injection points	Challenging to run test if in close proximity downstream from biomethane
Minimum scale and inclusion of commercial buildings	Must have 500-1,000 dwellings and ideally some commercial buildings (noting that HyDeploy at Keele has provided an extensive range of commercial applications)
Representative range of housing types	Dwellings across the two trials should be representative of UK housing stock and a range of user social demographics
Mix of steel and plastic pipes	Between the two trials, appropriate materials types should be covered.
Suitable Operating pressures	Sites should ideally accommodate the pressure drop inherent in the hydrogen grid entry unit (avoiding gas compression)
Suitable location for the hydrogen production and grid entry unit	Deliverable sites with suitable proximity distances to sensitive receptors and ease of connection of both supply electricity and connection to the gas network

In addition, there were a number of desirable attributes to manage project delivery risk, such as seeking to avoid the presence of IGTs, or particularly sensitive receptors on the network, as well as GDN related preferences, such as Cadent's desire to undertake the trial in the HyNet North West region. Both GDNs have undertaken a shortlisting process, with a suitable reference and alternative site identified as part of the project risk management strategy. Given the importance of delivery of the customer communications programme to management engagement, the specific locations are not identified in this document.

First Trial

The first trial will be undertaken in Cadent's region, specifically in the North West. Two sites have been shortlisted. The reference location requires only a single isolation from the network. It has 700 dwellings points and includes range of housing types and ages. About 20% of the houses are detached, and 46% semi-detached. About 21% of the stock is social housing, and a further 9% is rented. It has a relatively diverse range of network materials There are a number of potential locations for the hydrogen production and grid entry unit. It has no particularly sensitive receptors and does not involve and IGT. The reference site also falls within the Liverpool City Region (LCR) has been deemed by Ofgem as an 'Energy Regulatory Pilot Area' (ERPA) [56], enabling running of

[56] *LCR²Energy - Creating a Local, Competitive, Resilient Energy Ecosystem in Liverpool City Region*, Mark Knowles, 2016. See https://www.liverpoollep.org/wp-content/uploads/2015/11/Mark-Knowles-LCR%C2%B2Energy-Creating-a-Local-Competitive-Resilient-Energy-Ecosystem-in-Liverpool-City-Region.pdf

'real-world trials' ahead of UK implementation. The alternative location requires two isolations, has a range of housing types although less diversity of network materials types. There are potential locations for the hydrogen production and grid entry unit, although there are some more sensitive receptors and IGTs present on the network.

Customer engagement and Survey. Customer engagement plan which has been developed will be rolled out in the local region. It is anticipated this will include the offer of a site visit to the project at Keele. This will enable the delivery of the network and appliance survey process. During the first trial, the project will seek to engage with every customer on the relevant network in order to undertake safety checks on every appliances and installation. A qualified gas fitter and installation team will be developed to support this activity. This team will also provide the appropriate repair and replacement services as required. As part of this, training will be provided to Gas Safety engineers relating to hydrogen-blend operation to support the subsequent trial phase. Where required local testing on NG-H2 blends will be undertaken, this specialist work will be undertaken by KIWA in conjunction with the gas fitters. The network will be surveyed and modelled. The operational procedures will be assessed in light of the findings from the evidence base and refined where necessary.

Exemption development and submission. Based on the technical evidence base, site specific data and operational procedures review, the Quantitative Risk Assessment for this trial. This will underpin the Exemption application for submission to the HSE. Based on the positive experience with Keele, close engagement will be maintained with the HSE during the development of the application. The Exemption process is described in more detail in Section 7.0.

Installation. The necessary permissions and preparation of the site for the installation of the hydrogen production and equipment will be prepared in parallel to the survey and engagement work. Subject to the granting of an application, the hydrogen production, injection and monitoring equipment developed at Keele will be relocated, installed and commissioned on site.

Injection trial phase. A 10 month programme will be undertaken to confirm and understand the operational behaviour of the network and appliances. During this phase, a sample of installations will be checked and servicing will be offered to all customers on the network. This provides an opportunity to confirm that appliance behaviour is consistent with the basis of the Exemption.

<u>Second Trial</u>

The trial location for the second public trial has also been identified. It is located to provide access to a number of readily isolatable networks which can complement the characteristics of the first trial. It is a strategic location which already has good local authority support for this kind of trial, and is practically well suited to the installation and operation of the equipment. As part of risk managing project delivery, a reserve sites have also been identified.

The same process of customer engagement will be undertaken, building on the experience on the first public trial. The survey process will be significantly reduced, consistent with the philosophy of the programme. Gas Safe checks will be undertaken on a sample of properties, and no specific blend tests are expected to be required.

However, this will still need development of an appropriate qualified gas fitter and installation team to do the checks and any repair and replacement (there still be an obligation to address any safety related issues identified in the properties sampled).

The Exemption submission will be prepared, based on the additional technical work, particularly relating to poorly installed and maintained appliances, as well as the more limited survey data. Similarly, the necessary enabling site work will be undertaken in parallel to the survey and engagement work with the equipment relocated, installed and commissioned subject to the Exemption. During the 10 month injection trial phase, a sample of installations will be checked and servicing will be offered to all customers on the network.

C.5 Roadmap for Deployment

The overarching purpose of HyDeploy2 is to enable of hydrogen blending into the wider natural gas network. An integral part of the project is a full deployment plan. This will be undertaken concurrently with the development of the technical evidence base and trials, as it will feed into these as well as draw on their outcomes. This work package comprises four components. **Network models:** The scope of this work is system techno-economic assessment of exemplar regions. This will refine the understanding of cost optimal network injection points and pressure tiers, drawing on assessment of network capacity, scale of hydrogen sources and types, and existing/expected network control strategies. This work will refine the pressure tiers that must be evaluated in the technical programme. **Regulatory basis:** In order to undertake the trials themselves, it will be necessary to establish a suitable billing regime. However, for wider deployment a more enduring regime will be required. This work package will consider at a high level the practical deployment of metering and billing, based on the outputs from the Future Billing Methodology Project. It will also include engagement with regulators with regard to asset ownership and the transition from case by case Exemption to regulation changes with regard to GS(M)R. **Commercial basis:** Widespread deployment will require a suitable regime that reflects and internalises the cost of environmental damage associated with carbon emissions. This work package will include engagement with BEIS with regard to development of appropriate regimes to enable delivery of low carbon heat at lowest cost. This will include refinement of potential ownership models for hydrogen production and injection equipment designed to minimise cost to the consumer and addressing associated regulatory issues. **Skills and Training:** In order to deliver wider deployment of blending, it is necessary to establish the optimal approach for developing skills required within GDNs, but also amongst the wider gas fitter community. Drawing on the practical experience developed through the training delivered as part of the specific trials, recommendations will be made with regard to how the necessary skills and training for role out can be most effectively developed.

C.6 Dissemination

This programme is intended to unlock the process of hydrogen blending on the gas network as a means to deliver a practical means to reduce the carbon intensity of heat. Therefore, it is important that the findings of the project are properly disseminated to key stakeholders. This is addressed in detail in Section 5.0 of the main Bid documentation

Appendix D: HSL HyDeploy$_2$ technical programme and gap analysis

D.1 Introduction

To facilitate the HyDeploy 1 hydrogen blending trial at Keele University a rigorous approach was undertaken to ensuring that the first demonstration of hydrogen blended gas in the UK operates safely. To achieve this an extensive survey of existing programmes of work was undertaken to establish that baseline knowledge. Following on from this a programme of theoretical and analytical assessment, together with experimental test work, was undertaken to establish what effect the use of hydrogen blended gas could have on gas delivery at Keele University. The output from this was used in the HyDeploy Quantified Risk Assessment to show how the risk profile during the hydrogen injection period will change.

D.1.1 Key Findings in HyDeploy 1

The following briefly summarises the key scientific findings from HyDeploy 1, which provided the basis for the Exemption application for that project.

D.1.1.1 Materials

Polymers - Electrofusion bonding and stop-flow ("squeeze-off") studies on medium density polyethylene (e.g. PE80) pipes following six weeks of hydrogen soaking in 100% hydrogen at 2barg exhibited no degradation in the quality of electrofusion joints nor on the efficiency of stop-flow during squeeze off.

Metals - Uniaxial tensile testing of copper, yellow brass, grade B steel, and Stainless Steel alloy 304 plus two lap-shear trials on one lead-based and one non-lead-based solder after soaking in hydrogen, hydrogen blended gas indicated no increased degradation. Brass samples showed an unexpected high hydrogen uptake during trials which may be linked to the alloy lead content.

Asset Management - A detailed asset survey was conducted to establish the age and condition of all components on the network. This allowed a suitable regime to be established to monitor asset safety both during and after the trial once NG supplies are reconnected.

D.1.1.2 Gas Appliances

Laboratory assessment of a range of gas appliance showed no excessive levels of CO production, unwanted flame out occurrence or light back. Appliances were found to tolerate hydrogen concentrations up to 80 % mol/mol

A survey of 95% of the Keele University appliance stock identified that those appliances in a good operating condition, operated safely and in accordance with the laboratory finding when fed with hydrogen blended gas. A small number of remedial repairs were identified and a small number of installations were found to have minor gas leaks. All repair works were undertaken.

D.1.1.3 Gas Characteristics

The addition of hydrogen to natural gas results in a small increase in the flammable concentration range and an increase in flammable dispersion distances. However due to the lower volumetric energy content of hydrogen blended gas there is minimal change in the accumulation characteristics of the gas within enclosures (e.g. houses). Hydrogen blended gas has a slightly lower minimum ignition energy and it is expected that overpressures from comparable releases will be greater with hydrogen blended gas.

D.1.1.4 Gas Detection

Work on gas detection instruments during HyDeploy has shown several potential problems when using current instruments with blended gas. The cross sensitivity of CO sensors to hydrogen make it very difficult to differentiate between a small natural gas leaks and releases of carbon monoxide (CO incidents).

D.1.2 HyDeploy 2

HyDeploy 2 aims to establish the basis for roll out of blended gas into the wider gas network, without overly burdensome mitigation measures or operational limits. In addition to the asset and material ranges, one important additional aspect of the HyDeploy 2 programme is that the pressure range for assessment will be increased from 2 bar to 39 bar. Because of this increase in upper operating pressure, further work is needed to provide confidence in material performance and to identify safety factors for appliance operation and gas release characteristics/consequence. Therefore, a deeper understanding is required on the behaviour of hydrogen blended gas that will allow the technology roll out to move towards an 'unsupervised' model that will ultimately be applicable to a wider UK roll out.

The subsequent sections in this report briefly describe the areas that were identified during the HyDeploy 1 studies that would require further assessment prior to moving towards an unsupervised delivery model. In each case the knowledge gap is defined and the proposed approach to overcoming the shortfall is briefly presented.

D.2 Materials

D.2.1 Knowledge Gaps

The HyDeploy 2 project is planned to build upon the conclusions of HyDeploy 1 to further extend the study into larger and more diverse gas networks. A range of subject areas have been identified for assessment during HyDeploy 2, these include:

<u>Network Pressure</u>

The HyDeploy 1 studies focus on the low and medium network pressures up to 2 bar. Therefore confidence needs to be established in the safe use of hydrogen blended gas at higher system pressure (nominally 8 – 39 bar) of the distribution network, and for exposure periods greater than 10 years.

Similarly, the effect of higher pressures and gas composition on the effectiveness of repair solutions used routinely on the wider UK GDN should be undertaken. This will require some replication of the studies on electrofusion and squeeze off of polyethene (PE80) pipes following hydrogen soaking (this should also include butt jointing of over ground PE pipework which was not present on the Keele GDN and so not studied within HyDeploy 1).

UK network components

For the purpose of HyDeploy 1 the materials studies focus solely on those materials that were known to be present (e.g. only PE pipe). The materials scope should be widened to all materials that can occur on the UK GDN. The programme will identify and suitably assess materials that are not within the Keele GDN but may be present on other networks and so were not considered within HyDeploy1. Therefore in addition to assessment a higher pressure there should also be low pressure tests similar to those undertaken in HyDeploy 1.

The work should determine whether any "Aldyl" type based PE is present on the UK network and whether these materials differ in response to hydrogen gas compared to other PE types. Consideration will also be given to the condition of metallic components within the network (e.g. in terms of corrosion) and analyse the impact this condition has on their susceptibility towards hydrogen embrittlement.

Cyclic Loading

An area that was not assessed during the HyDeploy1 studies was of component operation. This will involve the mechanical testing of network components (e.g. steel springs in valves) to assess their susceptibility towards increased deterioration in function with cycle number and gas environment. The performance of these components is likely to be highly dependent on their specific dimensions, and will need bespoke test conditions and equipment. For example, in the case of valve springs, hydrogen-soaked springs would need to be removed from housings, cycled to their specified cycle life within a range of gaseous test environments and then tested mechanically for failure.

The testing will establish the operating conditions of pipeline and component materials in the distribution network (e.g. cyclic loading and temperatures) and how these may affect material and network safety when in contact with hydrogen blended gas.

Fatigue Threshold

A significant area that will be addressed under HyDeploy2, that was not studied in detail within HyDeploy 1, will be fatigue testing. Initially, fatigue tests will determine whether the fatigue conditions present within the GDN are sufficiently severe to initiate cracking in the materials regardless of being within a natural gas or hydrogen environments. Where cracks are initiated during fatigue tests, the crack growth rates will be measured after soaking in either methane, blended gases and hydrogen environments. If there are increased crack growth rates with hydrogen blended gas, these can be used to inform lifetime models for materials in the network.

Longer term behaviours

Establish the capability to extrapolate the short term experimental results from HyDeploy 1 to predict the long term operating exposures and time scales greater than the twelve months of the HyDeploy 1 trial duration.

D.2.2 Approach

In identifying the proposed body of work (see above) it is accepted that there is a potentially excessive breadth of the work, therefore the programme will be designed to be reactive to the results and focus on meeting the objectives of HyDeploy2. For example, whilst the number of candidate materials and experimental techniques available are potentially considerable, the final proposal will stress the need to prioritise parameters in order to produce an effective and achievable scheme of work. Figure 1 illustrates the kind of prioritisation that will be applied, both to the experimental techniques available and the materials analysed.

	Exp. technique	**Materials**
Higher priority ↑		
	Fatigue testing	High strength
	H_2 retention tests	steel
	Tensile tests	Welded Steel
	Product testing	Network
	Cathodic Charging	component
	Complex fatigue	Polymer
	Complex H_2 Retention	2nd steel grade
		Surface condition
		2nd weld
↓ Lower priority		condition

Figure D.1 Technical assessment priorities for HyDeploy2

The experimental output from these trials will progressively build confidence in the materials performance of any GDN network containing a hydrogen blend. The aim will be to provide short-term confidence to allow the second trial phase to begin, while also producing data applicable to long term exposures of a network over a wide range of pressures

It is anticipated that the experimental programme will take up to two years to complete. The core experimental work will be sub contracted to organisations that have demonstrable experience/expertise and existing test facilities in the given topic area. It is expected that these organisations will be universities and the work will be undertaken by post-doctoral researchers. HSL would then act as the technical project managers for the programme and would:

- Lead, supervise and coordinate the research between universities,
- Analyse results and relate them to risk assessment and risk prediction, and
- Produce reports and presentations on the project for collaborative parties.

In addition to low pressure baseline trials, the core programme will undertake a separate series of trials to assess the effects of higher pressures (8 – 39 bar) across the range of materials that are identified as being on a network. Some of the key areas that will be assessed will be:

- Tensile performance of relevant materials in 100% hydrogen blends.
- Characterisation of hydrogen absorption, retention and desorption from materials at operating conditions representative of the GDN.
- Detailed understanding of the effect hydrogen on the crack initiation and crack growth rate of pipeline materials.
- Undertaking fatigue specific testing from notched test samples or samples undergoing cyclic load / relaxation stress
- Assessment of the effect of surface finish and potential corrosion on material susceptibility to hydrogen embrittlement.
- Assessment of bond integrity for possible repair solutions on pipework
- Detailed assessment of materials proposed to be most susceptible to hydrogen effects, e.g. high strength ferritic steels, high strength ferritic steel weld joints, cast iron and martensitic spring steel.

D.2.3 Hydrogen uptake – Cathodic Charging

It is recognised that hydrogen embrittlement is typically a degradation mechanism which manifests itself over years or decades, and therefore an approach to building long-term confidence is essential. By scoping trials appropriately (e.g. by determination of hydrogen saturation concentration), the fundamental basis of material failure can be better described, thus allowing a predictive capability.

One process that may be used to accelerate hydrogen absorption is that of cathodic charging. This technique involves passing an electrical current through a specimen to chemically induce hydrogen absorption into the specimen. This process is much faster (and potentially cheaper) than long-term gaseous soaking but does require some preliminary trials to "calibrate" hydrogen uptake by charging, against soak time. It is proposed that by correlating the parameters for gaseous soaking with those of cathodic charging, it will be possible to simulate decades worth of gaseous soaking in a few days of cathodic charging.

D.3 Appliances

D.3.1 Appliance Fault Mode Assessment

It was demonstrated in the HyDeploy 1 laboratory test programme that appliances that are functioning correctly and well-maintained can safely burn hydrogen blended gas that meets the GS(M)R Wobbe Index specification in accordance with existing UK natural gas safety standards. In general, the addition of hydrogen to natural gas, which reduces the Wobbe Index and reduces the carbon content of the fuel, led to reductions in the quantity of CO produced by appliances. It was also shown that, in terms of CO production, ignition and light back, that appliances will tolerate blended gas levels up to at least 80 % mol/mol hydrogen. Therefore, there this an appreciable safety margin between the typical operating conditions that could be encountered at Keele University and the limits where operation of an appliances may lead to functional issues

<u>Knowledge Gap</u>

The appliances tested in HyDeploy 1, and those that will receive hydrogen blended gas during the HyDeploy 1 trial where well maintained and functioning correctly. An understanding of how poorly maintained, malfunctioning and maloperated appliances will respond to hydrogen blended gas is required to build the confidence that during an unsupervised trial these appliances will pose no greater risk. Additionally, an assessment of the performance of pre-GAD appliance is required to ensure there is no anomalous operating characteristics in the aging UK appliance stock.

Approach

- Review industry fault/incident data (DIDR, RIDDOR, SIU) and
- Engage with OEM's to define representative fault on fault conditions and identify potential consequences
- Undertake an experimental test programme to determine fault consequences with hydrogen blended gas
- Review onsite survey data from first public trial site with supplemental laboratory testing as required
- Review of pre-GAD appliance performance data and undertake lab testing of representative appliances

D.3.2 Safety Devices

The HyDeploy 1 laboratory test programme identified that the performance of a safety device in certain types of gas fire (an oxy pilot oxygen depletion sensor (ODS)) when operating with hydrogen blended gas did not meet the standard required by UK safety standards (BS 7977-1:2009). Further assessment of other gas fires with ODS' did, however, conform to standard and with an appreciable performance margin. For HyDeploy 1, the specific devices used at Keele were all tested.

Knowledge Gap

The finding highlights two key questions, firstly in relation to this specific safety device there may be design and quality issues across the UK appliance stock which warrant further fundamental assessment of the performance of this and similar safety device types. Secondly the finding from this one component type indicates that other findings from HyDeploy 1 laboratory testing require closer scrutiny where the key component types may be subject to design variations. In such cases a full understanding of the safety and / or performance implications need to be understood and assessed.

Approach

- Review of design and operation of safety device and critical component
- Engagement and collection of operational and quality data from component manufactures
- Commission additional laboratory testing as required

D.3.3 Building Leak Assessment

Analysis of the expected behaviour of hydrogen blended gas leaks compared to those with natural gas was undertaken during HyDeploy 1. In relation to understanding how hydrogen blended gas may change the outcome/consequence of a release/leak two approaches where considered. The first approach showed that when assuming leaks where turbulent then the release rate is greater with hydrogen blended gas. In the second approach the basis of the maximum permitted leak rate criteria was changed from being based on the equivalent energy release rate to one based on the flammable limits of the gas, and hence the increase in the flammable region due to the addition of hydrogen was taken into account. In this case it showed that the hydrogen blended gas has a lower maximum permitted leak rate.

Knowledge Gap

Direct assessment of these approaches through measurement of leak rates with hydrogen blended gas was not possible during the onsite testing programme at Keele University due to issues with temperature equilibration of the installation gas volume during. To corroborate the finding from HyDeploy 1 experimental data is required.

The important outcome from this work will be confidence in the theoretical understanding of hydrogen blended gas leakage in domestic / commercial properties. This will support the subsequent fire and explosion assessment and so will support the appropriate development of existing leak testing procedures (i.e. IGE UP1)

Approach

This may be achieved through a number of stages

- Development of a robust leak measurement test
- Assessment of leak rates in test installations (the gas migration test facility)
- Collection of leak rate assessment data during the HyDeploy1 trial at Keele.
- Assessment of in-situ natural gas and hydrogen blended gas leaks during the onsite survey in HyDeploy 2 prior to the first public trial.

D.3.4 Long Term Behaviour

Through a technical review and an industry consultation exercise information was gathered on potential longer-term effects of hydrogen blended gas on appliance integrity. Specific areas that were examined were molecular level interaction between hydrogen blended gas and material performance, and the thermal effects that may be associated with higher flame temperatures. Supported by appliance manufacturers, there is an expectation that the operation of appliances on hydrogen blended gas for a time period up to 12 months will not lead to any adverse consequences in terms of operation or safety performance. Over the longer term it was unclear how materials effect such as hydrogen attack may develop and affect component performance.

Knowledge Gap

The study identified seven areas where further assessment and evidence was required, which included analysis of key components following prolonged operation with hydrogen blended gas and further assessment of temperature changes due to operation with hydrogen blended gas. An area of concern for the OEM's was the effect of hydrogen blended gas on warranties and compliance with industry regulations

Approach

As part of the HyDeploy 1 trial at Keele University, a gas appliance testing facility will be installed that will allow the operation of a range of gas appliances to be carried out in a controlled environment, utilising the HyDeploy hydrogen blended gas throughout the course of the trial. The appliances (boilers, cookers and gas fires) will be operated in an intensive and cyclic manner to mimic longer term operation. It is proposed under HyDeploy 2 that data obtained from this programme will be assessed to understand whether existing materials of construction retain their integrity, and to understand how the maintenance of existing appliance may be affected.

The industry engagement activities initiated in HyDeploy1 will be continued to define the impact on the key protocols, warranties and regulation that the industry operates under.

D.3.5 Gas Safe Training and Procedures

As part of the Keele University survey in HyDeploy1 an assessment was made of Gas Safe related procedures that were relevant to the delivery and interpretation of the testing programme, specifically tightness testing.

Knowledge Gap

A detailed review of all procedures and activities undertaken by Gas Safe Engineers is required to allow an understanding of how hydrogen blended gas may affect activities performed within domestic and commercial properties. Development of training packages to inform the gas fitter community is required so that changes to the procedures are communicated clearly and unambiguously

Approach

- Assess and propose modification to the Gas Safe / British Standard / IGEM procedures to account for hydrogen blended gas
- Engage with Gas Safe to facilitate engagement across the gas fitter community
- Develop training packages & material with organisations local to the trials

D.4 Gas characteristics: Leak dispersion and ignition behaviour

D.4.1 Subsurface gas migration

The migration of gas from a subsurface leak source (e.g. a low to medium pressure pipe rupture) has a bearing on building proximity distances and gas leak sweep distances. For the HyDeploy1 trial at Keele University, allowance has been made for uncertainty surrounding how hydrogen blended gas may migrate through cracks, channels and ducts into a building. To mitigate the potential increase in the hazardous release distance, and the resulting increase in the building proximity distance, gas mains at Keele University will be limited to operation at 25% below the design pressures. Similarly, for gas leak sweep distance, the current nature of underground gas movement is unclear and so adjustments have been implemented to the sweep distances based on a worst case. This adjustment may not actually be necessary, and doing so adds complexity to gas network operators having to adopt different standards for blended gas versus natural gas.

Knowledge Gap

There is an absence of statistical data on the existing behaviour of natural gas in the cases of underground leaks. Furthermore, it is uncertain how hydrogen blended gas will behave when the gas leak occurs underground, since it may track along cracks, channels and ducts into a building, or may percolate through the ground and escape and disperse without presenting a major hazard. The path taken by the gas would depend upon the ground within which the pipe leaks, but also by the nature of the gas itself.

Approach

HSL has experience of conducting experimental and theoretical modelling of subsurface gas migration. Existing facilities and approaches will be utilised to assess the behaviour of natural gas and hydrogen blended gas. Integration of the data with the existing risk based approach for the assessment of building proximity distance will also be undertaken.

D.4.2 Gas leakage via permeation through PE pipes

Hydrogen gas permeates faster through the walls of PE pipes than the components of natural gas. This may have the potential of generating a permeated gas on the outside of a pipe that contains a higher proportion of hydrogen than the gas inside the pipe does. In most circumstances, the permeated gas would not be expected to accumulate and present a hazard, and this is the case at Keele.

<u>Knowledge Gap</u>

The potential for preferential permeation of hydrogen cannot be ruled out where permeated gas may accumulate (for example where PE pipes pass through other pipes – inserted mains – or ducts). If it found to be feasible hydrogen concentration greater than 20 % mol/mol could occur with the network then the implications of this on procedures needs to be quantified.

<u>Approach</u>

A model developed during HyDeploy1 will be refined and tested against experimental data obtained using a new piece of apparatus designed and built, possibly at HSL. The apparatus will aim to replicate in-field conditions. Permeated gas will be analysed and compared with predictions.

D.4.3 Ignition Potential

Assessment of existing experimental studies has demonstrated that hydrogen blended gas has a wider flammable range and the minimum ignition energy is lower than natural gas. This data has been used to determine how that explosion risk at Keele University will be modified during the HyDeploy1 trial. Wider mitigation and control measures could be put into place at Keele, particularly relating to leakage assessment and remedial works.

<u>Knowledge Gap</u>

An understanding of the frequency of different ignition sources of different strengths will allow further refinement of how explosions in domestic and industrial settings may occur. Particularly low strength sources that may now be relevant around the stoichiometric concentration where there is a reduction in the minimum ignition energy with hydrogen blended gas. This region is particularly important due to explosion strength peaking at the stoichiometric concertation.

The HyDeploy1 study has also identified that some fundamental data is missing in relation to propensity to ignition by frictional ignition sources. It is known that the behaviour of hydrogen in response to frictional ignition sources is markedly different to that of natural gas despite both gases have similar autoignition temperatures derived in standard hot oven tests. Whilst this is not so important in a domestic setting, where such frictional sources are not so likely to occur, the response to friction is more important in an industrial setting where rapidly moving mechanically components would be more commonplace. This needs to be understood for a wider rollout.

<u>Approach</u>

It is intended to carry out frictional ignition tests using the methods developed for the MechEx pre-normative research programme that informed the European standards on non-electrical equipment in potentially flammable atmospheres; this work was carried out on methane and hydrogen previously at HSL. Comparison would be made between methane, hydrogen and a range of hydrogen-methane blends.

D.4.4 Accumulation and consequences of internal gas releases

Existing data is available that allows comparison of the behaviour of blended gas and natural gas in model enclosures with idealised geometries. These tests mimic a single room where the ventilation rate results from simple vent sizes and locations. Models are available that describe this behaviour. Other data is available for hydrogen and methane in a real two-storey house, although there are no useful data for assessing the behaviour of the blended gas. To mitigate this shortfall HyDeploy 1 undertook analytical modelling of idealised and worst-case geometries to demonstrate gas build up within the QRA. In addition, mitigation and control measures were put in place at Keele, particularly relating to leakage assessment and remedial works.

<u>Knowledge Gap</u>

A method to quantify the dispersion and migration of hydrogen blended gas around a realistic house is required so that explosion development and overpressures can accurately be predicted. Important aspects to understand are releases with in confined spaces that then disperse into larger volumes (i.e. a release in cupboards), and how construction materials and methods can change the concentration profile.

Consequence and harm criteria for external explosion are available for a range of hydrogen blended gas concentrations, however the equivalent understanding when an explosion occurs in inside a domestic property is not available, and particularly where explosions propagate between rooms/enclosures, and where different levels of congestion may exist.

<u>Approach</u>

Existing dispersion models will be refined and validated from data obtained from a new scaled experimental rig which will replicate the layout of a two-story building. The experimental dispersion tests will allow the influence of doors, windows, building materials and service ducts / holes to be explored. The work will also demonstrate the main dispersion routes and any differences between the gases to be tested. HSL has existing explosion test vessels that will be adapted to allow explosion overpressures in multi room scenarios and with varying levels of congestion to be assessed.

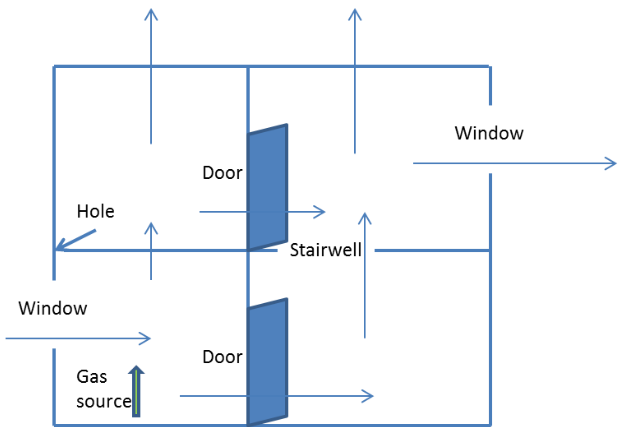


Figure D.2 Conceptual design for the gas migration experiment

D.5 Gas Detection

An extensive assessment of the functionality of gas detection instruments for hydrogen, natural gas and carbon monoxide was undertaken in HyDeploy1. This work assessed the cross sensitivity of the sensors to the other gas types, and in particular to the hydrogen concentration in natural gas. The instruments, which are used by Keele University and GDN operatives when performing routine and emergency interventions on the gas network, were found to be cross-sensitive to hydrogen blended gas to different degrees. In response to these findings the operational procedures that will be used during the HyDeploy1 trial at Keele University will be modified to ensure that a safe system of work is employed.

Knowledge Gap
The findings have highlighted that he current equipment in use by the gas industry should be developed to use sensor techniques that will alleviate the identified issues and prevent there being ambiguous situations with respect to interpreting the outcome of detector readings.

Approach
HSL will undertake an assessment of the detector technology sector and develop an outline proposal of how state of the art technologies can be implemented to provide gas detection equipment that will be fit for purpose for a hydrogen blended gas roll out in the UK. This information and the findings from the experimental test programme will be disseminated to the detector manufacturing community through a number of workshops. The objective of these activities will be to stimulate the market to develop a range of equipment that will meet the requirements of routine and emergency gas detection procedures.

Appendix E: HyDeploy: Key lessons learned

Project Status

The core project knowledge base has now been developed, facilitating the formulating of the Exemption application: development of the technical and scientific evidence; development & delivery of the customer engagement required to introduce the project and enter customer's homes; design of the equipment to safely inject hydrogen; construction of the Quantitative Risk Assessment; and presenting the case to the HSE. The level of evidence required by the HSE to undertake the trial should not be underestimated. This work has now been undertaken, and the project team has not identified any issues which would preclude setting out an Exemption at the 20 $\%_{vol}$ level.

The project team has worked particularly effectively in delivery, with all SDRCs to date delivered on time, and the project being held in high regard by stakeholders in the UK and internationally. The Advisory Board have been complementary about the quality of work undertaken and the foundational role this project plays in informing future heat policy.

Overall Technical Programme

The programme has delivered a comprehensive case for an Exemption to GSMR at 20 $\%_{vol}$ hydrogen. Lessons learned:

- This is necessarily an Exemption to deliver a hydrogen blend into the *specific* site at Keele for a trial period only. A complex FOAK project requires clear objectives,
- The focus of much of the work has been to ensure that the evidence for 'no change' is robust. This is often more arduous than justifying a specified change,
- HSL have provided a valuable summary of the key scientific/technical findings in Appendix D.

Quantitative Risk Assessment (QRA)

This is central to the Exemption. A detailed 200+ gate/event QRA has been developed, benchmarked against historic GB gas network experience. It has demonstrated that Keele University is a particularly safe network and provided the evidence that with limited, minimally disruptive mitigation measures operation of a blend does not prejudice the safety of the gas consumer, which the HSE are opining on. Lessons learned:

- The structure of the QRA is considerably more sophisticated than originally anticipated,
- The quality of available wider gas industry data is not always as detailed as would be ideal,
- The most challenging activity is translating the core scientific findings into quantitative data to input into events and gates,
- At Keele it is possible to take conservative positions on inputs, for example where the evidence base is currently more limited. This can be compensated with specific mitigation measures, given Keele's site and the available controls,
- For public network operation the evidence base needs to be extended, such that the assessments of risk can be more precisely drawn, requiring less conservatism. This is necessary since fewer specific measures can be put in place.

Customer Engagement

At Keele, the project achieved very good customer engagement. The team had a dedicated customer liaison member of staff who was passionate about the project and about addressing customer needs. Feedback was positive and good access was achieved. Lessons learned:

- Don’t underestimate the time and effort to communicate with customers. It is the critical few that require the majority of the effort,
- Issues that arise are often nothing to do with the project itself
- Timing of engagement is important for customers.

Example communications material is available upon request.

Supply Chain Engagement

The project has benefited from excellent support from appliance manufacturers who have provided time and equipment. Lessons learned:

- Collaborative workshops provide a valuable means to engage & share information

Procedures

A comprehensive set of detailed procedures have been reviewed and assessed for the Exemption application. Lessons learned:

- As anticipated, the outturn changes to procedures are relatively limited. However, demonstrating that existing procedures are safe and suitable is a considerable task even if the final outcome does not appear significantly different,
- A collaborative forum of operational knowledge combined with analytical science is invaluable

Equipment Development

Detailed designs have been developed for the hydrogen production and first of a kind injection equipment, as well the installation. An effective tender process was undertaken for the injection unit with good working relationship with the supplier, building on Biomethane entry unit experience. Lessons learned:

- The annual gas network demand profile is a challenging duty and correct siting is important,
- The practicalities of installation and detailed service provisions can present unexpected schedule and cost issues.

Regulatory

An approach to billing has been agreed in principle, but securing a simple solution to ownership of the electrolyser from a regulatory perspective has proved challenging. Lessons learned:

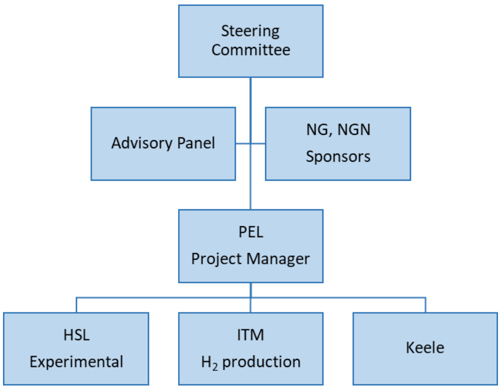
- Finding workable solutions to regulatory issues is complex and time intensive, even where the logical and commercial rationale is clear.

Team and Project Delivery

The team is well formulated, complementary and is delivering high quality work effectively. Lessons learned:

- There is a very valuable tension between scientific rigour and practical experience, that results from having a spectrum of expertise
- Formalised governance arrangements from separate teams within HSL has worked well,
- Communicating assessments of complex risk profiles effectively through organisations is important,
- Internal project reporting processes provide visibility to enable informed decisions, particularly when managing the budgets of development projects,
- Engagement with other projects enables sharing of information and best practice, avoiding duplication and improving outcomes.

Appendix F: Project Governance & Organogram



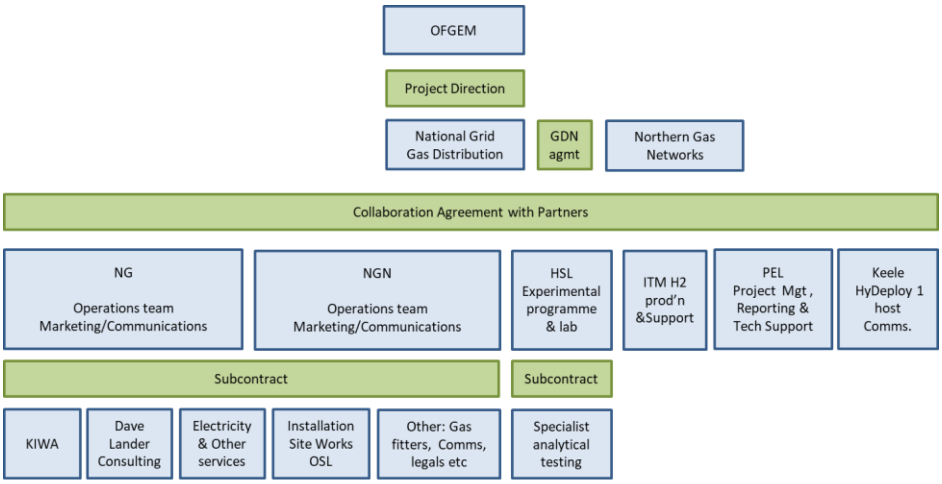
A summary of the proposed management structure for the project is shown below. The Partners have already developed an effective Collaboration Agreement for the project at Keele which will be used as the basis for this project.

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 made up of two representatives nominated by each of the project partners. The Chair of the Steering Committee is the Project Director for Cadent, should the Chair not be available the Chair shall be delegated to the Project Director for Northern Gas Networks. The role of the Steering Committee is to assure delivery of all the activities undertaken on the project to scope, time and budget, to provide overall direction to the work, and to sanction project expenditure at each project gateway.

The Project Director for Cadent is accountable for the successful allocation of Milestones and allocation of stage funding under the NIC allowance. The Project Director shall report to Cadent's Distribution Executive Committee progress of each Milestone and sanction for subsequent Milestone funding.

The Project Management is provided by Progressive Energy who will produce monthly reports summarising the progress of the project in accordance to the standing agenda of the Steering Committee, progress concerning research results, and plans to disseminate information / progress beyond the project partners. The Project Manager is responsible for the day to day operations of the project, coordinating and reporting to the Steering Committee, and acting upon its decisions, in particular with relation to budget management, and submitting requests for Milestone completion and sanctions to progress to subsequent project stages. The Project Manager shall commence stage activities upon unanimous agreement to continue to fund the subsequent stage. The Contract structure for the project is shown below



Appendix G: Project Programme

Letters of support for the programme of HyDeploy2 undertakings have been received by:

1. The Committee on Climate Change,
2. Energy Utility Alliance,
3. Bosch,
4. National Grid, Scotia Gas Networks & Wales and West Utilities,
5. Institute of Gas Engineers and Managers
6. The European Gas Research Group.

Full letters of support can be provided upon request

ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Appendix H: Risk Register

Category	ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre-Mitigation Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Mitigation Rating
Safety	1	Personnel risk during experimentation due to exposure to flammable gases	Injury to personnel and undermines project objectives	3	2	M	Agree appropriate levels of protection and minimal risk methodologies	Peer reviewed method statements and use of experienced researchers	3	1	L
Safety	2	Personnel risk during bottle testing e.g. slips, trips & falls	Non-fatal Injury to personnel & delay to bottle testing	3	3	M	Agree appropriate levels of protection and minimal risk methodologies	Peer reviewed method statements and suitable PPE	2	2	L
Safety	3	Public risk during bottle testing e.g. slips, trips & falls	Non-fatal injury to public & delay to project due to investigation	3	1	L	Minimise risks during design of testing	Ensure public are made aware of all potential risks	2	1	L
Safety	4	Public tampering of bottle wagon	Injury due to release of pressurised flammable gases	4	2	M	Bottle wagon design and protocols	Ensure adequate locking hardware, security and procedures	4	1	L
Safety	5	Personnel injury due to transporting and installing process equipment	Injury and programme delays	4	2	M	Agree appropriate levels of protection and minimal risk methodologies	Adherence to recognised standards and review of proposed procedures	3	1	L
Technical	6	Appropriate amount of instrumentation for monitoring the network	Lack of instrumentation will result in a lack of data to demonstrate network performance	3	3	M	Agree appropriate amount of instrumentation	Detailed design	4	1	L
Technical	7	Access for bottle wagon	Undermines study objectives	4	3	M	Bottle wagon design	Detailed design including long hoses for access	3	1	L
Technical	8	Robustness of instrumentation	Technical/project risk if credible data not gathered for the project	3	2	M	Use of approved and tested equipment	Programme activity	3	1	L
Technical	9	Variability in quality of test gases used	Incorrect data collected	3	3	M	Only use accredited suppliers	Test gases before use	3	1	L
Technical	10	Lower NG usage than historical range	Curtailment of blending	4	3	M	Reduced blending during this time	Alter test schedule	4	2	M
Technical	11	Long term degradation of components not covered in HyDeploy	Cost of repair / replacement	4	2	M	Integrity survey at the end of the study	Costs for ongoing inspection and maintenance agreed	3	1	L
Technical	12	Risk to high value components on the grid	Loss of grid integrity	4	1	L	Integrity survey	Costs for ongoing inspection and maintenance agreed	4	1	L
Technical	13	Understanding HSE requirements in terms of exemption process	Risk to granting exemption	5	2	M	Liaison with HSE throughout process	Developed programme	4	1	L
Technical	14	Not convincing HSE on the evidence to inject	Risk to project delivery	5	2	M	Appropriate design of evidence gathering programme	Continuous engagement with HSE			L
Project	15	Not agreeing site selections	Risk to project delivery	5	2	M	Early engagement with GDNs to identify candidate sites	Programme activity	5	1	M
Project	16	Risk of equipment vandalism	Cost, delay & safety	3	3	M	Protection arrangements	Construct suitable barriers, locks, monitoring etc	2	2	L
Project	17	Liability for long term	Cost to replace items	4	2	M	Scientific evidence base and	Review evidence gap	3	1	L

Category	ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre-Mitigation Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Mitigation Rating
		performance of appliances/network					experimental programme				
Project	18	Delay in customer engagement prior to each public trial	Delay to trials and overall programme	3	3	M	Pre-engagement with customers	Plan engagement well in advance with contingency	3	1	L
Project	19	Risk of access to properties	Unable to carry out necessary safety checks	5	3	H	Provide long enough schedule and incentive for engagement	Plan engagement and budget for incentive programme	3	2	M
Project	20	Delay in physical equipment installation and commissioning	Delay in trial start date	4	2	M	Schedule work	Detailed estimation of required resources	4	1	L
Project	21	Delay/budget overrun on potential network alterations	Delay in trial start date	4	3	M	Avoid critical path	Assess potential alterations early in programme	4	1	L
Project	22	Electrolyser siting leading to cost overrun for connections	Cost implications	3	3	M	Close liaison with GDNs	Inclusion of provisional electrolyser locations in site selection criteria	3	1	L
Project	23	Expansion plans at the trial sites	Further complexity of new users and reduced blending percentage	4	3	M	Close liaison with local planners	Review planning permission applications for major works	3	2	M
Project	24	Concern about warranties on domestic appliances	Potential ramifications for consumers	4	3	M	Appropriate engagement with Suppliers	Early engagement with warranty suppliers	3	2	M
Project	25	Cost of instrumentation - flow, pressure, composition, rhinology	Significant cost to the project	3	2	M	Careful specification and tendering	Leverage GDN buying power and companies looking to validate new technology	2	1	L
Project	26	Change to GS(M)R regulations	Risk of major disruption/cost to project	5	2	M	Regular liaison with HSE over potential changes to regulations	Maintain close watching brief	4	1	L
Project	27	Exemption not granted at desired blend level	Limit to extendibility of project	3	3	M	Ensure sufficient evidence is gathered to support case to HSE	Scientific evidence gap analysis and robust H2H programme	3	1	L
Project	28	Risk that further evidence required for wider adoption follow public trials	Limit to long-term value of project	3	3	M	Appropriate evidence programme design	Learn from HyDeploy and engage with HSE on evidence gap	3	1	L
Project	29	Risk of not being allowed storage of hydrogen if electrolyser not used	Not able to store quantities of hydrogen needed	4	2	M	Design appropriate hydrogen storage and delivery system	Early review of permissible limitations and regulatory constraints	4	0	L
Project	30	Very low summer flow curtailing blending	Limits generation of evidence to support project objectives	4	3	M	Design of mixing unit and site selection	Ensure demand range is part of criteria for site selection	4	1	L
Project	31	Risk of increased pressure drop along line	Not meeting gas regulations standards	3	4	M	Apply for exemption to standards if needed	Details process design and exemption application if needed	3	1	L
Project	32	Delay in customer appliance testing pre-trials	Delay to trials and overall programme	4	4	H	Avoid critical path	Appropriate communications plan and incentive structure	4	2	M
Project	33	Delay in exemption process	Delay to trials and overall programme	4	4	H	Regular liaison with HSE throughout process	Engagement with HSE	4	2	M
Project	34	Electrical supply capacity for electrolyser	Unable to produce hydrogen	4	1	L	Early determination of electrical requirements and need for reinforcements	Include contingency for reinforcement if needed	4	0	L
Project	35	Lack of support from gas suppliers	Unable to alter gas supply to customers	5	3	H	Early engagement and appropriate commercial	Adequately assign necessary resource	5	1	M

Category	ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre-Mitigation Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Mitigation Rating
							arrangements developed				
Project	36	Unable to agree appropriate billing regime with Ofgem, shippers and GDNs	Unable to provide blended gas to customers	5	3	H	Engagement with relevant organisations	Adequately assign necessary resource & continual engagement	5	1	M
Project	37	Lack of support from appliance manufacturers	Customers refuse to accept blended gas	5	3	H	Engagement with relevant organisations	Adequately assign necessary resource & continual engagement	5	1	M
Project	38	Damage to physical equipment during transit between sites	Cost and schedule implications	4	3	M	Appropriate procedures for transit	Ensure experienced professionals are used	3	1	L
Project	39	Unacceptable terms of potential insurance arrangements	Cost overrun	4	2	M	Organise commercial arrangements	Ensure sufficient resource is budgeted for negotiations	3	1	L
Project	40	Campaign against hydrogen blending (political, social etc)	Refuse of customers to accept blended gas	5	2	M	Engagement with influential organisations	Communications plan adequately resourced	5	1	M
Project	41	Lack of support from gas shippers	Deteriorates perception of hydrogen	4	3	M	Engagement with relevant organisations	Adequately assign necessary resource & continual engagement	4	1	L
Project	42	Change of strategy from GDNs away from hydrogen	Undermining of project objectives	5	2	M	GDN engagement	Engage with senior management	5	1	M
Project	43	Electrolyser or H2GEU design not appropriate for sites requirements	Curtailment of blending	4	4	H	Review of appropriateness	Compare site characteristics with process unit limitations	4	1	L
Project	44	Collection of social data from consumers during and after trials	Missed opportunity for social science	3	3	M	Design of social science programme	Allocate appropriate resource	3	1	L
Project	45	Hydrogen blending incident in related projects across EU etc	Loss of public/policy makers confidence in hydrogen	4	2	M	Engagement with other projects and communications	Design of communications with public	2	2	L
Project	46	SME partners going out of business	Programme delay as replacements found	4	1	L	Contingency planning	Steering committee oversight	3	1	L
Project	47	Trial sites not representative of UK	Undermines study objectives	4	3	M	Demographic comparisons	Sub-contract demographic study	4	1	L
Project	48	Pre-trial testing delays due to complexity and scale of residencies	Delay to programme and cost implications	4	4	H	Testing planning and ground surveys	Early assessments of sites	4	2	M

Appendix I: Project Cost breakdown

HyDeploy2 Budget	Partner Labour £000	Direct Costs £000	Total £000
Total Cost	***£ 6,048***	***£ 8,921***	***£ 14,969***
GDN Mandetory Contribution			***£ 1,497***
NIC Request (Before Interest)			***£ 13,472***
NIC BID PROGRAMME V12 180802	**£ -**	**£ -**	**£ -**
1 REMOVAL OF BARRIERS TO DEPLOYMENT OF BLENDS NOT COVERED IN HYDEPLOY	£ -	£ -	£ -
1 Extension of evidence base required to underpin public trials	**£ 2,101**	**£ 1,318**	**£ 3,419**
1 Materials	**£ 244**	**£ 560**	**£ 804**
a Literature review, Asset Assssment, Detailed specification	£ 69	£ -	£ 69
b Testing programme	£ 102	£ 560	£ 662
c Technical Reporting	£ 55	£ -	£ 55
d QA and Oversight	£ 19	£ -	£ 19
2 Appliances	**£ 430**	**£ 322**	**£ 751**
a Literature review, Review of long term data, Detailed specification	£ 46	£ 52	£ 98
b Sensor testing	£ 31	£ 32	£ 63
c Leak tightness procedure development	£ 53	£ 8	£ 60
d Appliance testing, poorly maintained/adjusted	£ 62	£ 86	£ 148
e Survey oversight, interpret and write up results	£ 38	£ -	£ 38
f Review of Trial One Findings, specify & deliver further Lab work	£ 22	£ 66	£ 88
g Technical workshops with Manufacturers (Domestic/Commerical)	£ 42	£ 4	£ 46
h Meter assessment	£ 25	£ 70	£ 95
i Interpretation of results and links to QRA	£ 29	£ 4	£ 33
j Technical Reporting	£ 54	£ -	£ 54
l QA and Oversight	£ 28	£ -	£ 28
3 Gas Characteristics	**£ 776**	**£ 267**	**£ 1,043**
a Literature review	£ 13	£ -	£ 13
b Blended gas below ground gas behaviour experiment	£ 105	£ 17	£ 121
c Blended gas frictional ignition experiments	£ 103	£ 27	£ 129
d Blended gas preferential permeation and accumulation	£ 54	£ 12	£ 66
e Blended gas accumulation and behaviour in buildings	£ 202	£ 77	£ 278
f Blended gas detection within multi room enclosures	£ 8	£ 52	£ 60
g Internal explosion assessment blended gas	£ 202	£ 77	£ 278
h Interpretation of results and links to QRA	£ 43	£ 8	£ 50
i Technical Reporting	£ 28	£ -	£ 28
j QA and Oversight	£ 19	£ -	£ 19
4 Gas Detection	**£ 115**	**£ 150**	**£ 265**
a Collaborative workshops to develop instruments	£ 70	£ -	£ 70
b Development of specifications & Procurement of equipment	£ 35	£ 112	£ 147
c Review of odorisation	£ 10	£ 39	£ 49
5 Procedures development and refinement	**£ 336**	**£ 20**	**£ 356**
a Gas Safe process development	£ 25	£ -	£ 25
a Network Procedural development & safety case changes	£ 254	£ 20	£ 274
b Techncial support for trial training	£ 56	£ -	£ 56
6 Scientific programme Management	**£ 201**	**£ -**	**£ 201**
a Programme Management	£ 201	£ -	£ 201
2 Extension of evidence base required for wider deployment	**£ 490**	**£ 1,560**	**£ 2,050**
1 Higher pressure tier operation and procedures	**£ 43**	**£ -**	**£ 43**
a Specification and review of materials testing for networks	£ 43	£ -	£ 43
2 Address barriers to connection of other LTS users (industrial)	**£ 392**	**£ 1,560**	**£ 1,952**
a Industrial Equipment Materials of contruction	£ 31	£ 145	£ 176
b Burner Laboratory testing	£ 49	£ 175	£ 224
c Burner field trial development	£ 52	£ 145	£ 197
e Burner field trial	£ 58	£ 475	£ 533
f Process resilience to composition variation	£ 15	£ 135	£ 150
g Direct Fire field trials	£ 58	£ 485	£ 543
h Safety and procedural Assessment	£ 131	£ -	£ 131
3 Collation of evidence base relating to other users	**£ 55**	**£ -**	**£ 55**
a Review of Combined Heat and Power applications	£ 28	£ -	£ 28
b Review of position for CNG transport (H2 blend constraints)	£ 26	£ -	£ 26
3 PUBLIC NETWORK TRIALS	£ -	£ -	£ -
1 Generic Activities applicable to all Sites	**£ 632**	**£ 509**	**£ 1,141**
1 Selected trial areas mobilisation	**£ 66**	**£ 30**	**£ 96**
a Review of demographic attibutes	£ 18	£ 30	£ 48
b Finalisation of H2 Production and H2GEU installation sites	£ 24	£ -	£ 24
c High level BoD for Selected Sites	£ 24	£ -	£ 24
2 Local Stakeholder Engagement Planning & Initial activities	**£ 282**	**£ 222**	**£ 504**
a Customer perceptions assessment	£ -	£ 50	£ 50
b Develop Customer Engagement Plan for all sites	£ 210	£ 27	£ 237
c Develop, launch and maintain Website	£ -	£ 55	£ 55
d Develop & produce written literature	£ -	£ 85	£ 85
e Set up customer helpline	£ -	£ 5	£ 5
d Undertake engagement with Key Supply chain stakeholders	£ 72	£ -	£ 72

3		**General Pre-Exemption Activities**	**£ 284**	**£ 257**	**£ 541**
	a	Pre-Exemption local testing preparation	£ 43	£ -	£ 43
	d	Assess existing H2GEU and Electrolyser against public trial requirements	£ 56	£ 8	£ 64
	b	Review of Existing Network Safety Case for Network(s)	£ 30	£ -	£ 30
	c	Fault Tree and QRA structural refinement	£ -	£ 32	£ 32
	d	Initial Engagement with the HSE	£ 21	£ 25	£ 46
	e	General Billing process activities	£ 67	£ 152	£ 219
	f	Governance, liabilities and insurance review	£ 66	£ 40	£ 106
2		**First Site Specific Programme**	**£ 696**	**£ 3,012**	**£ 3,708**
1		**Local Engagement**	**£ 35**	**£ 143**	**£ 178**
	a	Role out Engagement plan with Key stakeholders	£ 18	£ -	£ 18
	b	Deliver engagement, inc schedule & arrange bookings	£ 7	£ 95	£ 102
	c	Local Engagement Events	£ 10	£ 48	£ 58
2		**Pre-Exemption Local Evidence Gathering**	**£ 154**	**£ 643**	**£ 797**
	a	Network asset assessment	£ 54	£ 20	£ 74
	b	Local Gas network team & Fitter Training	£ 31	£ 15	£ 46
	c	Local infrastructure development for testing phase	£ 20	£ 30	£ 50
	d	Testing all installations and appliances on network (H2H Tests)	£ 27	£ 566	£ 593
	e	Consortium evaluation of test data	£ 22	£ 12	£ 34
3		**Develop & Submit Site Specific Exemption**	**£ 170**	**£ 261**	**£ 431**
	a	Engage with HSE	£ 53	£ 14	£ 67
	b	Populate QRA with final equip installation, network and appliance data	£ 27	£ 38	£ 65
	c	Finalise Exemption document drawing on local data & operational requirements	£ 42	£ 20	£ 62
	d	Submit Exemption	£ -	£ 175	£ 175
	e	Engage with HSE during evaluation	£ 48	£ 14	£ 62
4		**Preparation for site installation relating to Trial**	**£ 72**	**£ 922**	**£ 994**
	a	Relating directly to compound area itself	£ 44	£ 922	£ 966
	b	Network related	£ 11	£ -	£ 11
	c	Internal governance process to proceed to trial	£ 17	£ -	£ 17
5		**Installation of equipment**	**£ 14**	**£ 225**	**£ 239**
	a	Compound construction	£ 14	£ 140	£ 154
	b	Delivery and installation of equipment	£ -	£ 60	£ 60
	c	Network measurement (Pressure/rhinology and sampling point)	£ -	£ 25	£ 25
6		**Commissioning of installation**	**£ 10**	**£ 45**	**£ 55**
	a	Commissioning Works	£ 10	£ 45	£ 55
7		**Live trial phase**	**£ 87**	**£ 619**	**£ 706**
	a	Power cost of operation (including ramp up to full)	£ 5	£ 98	£ 103
	b	O&M for equipment	£ 32	£ 70	£ 102
	a	Security for compound	£ 2	£ 40	£ 42
	b	Other Utilities	£ 2	£ 20	£ 22
	a	data acquisition	£ 13	£ 65	£ 78
	b	spot checking of appliances and installations	£ 12	£ 40	£ 52
	a	servicing of appliances during trial	£ 16	£ 90	£ 106
	b	Provision for Billing allowance for trial	£ 5	£ 196	£ 201
8		**Technical Oversight during trial and post trial assessments**	**£ 131**	**£ 88**	**£ 219**
	a	Appliances and installation	£ 24	£ 32	£ 56
	b	Network related	£ 12	£ -	£ 12
	c	Technical Oversight & Review against trial objectives and roll out barriers	£ 95	£ -	£ 95
	d	Provision for replacements post trial	£ -	£ 56	£ 56
9		**Site Reinstatement**	**£ 14**	**£ 52**	**£ 66**
	a	Decommissioning Activities	£ 4	£ 52	£ 56
	b	Handover of equipment	£ 10	£ -	£ 10
10		**Local stakeholder engagement close out**	**£ 8**	**£ 14**	**£ 22**
		Local Communications	£ 8	£ 14	£ 22
3		**SECOND SITE SPECIFIC TRIAL PROGRAMME**	**£ 665**	**£ 2,296**	**£ 2,961**
1		**Local Engagement**	**£ 35**	**£ 143**	**£ 178**
	a	Role out Engagement plan with Key stakeholders	£ 18	£ -	£ 18
	b	Role out Engagement with local members of public	£ 7	£ 95	£ 102
	d	Local Engagement Events	£ 10	£ 48	£ 58
2		**Pre-Exemption Local Evidence Gathering**	**£ 123**	**£ 287**	**£ 410**
	a	Network asset assessment	£ 54	£ 20	£ 74
	b	Local Gas network team & Fitter Training	£ 31	£ 15	£ 46
	c	Local infrastructure development for testing phase	£ 6	£ 18	£ 24
	d	Testing all installations and appliances on network (H2H Tests)	£ 10	£ 222	£ 232
	e	Evaluate test data	£ 22	£ 12	£ 34
3		**Develop & Submit Site Specific Exemption**	**£ 170**	**£ 261**	**£ 431**
	a	Engage with HSE	£ 53	£ 14	£ 67
	b	Populate QRA with final equip installation, network and appliance data	£ 27	£ 38	£ 65
	c	Finalise Exemption document drawing on local data & operational requirements	£ 42	£ 20	£ 62
	d	Submit Exemption	£ -	£ 175	£ 175
	e	Engage with HSE during evaluation	£ 48	£ 14	£ 62

4 Preparation for site installation relating to Trial	**£ 72**	**£ 562**	**£ 634**
a Relating directly to compound area itself	£ 44	£ 562	£ 606
b Network related	£ 11	£ -	£ 11
c Internal governance process to proceed to trial	£ 17	£ -	£ 17
5 Installation of equipment	**£ 14**	**£ 225**	**£ 239**
a Compound construction	£ 14	£ 140	£ 154
b Delivery and installation of equipment	£ -	£ 60	£ 60
c Network measurement (Pressure/rhinology and sampling point)	£ -	£ 25	£ 25
6 Commissioning of installation	**£ 10**	**£ 45**	**£ 55**
a Process	£ 10	£ 45	£ 55
7 Live trial phase	**£ 87**	**£ 619**	**£ 706**
a Power cost of operation (including ramp up to full)	£ 5	£ 98	£ 103
b O&M for equipment	£ 32	£ 70	£ 102
a Security for compound	£ 2	£ 40	£ 42
b Other costs	£ 2	£ 20	£ 22
a data acquisition	£ 13	£ 65	£ 78
b spot checking of appliances and installations	£ 12	£ 40	£ 52
a servicing of appliances during trial	£ 16	£ 90	£ 106
b Provision for Incentive for trial	£ 5	£ 196	£ 201
8 Technical Oversight during trial and Post trial assessments	**£ 131**	**£ 88**	**£ 219**
a Appliances and installation	£ 24	£ 32	£ 56
b Network related	£ 12	£ -	£ 12
c Review against trial objectives and roll out barriers	£ 95	£ -	£ 95
d Provision for replacements post trial	£ -	£ 56	£ 56
9 Site Reinstatement	**£ 14**	**£ 52**	**£ 66**
a Decommissioning Activities	£ 4	£ 52	£ 56
b Handover of equipment	£ 10	£ -	£ 10
10 Local stakeholder engagement close out	**£ 8**	**£ 14**	**£ 22**
Local Communications	£ 8	£ 14	£ 22
	£ -	£ -	£ -
3 DEVELOPMENT OF DEPLOYMENT PLAN FOR HYDROGEN BLENDING ON NETWORK	£ -	£ -	£ -
1 Network models for deployment	**£ 55**	**£ -**	**£ 55**
1 Cost optimal injection points / pressure tiers for deployment	**£ 55**	**£ -**	**£ 55**
a Network Capacity assessment, by region or case study?	£ 21	£ -	£ 21
b Summary of hydrogen sources (by region, by time, by type)	£ 9	£ -	£ 9
c System techno-economic assessment (Scale-vs pressure-vs compression-vs cost)	£ 11	£ -	£ 11
d Evaluate against existing and future gas network control systems	£ 11	£ -	£ 11
e Reference aggregated model with contribution from different sources/tiers	£ 3	£ -	£ 3
2 Regulatory basis for deployment	**£ 96**	**£ 50**	**£ 146**
1 Billing issues on national basis	**£ 68**	**£ 38**	**£ 106**
a Anticipated billing model	£ 34	£ 28	£ 62
b How this is deployed practically with shippers/suppliers etc	£ 34	£ 10	£ 44
2 Transition individual Exemptions	**£ 28**	**£ 12**	**£ 40**
a GS(M)R, noting potential mode to standards	£ 14	£ 6	£ 20
b Gas thermal Regs (Billing)	£ 14	£ 6	£ 20
3 Commercial basis for deployment	**£ 48**	**£ 20**	**£ 68**
1 Ownership models (Production/h2 distribution/ H2 entry units)	**£ 24**	**£ 20**	**£ 44**
a Assessment for Production, Hydrogen distribution, Entry units	£ 24	£ 20	£ 44
2 Policy engagement to enable roll out	**£ 24**	**£ -**	**£ 24**
a Evidence base for engagement with BEIS	£ 24	£ -	£ 24
4 Skills and Training	**£ 72**	**£ 18**	**£ 90**
1 Training development	**£ 72**	**£ 18**	**£ 90**
a Development of training Strategy & plans for wider roll out	£ 72	£ 18	£ 90
4 PROJECT MANAGEMENT	£ -	£ -	£ -
1 Dissemination and reporting	**£ 293**	**£ 80**	**£ 373**
1 Conferences	**£ 65**	**£ -**	**£ 65**
a Publications Conferences & Events	£ 65	£ -	£ 65
2 Project Corporate Events	**£ 78**	**£ 60**	**£ 138**
a Launch	£ 39	£ 30	£ 69
b Close out	£ 39	£ 30	£ 69
3 OFGEM Reporting	**£ 150**	**£ 20**	**£ 170**
a Annual Reports	£ 46	£ -	£ 46
b Milestone Reports	£ 26	£ -	£ 26
c Close out Reports	£ 72	£ -	£ 72
d Independent Review	£ 6	£ 20	£ 26
2 Project Management	**£ 900**	**£ 58**	**£ 958**
1 Overall project management	**£ 404**	**£ 58**	**£ 462**
2 Cost management & Reporting	**£ 124**	**£ -**	**£ 124**
3 Governance	**£ 20**	**£ -**	**£ 20**
4 Project meetings	**£ 269**	**£ -**	**£ 269**
5 Project Steering Committee	**£ 45**	**£ -**	**£ 45**
6 Advisory Board	**£ 38**	**£ -**	**£ 38**
TOTAL			**£ 14,969**

Appendix J: Project Partner's Summaries and CVs

Cadent

Cadent owns and manages the gas distribution system across four of the eight UK networks: West Midlands; North West England; East of England; and North London. Its network delivers gas to around 11 million consumers through 82,000 miles of pipeline. Cadent believes that the network plays an important role in meeting future energy needs by delivering low carbon gas alternatives. Until 2017, Cadent was part of National Grid.

Andy Lewis is Future of Gas Portfolio Manager, Cadent. He works within the Innovation Team at Cadent and is responsible for the Future of Gas portfolio. During his career Andy has been involved in all aspects of project initiation, delivery and subsequent implementation of the projects.

Lorna Millington is Design Manager, Cadent, and she has worked for National Grid Gas Distribution since 1997. During her career she has been involved in all aspects of planning above and below 7 bar networks, focussing on the network analysis to support the decisions. Her current role as Design Manager includes the evolution of the energy system on the potential use of the Gas Distribution network.

Northern Gas Networks

NGN delivers gas to 2.7 million homes and businesses in the North East, Northern Cumbria and much of Yorkshire. It owns and maintains more than 37,000km of gas pipelines, which cover an area that stretches from the Scottish border to South Yorkshire and has coastlines on both the east and west sides of the region.

Adam Madgett recently joined NGN last year as an Assistant Integrity Engineer responsible for metering and gas quality within the LDZ. He also represents NGN as a Gas Futures Ambassador, where he has taken an active lead in areas of innovation within the business. Adam has been heavily involved with the HyDeploy project from the beginning and he is project lead on the Hystart NIA which aims to feed its outputs directly into this project.

Health & Safety Laboratories

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. We have been developing health and safety solutions for over 100 years and HSL has a long track record in hydrogen activities.

Catherine Spriggs: MEng Civil Engineering Design & Management / Masters in Leadership for Sustainability / Chartered Civil Engineer. Catherine has over 15 years' experience of working on complex projects in the business, science and construction sectors. She joined the Health and Safety Laboratories in 2012 and works in the Major Hazard team and is managing HSL's HyDeploy team.

Phil Hooker BSc(Hons) Physics, spent 25 years in the process industries in various technical roles including process technology, quality and, for the last 10 years, in process hazards, with a particular speciality in hydrogen research. He has been instrumental in the HyDeploy analytical work relating to gas characteristics and their link to the QRA.

Dave Hedley: B.Eng, Electrical and Electronic Engineering, PGD Computer Science. David's career at HSL started with work on gas detection instrumentation, followed by research work on gas explosions & mitigation measures as well as hydrogen safety.

Mark Pursell: CEng MIChemE. Mark is a Senior Engineer in the Explosive Atmospheres Team. He has been instrumental in leading the appliances work for the HyDeploy project, managing the work streams internally and by KIWA, and the interpretation into the QRA.

Progressive Energy

Progressive Energy (PEL) comprises a team of highly experienced clean energy industry professionals providing the skill sets necessary to undertake and support all aspects of the development and implementation of energy projects. It has extensive experience in multi-partner project management and has partnered in other NIC programmes.

Dr Chris Manson-Whitton is a Director of Progressive Energy, delivering projects and working with investors, technology providers and public bodies in the energy sector. His work encompasses hydrogen, biomass, and carbon capture & storage projects. He is chair of the Advisory Board for the ESPRC SUPERGEN bioenergy research hub.

Tommy Isaac Meng CEng is a chartered chemical engineer with experience in both the UK nuclear industry and oil & gas, spanning safety analysis, market assessment, project development, process support and operational strategy. He is a key part of the HyDeploy team at Progressive. Prior to joining Progressive he worked for ExxonMobil.

ITM Power PLC

ITM Power manufactures integrated hydrogen energy solutions which are rapid response and high pressure that meet the requirements for grid balancing and energy storage services, and for the production of clean fuel for transport, renewable heat and chemicals. ITM Power was admitted to the AIM market of the London Stock Exchange in 2004.

Dr John Newton, CEng joined ITM Power in 2012 from RWE npower where he was CIO for the UK generation business. John has 20 years' utility experience in various roles including; R&D, supply chain management, international business development and engineering consultancy.

Keele University

Keele University (KU) was established in 1949 on radical educational principles. It is a strategic aim of KU to become a truly green university, an ambition that underpins all its other goals. It is hosting the first HyDeploy project

Dr Ian Madley is Head of Partnership Development for the Natural Science department and leads KU's Smart Energy Network Demonstrator project. He has more than 30 years' experience as a leader and driver of growth or major change.